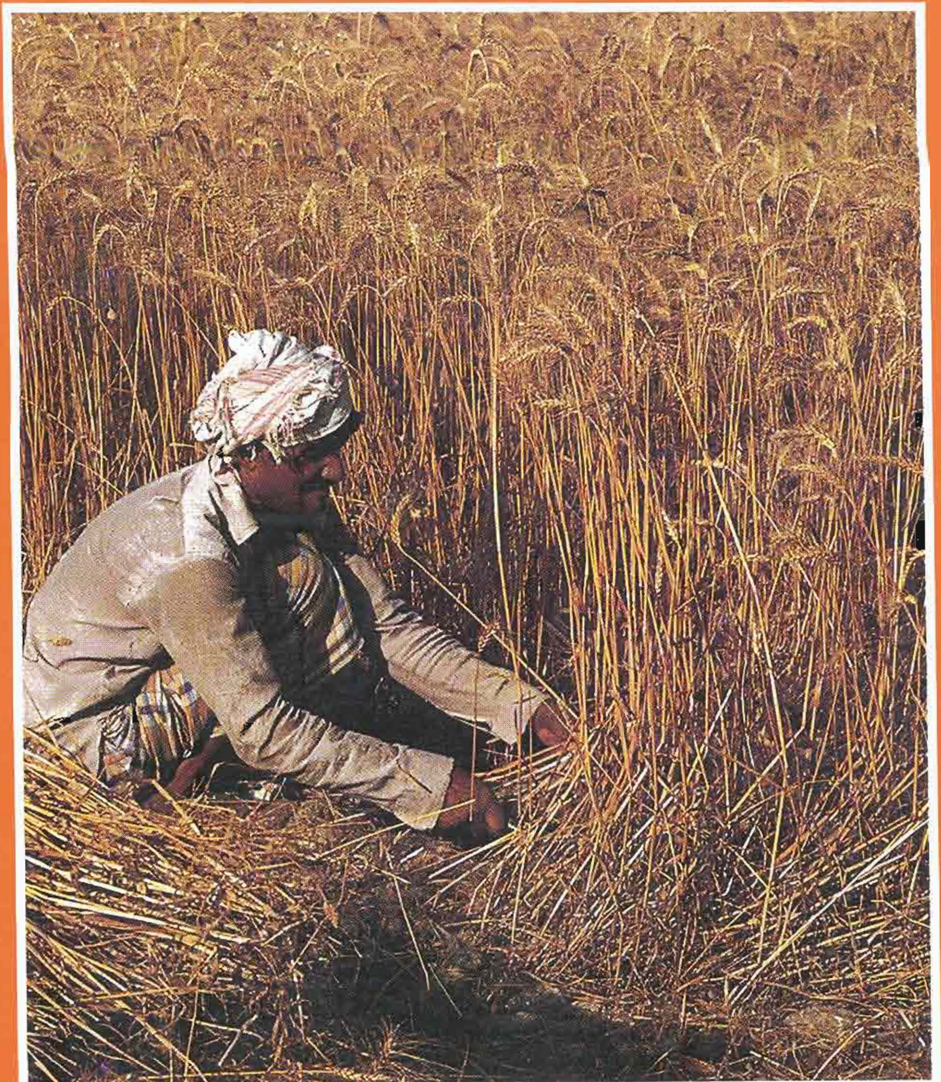
Wheat Research and Development in Pakistan



Pakistan Agricultural Research Council/CIMMYT
Collaborative Program

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Foreword by Norman E. Borlaug

I wish to congratulate PARC and CIMMYT for publishing this survey of Pakistan's wheat research and development. I have personally been involved in Pakistan wheat production for more than 25 years. I remember with special pride and fondness the mid-1960s, when the government of West Pakistan launched a massive effort to deliver improved wheat technologies to farmers. Research and extension officers worked side-by-side and hand-in-hand with farmers to test and demonstrate the new wheat production technology on several thousand test plots. The yield advantage quickly persuaded the farmers to adopt the recommended technology.

National wheat production increased from 4 million tons in 1965-66 to over 7 million tons by 1968-69, making Pakistan the first developing country in Asia to achieve self-sufficiency in wheat production. By 1969-70, more than 50% of all Pakistani wheat farmers (and a much higher percentage in irrigated areas) had adopted the new varieties and begun using chemical fertilizer and improved cultural practices. By the late 1980s, more than 80% of all farmers were using semidwarf wheat varieties and chemical fertilizers, and national production ranged between 12 and 14 million tons annually.

The often vitriolic criticism leveled against the Green Revolution continues to baffle me. First, if the wheat technology we introduced was not appropriate, why have tens of millions of farmers so enthusiastically adopted it? These technologies have clearly improved the farmer's standard of living and reduced his drudgery. The increased productivity of the new technologies has also lowered the real cost of a kilogram of wheat, a major benefit for low-income consumers. Obviously, it was and is unrealistic to assume that any single change in production technology could correct all of the social, economic and political inequities that had accumulated over centuries.

The high-yielding varieties helped to make profitable a whole host of other technological improvements, including the use of chemical fertilizers, tubewell irrigation, tractors and threshers. This, in turn, brought new jobs and skills to rural areas, especially in the irrigated areas of the Indus basin. Thousands of small foundries, machine shops, and farm service and supply businesses sprung up to support a new, more productive agricultural sector. These businesses are staffed with metal workers, mechanics, electricians, and equipment operators—all new professions in agricultural areas.

There were many heroes in Pakistan's wheat revolution. Foremost were the millions of farmers who discarded old traditional methods and enthusiastically took up the new technology. The active support of President Ayub Khan was also crucial. President Khan frequently visited farmers' test plots throughout the country, and even grew demonstrations on his own farm. Moreover, he had the vision, wisdom, and political courage to modify economic policies to foster rapid adoption of the new technology and, thereby, greatly increase food production.

The Minister of Agriculture for West Pakistan, Mr. Malik Khuda Baksh Bucha, also played a pivotal political role, putting his prestige and career on the line to push ahead rapidly with the introduction of the new production package. It was Minister Khuda Baksh Bucha, with the able assistance of the late Amir Mohammed Khan (then Secretary of Agriculture), who set up the Accelerated Wheat Improvement Program, committed scarce foreign exchange to import wheat seed and fertilizer during the initial years, and convinced his government that agriculture must have a much higher priority in the nation's overall economic development plans.

The wheat revolution's field commanders were S.A. Qureshi from the Punjab, M. A. Munshi from the Sind, M. Suleman Khan from the Northwest Frontier; and Ignacio Narvaez from Mexico. Together, these four individuals coordinated a massive farm demonstration campaign to introduce the high-yielding varieties and improved agronomic practices to Pakistani farmers in the shortest time possible. Finally, behind the scene were the financial support of the Ford Foundation, the steady guiding hand of Haldore Hanson, the Foundation's country representative, and the wise counsel of Oddvar Arsvik, an agricultural economist, and Robert Havener, the agricultural program officer.

In the 20 years since the Green Revolution began, the Government of Pakistan has continued building its research and extension services to meet the changing and growing demands of wheat producers. Many new research facilities have been constructed, scores of Pakistani researchers have been awarded Ph.D degrees, and hundreds have earned M.Sc degrees.

Pakistani wheat production is clearly in a post-Green Revolution stage. The initial yield gains obtained from the high-yielding wheats and chemical fertilizers are now behind us. While national yields have doubled, they could and should be doubled again. But because of poor agronomic practices, only 20-40% of the maximum genetic yield potential of the best available commercial varieties is being utilized by farmers.

In my judgment, increased wheat productivity will come about through improved crop management of the major rotations in which wheat is grown. Those research administrators that are looking for new miracle plants that produce fabulous yields even when grown under poor agronomic practices have a long wait ahead. Higher wheat yields will come from the integration of improved practices in soil fertility, water management, land preparation, stand establishment, weed control, and plant protection.

I have been impressed with the no-till wheat trials sown after basmati rice. This technology permits more timely planting and overcomes the chronic problem of late sowing of wheat, which results in a substantial decrease in yield. The tillage treatments on barani wheat land that break the hard pan, reduce run-off and allow better rainfall percolation and greater depth of root development, can also produce substantial yield gains in many rainfed production environments. Finally, improved weed control and more balanced fertilizer treatments hold promise for increased yields and profitability in wheat production.

I must caution that wheat research alone, no matter how well done, does not automatically lead to increased productivity on farmers' fields. Both institutional and individual ''integrators'' are needed to link research and production into an effective technology generation system, if improved technologies are to reach farmers.

I applaud the achievements of Pakistani wheat research but warn my colleagues that we cannot afford to become complacent. During the past few years, yield increases have faltered and national production has leveled off. The consequence has been rising wheat imports. In contrast, India has continued to experience increasing average yields and new records in national production.

We agricultural scientists have a moral and professional responsibility that goes beyond our experiments. We also have an obligation to make our case with political leaders so that advances in research are brought to fruition on farmers' fields.

We have the knowledge to increase wheat yields by 50 to 100% in most environments, with accepted levels of risk. But failures in the technology delivery system have kept yields unnecessarily low in most wheat-growing areas. I believe that private enterprise can play a much greater role in the future in getting improved technology to the farmer.

I would be remiss if I did not urge the government of Pakistan to come to grips with the worsening waterlogging and alkalinity/salinity problems resulting from the lack of an adequate drainage system in the Indus irrigation system. The productivity of untold hundreds of thousands of hectares is already seriously affected, and the area affected continues to increase. To ignore the situation invites disaster. Asking plant breeders to develop varieties with a high level of tolerance to waterlogging and alkalinity/salinity is not a viable solution. This is first and foremost an engineering problem and must be dealt with accordingly.

El Batan, Mexico December 1, 1988

Norman E Borlaug

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Preface

This report is mainly a story of accomplishment. It portrays the work of many individuals who have contributed to the notable achievements made in Pakistani wheat production during the past 25 years. The report begins with an overview of the agricultural sector and identifies key developments that have contributed to Pakistan's wheat revolution It provides a comparison of the wheat economy between 1967 and 1987 and identifies the major factors responsible for its growth and development. The evolution and contributions of the national wheat research system are traced forward, starting with colonial times.

The report ends with a summary of recent wheat research data for the major crop rotations in which it is grown and provides the current best recommendations for increasing national wheat productivity in the near-term. The report ends with comments about Pakistan's institutional framework for wheat research, and suggests ways this system might be further strengthened.

Special attention is also given to the collaboration between Pakistan's wheat research institutions and the International Maize and Wheat Improvement Center (CIMMYT) This 25-year partnership—and the special place occupied by scientist Norman E. Borlaug—is one of the most productive examples of international research cooperation.

The report was commissioned by the Pakistan Agricultural Research Council (PARC), the International Maize and Wheat Improvement Center (CIMMYT), and the United States Agency for International Development (USAID) as part of the PARC/CIMMYT Collaborative Maize and Wheat Program. Mr. Christopher R Dowswell, former Head of CIMMYT's Information Services and currently a consultant in agricultural communications, was commissioned to prepare the report. We congratulate Mr Dowswell for an absorbing account of a multidimensional story of wheat research and development.

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Dr D.L. Winkelmann
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Agriculture in Pakistan

A Nation of Farmers

Agriculture has always been the most important sector of Pakistan's economy. At the time of independence in 1947, the agricultural sector accounted for 52% of GDP. In 1987, this sector still accounted for 26% of GDP and 30% of the export earnings (even higher if thread and cloth are included).

Seventy percent of Pakistan's 100 million people live in rural areas where most gain their livelihood from agriculture related activities. The Punjab province is home for 56% of the population, with the Sind province for 22%, and the Northwest Frontier Province (NWFP) for 13% (Table 1). Approximately 50% of the total national labor force (66% at the time of independence) is directly engaged in agriculture, and many more indirectly. Despite the decline in relative size of the agricultural workforce, it has increased in absolute terms by 43% between 1970 and 1985; 15 million people of the economically active population are engaged in agriculture.

Table 1. Population Statistics, Pakistan, 1987

Province	Population (000)	% total	Rural (000)	Rural as % total
Punjab	56,170	56	42,183	75
Sind	22,480	22	12,364	55
NWFP	13,170	13	11,195	85
Baluchistan	6,170	6	5,245	85
FATA*	2,690	3	2,640	100
Islamabad	425	0.4	158	35
Pakistan	101,080	100	70,756	70

* Federally Administered Tribal Areas

Source: Government of Pakistan's Facts & Figures, 1983-84 (estimated 1987 population extrapolated from these data).

Land and Water Resources

Pakistan has a total land area of 79.1 million hectares. Of this total, 19.8 million ha are classified as cropped area (Table 2). The estimated net area sown to crops is 15.4 million ha, and 4.4 million ha are cropped more than once annually. Seventy percent of the cropped area is in the Punjab. Seventy nine percent of all cropped land is irrigated.

Table 2. Cropped Area of Pakistan, by Province

Province	Cropped Area ('000 ha)	Hectares Per capita	Percent Irrigated
Punjab	13,480	0.21	83
Sind	3,720	0.25	85
NWFP	1,950	0.14	42
Baluchistan	640	0.24	80
Pakistan	19,790	0.20	79

Source: Agricultural Statistics of Pakistan, 1986

Nearly 70% of Pakistan's agricultural area is located in the basin formed by the Indus river and four major tributaries (Jhelum, Chenab, Sutlej, Ravi). Since rainfall is generally not sufficient for agriculture on the Indus plains, an elaborate system of irrigation has been built, primarily over the last 100 years. This system today consists of 68,000 km of canals and 225,000 tubewells. In the crop year 1983-84, it provided approximately 60 million acre feet (m.a.f.) during the summer (Kharif) season and 43 m.a.f. (Table 6, page 5) during the winter (Rabi) season.

An additional 4 million ha of land are in rainfed (Barani) agricultural production in the high plains of northern Punjab, the foothills and mountain valleys of NWFP, some areas west of the Indus river, and in lower portions of the Sind Province. These areas can be further classified into high and low rainfall zones. Areas with rainfall above 500 mm cover 1.65 million ha and generally support dependable cropping. Areas with 300 to 500 mm of moisture cover another 850,000 ha. An additonal 1.5 million ha are in torrent flood and riverain areas. These are low-intensity and/or low-yielding areas that support wheat production through either runoff or residual moisture.

Farm Size

Of the roughly 4 million farms in the country, 90% are less than 10 ha in size, 74% are less than 5 ha, and 34% are smaller than 2 ha (Table 3). Despite the number of small landholders, 36% of the cultivated area is located on farms larger than 10 ha, which comprise only 9% of the total number of Pakistan's farms.

Table 3. Number and Cultivated Area of Private Farms

(ha)	Number of Farms (million)	% of Total	Cultiv. Area	% of Total	Av.farm Size, ha (million)
Under 2	1.4	34	1.2	8	0.9
2 to 4.99	1.6	40	4.8	30	3.0
5 to 9.99	0.7	17	4.1	26	5.9
10 to 19.99	0.3	6	2.8	18	9.3
20 to 59.99	0.1	3	2.0	13	28.0
over 60	0.01	—	0.9	6	90.0
Total	4.1	100	15.8	101	3.9

Source: National Census, 1980

Crop Production

Crop production accounts for about 70% of the gross agricultural product, with livestock the remaining 30% (approximately 15% of the cropped area, 3 million ha, is also used for fodder production). A large number of crops are grown, the principal ones being wheat, cotton, rice, sugarcane, maize, and gram (Table 4). The first three—wheat, cotton and rice—account for over two-thirds of the annual cropped area (excluding fodders) and more than 60% of the value added in crop production.

Table 4. Major Crops in Pakistan by Area and Value Added, 1985-86

Crop	% Area	% Value added
Wheat	42.5	33.3
Cotton	13.1	14.5
Rice	11.7	13.2
Sugarcane	5.3	12.3
Maize	4.3	2.5
Gram	5.9	1.4
Others	16.8	22.6

Source: Hamid et al., 1987

There are two primary seasons for crop production: the moonsoon Kharif season, from June to October, and the lower-rainfall winter Rabi season, from October to May. Each season has distinctly different climates and produces distinctly different crops (Table 5). Wheat is the dominant crop during the Rabi season, accounting for 69% of the total cropped area. Excluding fallow areas, wheat is grown on 80% of the actual cropped area during the Rabi season (Byerlee et al., 1986). In the Kharif season—Pakistan's most profitable and highest value added season—the main crops are cotton, rice and sugarcane. These are collectively produced on 61% of the total crop area.

Table 5. Major Crops in Pakistan by Season and Farm Size

Farm Size	Summer Kharif Season				Winter Rabi Season	
	Rice	Cotton	Sugar-Cane	Maize	Wheat	Pulses
	% area					
All farms	26	27	8	6	69	13
< 5 ha	29	26	8	10	73	17
> 10 ha	22	30	7	3	63	13

Source: Agricultural Statistics of Pakistan, 1986

Agricultural Development Stages

Pakistan has adopted various development strategies over its 40-year history. Initially, in the desire to encourage industrialization the government adopted policies that discriminated against agriculture and which led to the stagnation of this sector. By the late 1950s, the former breadbasket of British India had become a net importer of wheat, relying on concessionary PL 480 wheat purchases from the U.S. government and Canadian imports to feed its population.

The war with India in September 1965 resulted in U.S. sanctions which suspended PL 480 shipments and highlighted the hazards of import dependence for such a vital food grain. Drought during the 1965-66 season added to national deficits in wheat. In 1966-67, the country had to import 1.2 million tons of wheat and in 1967-68, 1.5 million tons. Even with these imports, there was a decline in per capita availability of wheat, an increase in real prices, and a decline in general nutritional levels. To reverse this crisis situation, the government increased its expenditures in the 1960s on irrigation, agricultural credit, and modern inputs such as fertilizer.

International aid agencies have played an important role in the modernization of Pakistani agriculture. During the 1950s and early 1960s, the Food and Agriculture Organization (FAO) was actively involved in the introduction and transfer of fertilizer use technology. Between 1967 and 1980, the Ford Foundation provided strategic funds for stationing resident advisors in wheat, maize and rice research and for graduate student training of future research leaders. Since the late 1960s, the major donor in agricultural development has been USAID, which has funded large portions of national development budgets for irrigation, salinity control and land reclamation, energy generation, and the strengthening of federal and provincial research systems. U.S. PL480 Rupee grant funds have had an important catalytic effect for many research initiatives at provincial and federal institutions. The World Bank has also provided substantial grant funds to help expand national agricultural research and extension systems and create national industries to produce inputs such as fertilizer and seed.

Water Resource Development

During the 1960s and 1970s, surface irrigation was substantially expanded through the construction of an elaborate system of link canals and the Tarbela and Mangla dams. The profitability of production based on the new, high-yielding wheat and rice varieties, among other crops, spurred a 20-fold increase in the number of private and public tubewells, which have helped to triple water availability at the farm gate during the wheat-growing Rabi season (Table 6).

Table 6. Irrigation Water Availability during the Winter (Rabi) Season, by Source of Water

Crop year	Canals	Tubewells Public	Tubewells Private	Total
	(000,000 of acre feet)			
1960-71	15.7	0.2	0.7	16.6
1970-71	15.9	2.2	6.6	24.7
1980-81	22.7	3.7	12.6	39.0
1985-86*	22.4	5.4	14.2	42.0
1986-87*	25.5	5.4	14.6	45.5

* Unpublished data of Ministry of Food and Agriculture

Source: Agricultural Statistics of Pakistan, 1986

The additional water from tubewells has resulted in much higher cropping intensity and given farmers much greater control over the timing and application of water, leading to a rapid increase in their numbers: from 8,000 in 1960-61 to 90,000 in 1970-71, to over 225,000 in 1985-86. Since 1980, annual tubewell installation has declined, as the most profitable sites have already been exploited. Even so, it is estimated by WAPDA that 78% of the ultimate groundwater potential is currently being exploited (Hamid et al., 1987). As much as 50% of the total supply, however, is being wasted between the canal head and the farm gate, providing considerable scope for improved on-farm water management as well as expansion in the area under irrigation.

Fertilizer Sector Development

In 1959, the FAO-sponsored Rapid Soil Fertility Project helped to introduce and popularize the use of chemical fertilizers. Large-scale farmers were the first to start using nitrogenous chemical fertilizers, quickly followed by smaller landholders. In recent years, larger quantities of phosphatic fertilizers are also being used. On the whole, nutrient use has increased more than 20-fold since 1965, and today virtually all Pakistani farmers use chemical fertilizers on some crops (Table 7).

Initially, the government of Pakistan relied on massive fertilizer imports to launch the ''Green Revolution.'' With the expansion in national capacity for nitrogen fertilizer production, imports have changed in composition in recent years. The addition of new nitrogen fertilizer plants in 1980 and 1983 have resulted in the country being essentially self-sufficient and even exporting small amounts of urea. The major imports are in phosphatic fertilizers.

The installed fertilizer production capacity of Pakistan has increased from 21,000 nutrient tons in 1958 to over 1.2 million nutrient tons in 1986, with 90% of this capacity devoted to nitrogenous fertilizer production (Table 7). The National Fertilizer Corporation is the primary producer. Major development in nitrogenous fertilizer manufacturing occurred in the late 1960s and early 1970s, and again in the late 1970s and early 1980s.

Table 7. Fertilizer Imports and Production in Pakistan

Crop year	Nitrogen Imports	Nitrogen Prod.	Phosphorus Imports	Phosphorus Prod.	Potassium Imports	Total Nutrients
	'000 nutrient tons					
1965-66	23	47	0.5	1	0	72
1970-71	108	129	37	5	5	283
1975-76	74	317	109	11	0	511
1980-81	322	582	231	58	21	1,214
1985-86*	84	1,035	207	93	40	1,459
1986-87*	135	1,119	341	93	46	1,734

* Unpublished data of Ministry of Food and Agriculture

Source: Agricultural Statistics of Pakistan, 1986

A considerable subsidy has promoted fertilizer use among farmers for the past 20 years. This subsidy reached its peak during the Fifth Five-Year Plan, 1978-83, accounting for half of the agricultural budget. In the Sixth Five-Year Plan, 1983-88, the stated objective is to remove the subsidy. This has already been done for nitrogen fertilizers and is gradually occurring in the case of phosphate fertilizers.

Mechanization

The rapid expansion of tubewells and the adoption of early-maturing, high-yielding varieties of wheat and rice (coarse grain) permitted widespread double cropping in Pakistan. This cropping intensification soon resulted in labor shortages during peak demand periods, often when harvesting and planting periods overlapped in the prevailing rotational patterns. Labor shortages were exacerbated by the emigration of 3 million Pakistani workers to higher paying jobs in the Middle East and by land reform measures that put pressure on absentee landlords to farm their underutilized holdings.

By the 1970s, pressure from the farming community led the government to remove duties on imported tractors and ancillary machinery, to offer loans with attractive terms to purchase such machinery, and to encourage foreign investment in local tractor production. The infrastructure of mechanics, workshops and fuel stations that developed to support tubewell operations also served the operational requirements of the tractor industry and thus helped to encourage its rapid growth (Table 8).

Table 8. Number of Tractors and Threshers in Pakistan in Relation to Cultivated Wheat Area

Crop year	Wheat Area '000 ha	Tractor No. '000	Area/ tractor (ha)	Threshers No. '000	Area/ thresher (ha)
1960-61	4,639	4.2	1,105	0	N.A.
1970-71	5,978	20.2	296	2.0	2,989
1980-81	6,982	97.4	71	36.6	196
1985-86	7,401	189.8	39	57.0*	129

* estimate provided by industry manufacturers

Source: Mustafa et al., 1984; Agricultural Statistics of Pakistan, 1986.

The use of tractors first began on the irrigated farms of the Sind and Punjab provinces, and later spread to the barani areas in the northern part of the country. Between 1960 and 1985, the number of tractors in use grew from 4,000 to 190,000. Today, tractor power is the primary source for land preparation on 75% of all farms. Tractors, along with the ubiquitous Suzuki mini-vehicle, have also played a very important role in local transportation. With a trolley trailer hitched on the back, the tractor is the primary local transport for fertilizer, grain and livestock.

The old wheat-threshing methods of hand and bullock have given way to machinery, which accounts for 97% of all the wheat threshing. Approximately 57,000 tractor-driven stationary threshers, produced by hundreds of relatively small machine shops and foundries, are in use throughout the country. In recent years, importation has begun of self-propelled combines for rice and wheat harvesting. It is estimated that between 850 and 950 combines were in operation in 1986-87, harvesting over 100,000 ha of wheat. Easy credit is being supplied by ADBP to purchase these machines, and custom combine services are charging less to cut and thresh wheat than it would cost with hand methods (Smale, 1987). For the larger production units, combine harvesting is likely to increase in future years. However, the small size of many farm fields may limit the spread of such machinery.

The National Agricultural Research System

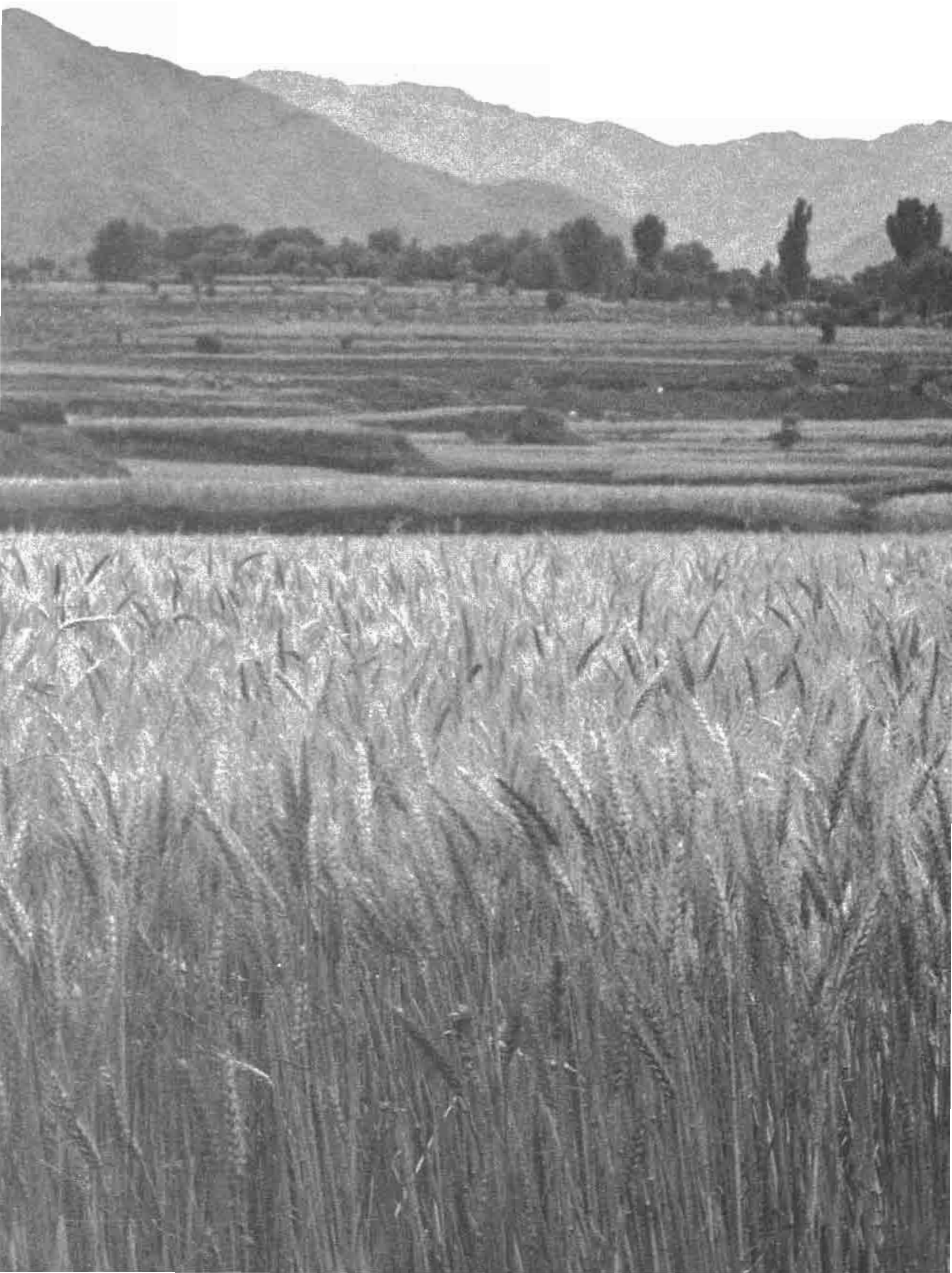
Starting from a meagre inheritance of research facilities after partition in 1947, the agricultural research infrastructure in Pakistan has grown considerably over the past 30 years. (Wahid, 1982). Today, it is a mixed federal-provincial research system that includes nearly 50 research institutions and over 125 experiment stations, three agricultural universities, and a half-dozen agricultural colleges and specialized training schools (PARC, 1986).

In 1984, approximately 0.4% of agricultural GDP was spent on research in Pakistan, compared with 1.7% in the USA (Nagy, 1984). Most agricultural research is conducted by provincial organizations, although the federal research system has been the strongest growth area during the past decade. In the 1980s, PARC has become the main federal body for agricultural research coordination and support.

There are approximately 4,500 sanctioned positions for professionals in the agricultural sciences in Pakistan (PARC, 1986). Of these posts, approximately 3,600 are filled by some 300 Ph.Ds, 2,200 MScs and 1,100 BScs. Eighty percent of these posts are located at research institutes, primarily in the provinces, and the remaining 20% are in the agricultural universities. Among this pool of agricultural scientists, perhaps 20-25% are engaged in research or teaching related to wheat production.

Extension Education and Technology Transfer Programs

Agricultural extension in Pakistan is a provincial responsibility. The effectiveness of the extension service as an agent of agricultural change it is still very low. In theory, the extension service is the intermediary between the research system and farmers, getting information to the latter, and providing feedback on farmers' problems to the former. However, in practice the first set of linkages is weak and the second non-existent. PARC has attempted to strengthen technology linkages between research and extension organizations through its Crop Maximization Program in wheat, rice and maize, and through its Barani Agricultural Development Project (BARD) in northern Punjab, Islamabad Capital Territory, and southern NWFP. However, the ties between research and extension remain tenuous.



The Performance of the Wheat Economy

Pakistan is one of the top 10 producers of wheat in the world, accounting for approximately 2% of the global wheat supply (Table 9). Among the major producers, Pakistan has the third highest growth rates in yield and production over the past 20 years. Wheat is produced throughout most of Pakistan on 7.4 million hectares (ha) during the winter Rabi season (Figure 1). Of this total area, nearly 6.0 million ha are irrigated and about 1.4 million ha are rainfed. Wheat is by far the most important crop in the country, claiming three times the area and twice the value added share of the next two crops, cotton and rice, which are Pakistan's two main export earners.

Table 9. World's Top 10 Wheat-Producing Countries

	1984-86 Average Annual Production (Mt)	% World	% Annual Growth 1961-65 to 1984-86	
			Yield	Production
China	87.9	17	6.3	7.2
USSR	79.7	15	2.3	1.0
EEC 10	69.6	13	3.2	3.4
USA	64.5	12	1.7	3.1
India	45.5	9	3.8	6.6
Canada	25.8	5	1.4	2.4
Turkey	17.8	3	2.6	3.4
Australia	17.2	3	0.9	3.4
Pakistan	12.2	2	3.2	5.0
Argentina	10.4	2	1.0	1.5

Source: FAO Production Data Tapes

With the expansion in irrigated area, the cropping intensity in wheat-growing areas of Pakistan has increased considerably during the past 20 years, and wheat today generally forms part of a multiple-crop rotation. The major cropping patterns are cotton/wheat and rice/wheat rotations, which respectively account for 37 and 21% of the total national wheat area. Maize/wheat rotations are important in the NWFP and central Punjab. Wheat grown in rotation with sugarcane, pulses and fallow is also important.

Uses of Wheat

Wheat is the staple food grain of Pakistan, supplying 72% of the calories and protein in the average diet, principally in the form of

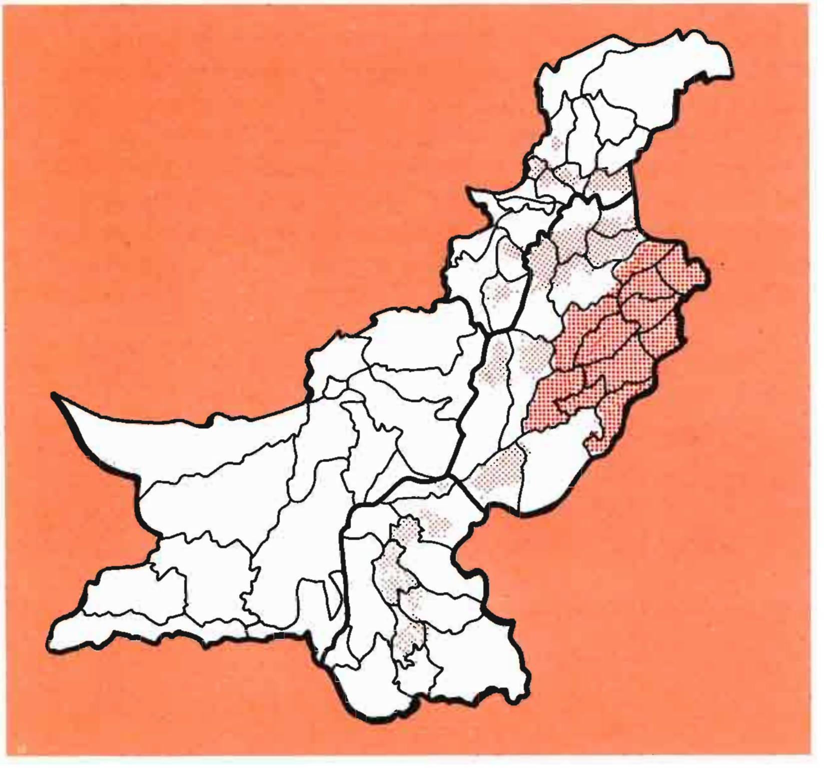


Figure 1. Wheat Production Areas of Pakistan

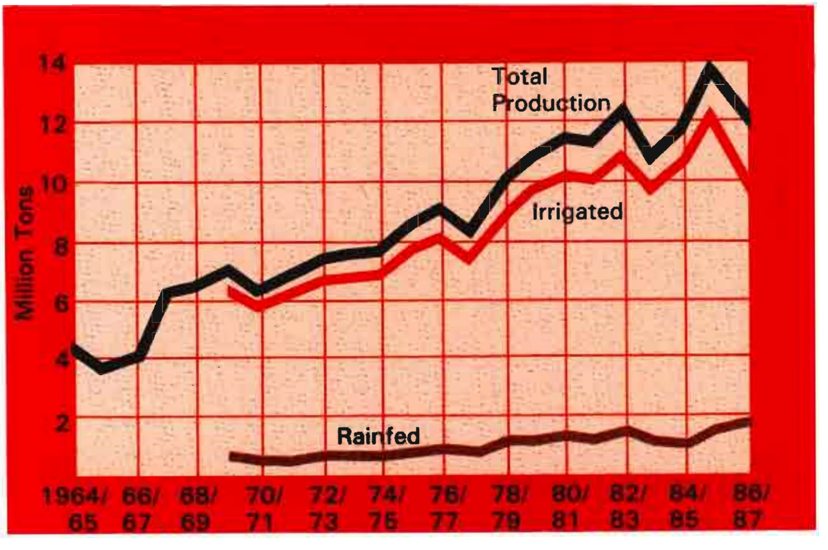
chappati and nan, two unleavened bread products. Per capita wheat consumption, at 120 kg a year, is among the highest in the world. Consumer preference is for a white or amber grain color, with reasonable hardness for enhanced storability. High gluten strength is preferred, since it results in more elastic dough, a property that helps preserve freshness in the baked products. Higher water-absorbing capacity is also preferred since it permits thinner and more numerous chappatis to a given amount of flour.

The wheat straw—or bhusa—is also very important as a fodder. Although not officially sanctioned, it is estimated that 5 to 10% of the wheat harvest (depending on the year and relative prices) is also utilized as feed grain (usually lower quality grades). This percentage has increased sharply in recent years, as per capita consumption of poultry, meat and eggs has grown, and because wheat is cheaper than alternative feed-grain substitutes.

Changes in Production

Pakistan has achieved remarkable progress in the development of its wheat-producing sector during the past 20 years. In 1964-65, Pakistani wheat varieties were tall genotypes with excellent milling and baking quality but with high levels of leaf-rust susceptibility. Moreover, mainly because of their tall, weak stems, they could not be fertilized above 50 kg of N per hectare, which placed an effective 2.5-to-3 t/ha ceiling on yield potential. Commercial yields, however, were generally under 1 t/ha with less than 10 kg/ha of fertilizer (almost exclusively nitrogen) the norm.

The widespread introduction in 1966-67 of the high-yielding, semidwarf varieties (HYVs) from Mexico, together with increased fertilizer use, the adoption of better agronomic practices and new price support policies launched the Green Revolution in Pakistan. The result was a nearly three-fold increase in wheat production, from 4.3 to approximately 12.5 million tons per cycle, between 1965 and 1987 (Figure 2). This represents a 5.5% rate of gain per year, considerably ahead of the population growth rate of 3.4% per year during this same period.



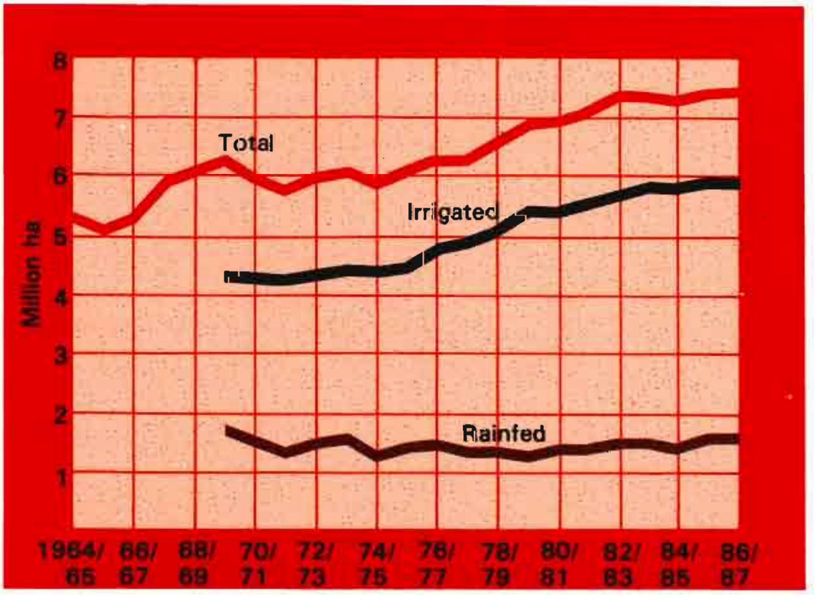
Sources: PARC Statistical Bulletin on Wheat in Pakistan, 1983; Agricultural Statistics of Pakistan, 1986

Figure 2. Wheat Production in Pakistan, by Type of Moisture Regime

Pakistan's increasing wheat harvests have boosted per capita grain availability 50%, from 80 kg/person in 1964-65 to 120 kg/person in 1986-87. Although production has continued on a general upward trend, major year-to-year variations in production have occurred due to inclement weather, disease epidemics, and discriminatory public policies (e.g., the reduction in the fertilizer subsidy). Since 1983-84, national production has been between 11 and 14 million tons.

Changes in Area

Over the past 20 years, the area devoted to wheat cultivation in Pakistan has expanded at a rate of 1.8% a year, increasing from roughly 5.3 million ha in 1966-67 to 7.4 million ha in 1985-86 (Figure 3). Since 1970-71, virtually all of the new wheat area has been in the 'irrigated' category which has increased 35%. In contrast, rainfed production zones have declined 8% to 1.45 million ha.



Source: PARC Statistical Bulletin on Wheat in Pakistan, 1983; Agricultural Statistics of Pakistan, 1986

Figure 3. Wheat Area in Pakistan

The Punjab Province, with 5.3 million ha planted to wheat, is overwhelmingly dominant in the wheat economy, accounting for 72% of the national area (Table 10). During the past 15 years, the total area planted to wheat in the Punjab has increased 22%, or roughly 1 million ha. However, irrigated wheat area in the Punjab has increased 30%, or about 1.1 million ha, while the rainfed area has declined 16%, or more than 150,000 ha.

In the Sind Province, roughly 1 million ha are planted to wheat. During the past 15 years, the total wheat area has increased 23%, or 200,000 ha. During this period, the irrigated area increased 40% while the rainfed area declined 69%.

In the NWFP, nearly 800,000 ha are planted to wheat. During the past 15 years, the total area planted to wheat has increased 33%, with equal rates of growth in both the irrigated and rainfed areas.

In the Baluchistan Province, some 250,000 ha of wheat are grown. During the past 15 years, the total area planted to wheat has increased 54%, almost exclusively due to expansions in irrigated area, which has nearly doubled.

Another 100,000 ha of wheat is grown in the State of AJK and in the Federally Administered Tribal Areas (FATA). Little information on moisture regimes is available for these areas, although irrigation is generally required for cultivation.

Changes in Yields

Before the introduction of HYVs, national wheat yields averaged about 0.8 t/ha. Over the past 20 years, farmers have improved

Table 10. Changes in Irrigated and Rainfed Wheat Area, by Province

Provin.	1970-71 Irr.	Rain.	Total	1985-86 Irr.	Rain	Total	% Change Irr.	Rain.	Total
	000 ha								
Punjab	3,381	1,009	4,390	4,494	849	5,343	+30	- 16	+22
Sind	707	130	837	991	40	1,031	+40	- 69	+23
NWFP	230	360	590	305	477	782	+33	+33	+33
Baluch.	89	72	161	172	76	248	+93	+ 6	+54
Total	4,406	1,571	5,977	5,962	1,441	7,403	+35	- 8	+24

Source: Agricultural Statistics of Pakistan, 1986

this figure by 142%. During the early period of HYV adoption—1967 to 1976—yields grew at the rapid rate of 5.85% a year. In more recent years—1977 to 1986—as the proportion of farmers using HYVs has exceeded 90%, the growth in yields has slowed to 2.91% a year (Figure 4).

Considerable variation still occurs in average wheat yields from year to year. In 1970-71 and 1977-78, leaf rust epidemics caused temporary yield depressions. In 1981-82 and 1986-87, high rainfall and flooding during harvesting reduced yields. In 1983-84 and 1984-85, drought and high temperatures at flowering and grain filling depressed yields. During 1985-86, the nation's wheat farmers obtained an average yield of 1.9 t/ha (2.1 t/ha in irrigated areas and 1.0 t/ha in rainfed areas). The 1986-87 wheat season saw drought and heat stress during grain filling and heavy rains and flooding during harvest time which caused considerable grain damage in irrigated areas. On the other hand, yields in rainfed areas were generally better than normal due to the higher rainfall. Overall, the average national yield was 1.6

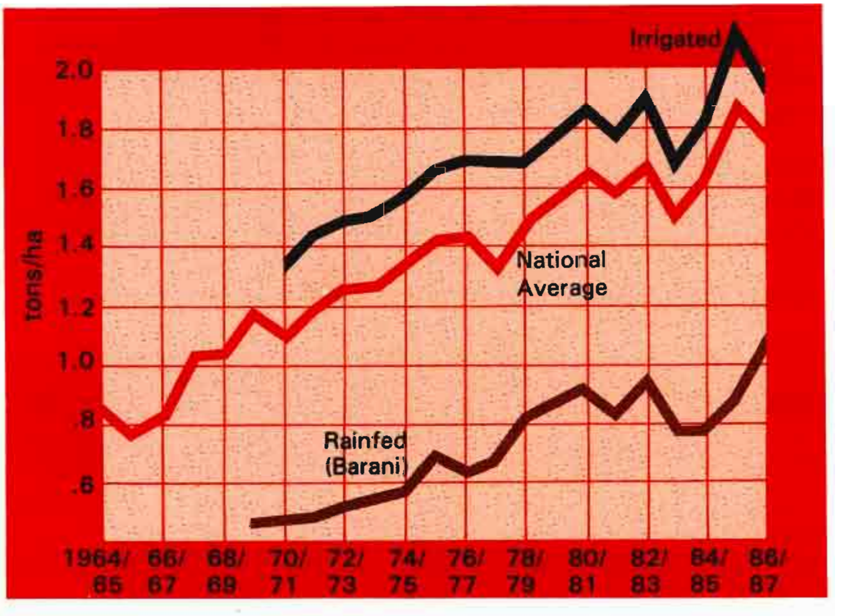


Figure 4. Wheat Yield in Pakistan, by Type of Moisture Regime

t/ha, with the average yield in the irrigated areas dropping to 1.8 t/ha and the average yield in rainfed areas climbing to 1.2 t/ha. Pakistan's wheat research establishment has released a continuing stream of improved HYVs with higher yield potential and other superior characteristics for irrigated and rainfed areas. Breeders have achieved an approximately 1% increase per year in varietal yield potential during the past 20 years. (Byerlee and Heisey, 1989). This means the latest varieties released today have a 15-20% yield advantage over the original HYVs released originally. Despite this yield advantage, the changeover from older to newer HYVs has been slower in Pakistan than in other countries with similar production environments. (This issue is discussed further in Chapter Six.) This situation contrasts with Mexico and India, countries where farmers change varieties every 3 to 5 years.

Expansion in Fertilizer Use

One of the key decisions made in Pakistan during the early testing of the new semidwarf wheat varieties was to encourage heavy applications of fertilizer (120 kg of N; 35 kg of P) through subsidized prices. While the official dosage recommendations were rarely followed by the farmer, progressively larger amounts of fertilizer have been applied over time (Table 11). Initially, only nitrogenous fertilizers were used. However, in recent years, the demand for phosphate fertilizers has greatly increased. The average fertilizer application on wheat for the country is 110 kg/ha of total nutrients, with higher dosages in irrigated areas and lower ones in rainfed zones. The current average N:P ratio for wheat is 3:1, compared with 8:1 in 1970-71.

Table 11. Fertilizer Use on Wheat

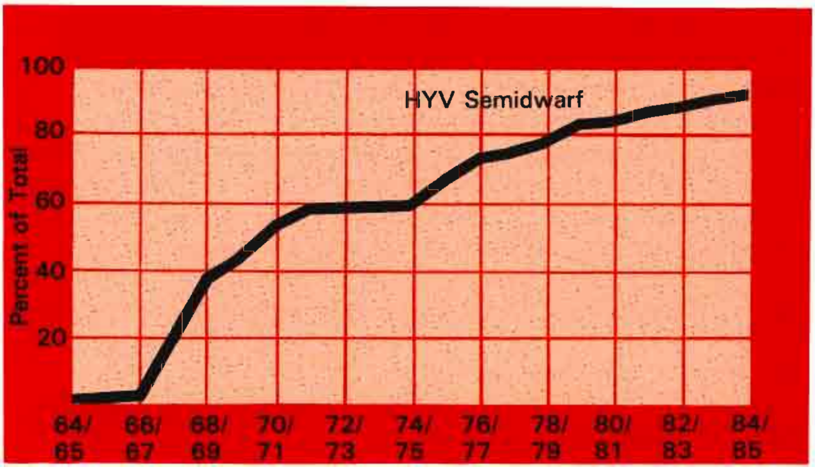
Crop Year	N	P	K	Total	Wheat Area '000 ha	Nutrients kg/ha
	('000 tons of nutrients)					
1965-66	3	—	30	5,155	5.4	
1970-71	88	13	—	101	5,978	16.9
1975-76	213	52	1	266	6,111	43.5
1980-81	405	109	5	519	6,981	72.2
1984-85	491	153	12	656	7,259	90.4
1985-86*	571	187	18	776	7,403	104.8
1986-87*	637	198	20	855	7,706	111.0

* Unpublished data of Ministry of Food and Agriculture

Sources: PARC Statistical Bulletin on Wheat in Pakistan, 1983; Agricultural Statistics of Pakistan, 1986

Adoption of High-Yielding Varieties

The use of high-yielding, fertilizer-responsive semidwarf wheat varieties has spread dramatically over the past 20 years (Dalrymple, 1986). HYVs were first adopted in the irrigated areas of the Punjab and Sind provinces. Within four years of introduction, half of the national wheat area was planted to semidwarf HYVs. Today, these genotypes are grown on 91% of all wheat land (Figure 5). It took another 10 years for significant HYV adoption to occur in the rainfed areas. In 1970-71, only 15% of the rainfed areas were planted to HYVs, compared with 65% in the irrigated areas. HYV use in rainfed areas remained low until the mid-1970s, when increased availability of fertilizers together with disease epidemics and crop failures finally induced farmers to switch to the semidwarf varieties. By 1980-81, 50% of the rainfed areas were planted to HYVs; in 1986-87, this figure was closer to 70%.



Sources: PARC Statistical Bulletin on Wheat in Pakistan, 1983; Agricultural Statistics of Pakistan, 1986

Figure 5. Pakistan's Total Wheat Area Occupied by HYVs

Seed Industry Development

Pakistan's wheat seed industry dates back to colonial times, when government farms were established to multiply seed of wheat, cotton and several other crops. As with other self-pollinated crops, wheat seed can be saved by the farmer with little change in genetic make-up or yield potential. New commercial seed purchases, therefore, are only necessary when a new variety is adopted.

To speed up the adoption of HYVs in Pakistan in the mid 1960s, massive amounts of seed were imported from Mexico. In total, some 50,000 tons of HYV seed were purchased between 1965 and 1968. At the same time, plans were made to develop the national seed industry to supply the requirements for HYV seed. This task is a provincial responsibility and was first assigned (as were fertilizer imports and distribution) to the Agricultural Development Corporation (ADC) of West Pakistan, which never became an effective seed producer. After the separation of Bangladesh, the ADC was dissolved and seed production and distribution were taken over by the new provincial governments. In the Punjab province, seed industry activities were assumed by the Punjab Agricultural Development & Supply Corporation (PAD & SC). This seed producer had greater success than the ADC.

In 1976, a major seed industry project was designed and implemented with the financial and technical assistance of the World Bank. A new National Seed Law was enacted also in that year, establishing the framework for a modern seed industry. Standards for seed certification were to be set by the federal government, while the Provinces were given the responsibility of naming and releasing varieties for commercial use and producing seed for sale to farmers. As part of the project, the Punjab Seed Corporation (PSC) and the Sind Seed Corporation (SSC) were established. Of the two, the PSC is dominant, producing 10 times more seed than the SSC (Table 12).

Table 12. Provincial Distribution of HYV Wheat Seed

Crop/Year	Punjab	Sind	NWFP	Baluchistan	Total
	'000 tons				
1970-71	5.4	1.8	0.9	0.3	8.3
1972-73	5.0	0.9	1.2	2.7	9.9
1974-75	11.3	1.0	1.6	1.0	15.3
1976-77	44.5	2.1	2.6	1.6	50.8
1978-79	22.2	3.6	3.0	1.1	29.8
1980-81	43.9	3.6	1.8	0.9	50.1
1982-83	41.4	4.4	3.1	0.2	49.1
1984-85	48.5	4.2	3.0	1.3	57.1
1986-87*	35.2	3.1	3.0	0.6	41.9

* unpublished data of Ministry of Food and Agriculture

Source: Agricultural Statistics of Pakistan, 1986

These two public-sector corporations originally organized the three primary steps of the production process in the following way: pre-basic seed was produced by the research institutes, basic seed on the Corporation's seed farms, and certified seed production by registered contract growers. Because the quantity of pre-basic seed coming from the agricultural research institutions was insufficient, the PSC in recent years has done most of the pre-basic seed production, in close cooperation with the Ayub Agricultural Research Institute (AARI) Wheat Research Institute staff.

The SSC still has problems of quality control (the seed of different varieties tends to get mixed at the processing plants). Neither seed corporation produces sufficient seed of new varieties to ensure an orderly switch from the non-recommended commercial varieties currently in use. Seed distribution at the local level is especially inadequate, despite the existence of an extensive network of rural supply outlets for other inputs, such as fertilizer. A major problem identified by seed dealers is the low profit margin allowed by the government for wheat seed. This is about 4.5%, compared to the 18% that dealers make on fertilizer sales (Chaudhry and Heisey, 1987). It is thus little wonder that seed distribution is ineffective, given the lack of incentive for tying up operating capital in wheat seed production.

Marketing System

Pakistan's wheat marketing system has been strengthened through improvements in the infrastructure for storage, milling, and distribution. Government procurement nearly tripled from 1970 to 1987 (Table 13). The national food corporation used to

Table 13. Government Procurement of Wheat

Crop Year	Punjab	Sind	Procurement NWFP	Baluchistan	Total	% Total Production
	'000 tons					
1970-71	827	190	1	—	1,107	16
1975-76	894	333	1	8	1,236	27
1980-81	2,362	552	24	17	2,955	35
1985-86*	4,102	816	68	50	5,036	36
1986-87*	2,936	968	37	27	3,968	33

* Unpublished data of Ministry of Food and Agriculture

Source: Agricultural Statistics of Pakistan, 1986

market wheat grain at subsidized rates through government ration shops. While subsidies have persisted, the ration shops were discontinued in 1986.

Storage capacity has increased dramatically from under 1 million tons in the mid 1960s to 4.0 million tons in 1984-85 (Table 14). The most significant expansion occurred in federal storage capacity, reflecting programs to provide food for the large population of Afghan refugees. Additional storage capacity is still needed, however, if Pakistan is to supply consumer demand exclusively from domestic production and reserves.

Table 14. Government Wheat Storage Capacity

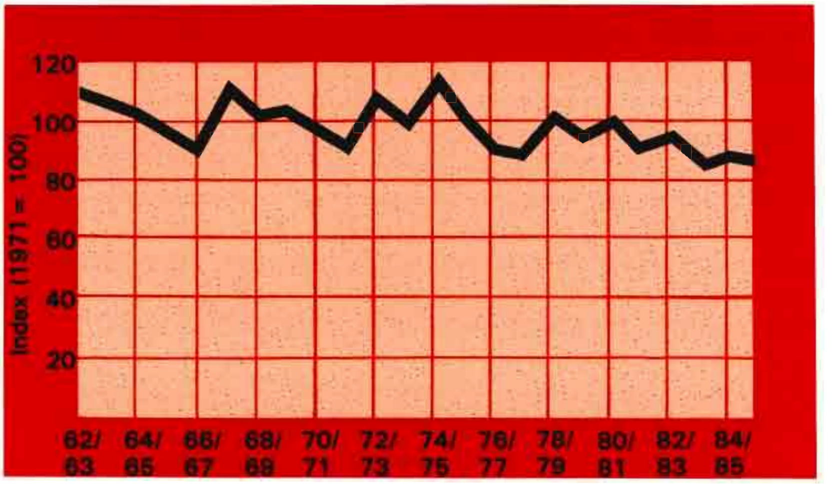
Crop Year	Storage Capacity					
	Punjab	Sind	NWFP	Baluchistan	Federal	Total
	'000 tons					
1978-79	1,076	402	145	73	90	1,786
1980-81	1,305	444	560	61	79	2,053
1982-83	1,972	561	303	85	429	3,350
1984-85	2,179	605	189	113	951	4,037
1985-86*	2,610	767	486	224	90	4,187

* Unpublished data of Ministry of Food and Agriculture

Source: Agricultural Statistics of Pakistan, 1986

Price Policy

Government wheat price policy has gone through several phases during the past 40 years and real prices have declined (Figure 6). In the first phase, the period up to 1966-67, the primary motivation behind wheat price policy was to provide cheap wheat to the urban consumer. This was achieved by importing wheat at an overvalued exchange rate (e.g., PL 480 concessionary sales, etc.). Towards the end of this period, the price discrimination against wheat production was lessened by large government investments in irrigation and subsidies on the price of new inputs, such as chemical fertilizer (Hamid et al., 1987). However, although wheat production expanded, yield levels did not become appreciably higher until the introduction of the HYV seed-fertilizer technology in the late 1960s.



Source: Hamid et al., 1987

Figure 6. Index of Real Price of Wheat in Pakistan

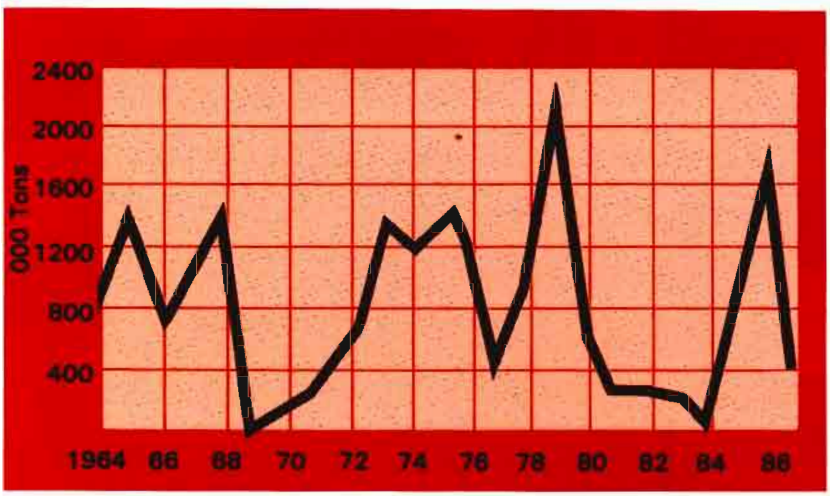
In support of the Accelerated Wheat Improvement Program, the government procurement price for wheat was raised 25% just prior to planting in the 1967-68 season. Furthermore, the government announced its intention to defend the new price for a minimum of three years, an assurance that encouraged farmers to make additional investments in tubewells, fertilizers and other inputs.

The second phase in price policy was the period of 1971-78, when the old mechanisms of discrimination were replaced by new ones: explicit taxes on agriculture, a government monopoly on cotton and rice exports, and a ban on wheat exports (Hamid et al., 1987). The oil shock and resulting worldwide inflation set off a domestic price spiral during the 1970s. Price policy again became a constraint on the growth of wheat production.

The third phase covers the period from 1978 to date. The stated policy has been to move towards product and input prices that reflect the import parity of these commodities. In line with this policy, the government has eliminated the subsidy on pesticides and nitrogenous fertilizers manufactured locally, although imported phosphatic fertilizers are still highly subsidized. During most of this period, price policy has been conducive to wheat production and increased productivity (Hamid et al., 1987).

Trade

Annual wheat imports have varied considerably (Figure 7). Until the introduction of the HYVs and the popularization of chemical fertilizer use, wheat imports were large and increasing. In 1967, Pakistan was only producing 80% of its national wheat requirement. By 1969, it had again become self-sufficient. This self-sufficiency was short-lived, and by the early 1970s, imports were once more on the rise, surpassing 1 million tons by 1972-73. They continued to increase until 1976-77, when national production was nearly equal to the demand. However, the rust epidemic of 1977-78 led to imports of nearly 2 million tons in 1979, 20% of demand. From this all-time high, imports have dropped, averaging less than 5% of demand during the 1980-86 period. In second half of the 1980s, Pakistan has begun anew to import larger quantities of wheat, now amounting to roughly 10% of national demand. In 1985-86 and again in 1987-88, 1.5 million tons a season were imported.



Source: FAO Trada Data Tapes

Figure 7. Wheat Imports in Pakistan

DEMONSTRATION PLO
WHEAT
VARIETY VARIETY
C-591
DETAILS
1. NAME OF GROWER
2. LOCALITY
3. AREA OF PLOT
4. DATE OF SOWING
5 METHOD OF SOWING
6. IRRIGATIONS
7 INTERCULTURINGS
TILLERS PER PLANT

The Evolution of Wheat Research

Agricultural research came of age in this century. By the early 1900s, building upon recent discoveries in soil chemistry and physics, plant genetics, plant pathology and entomology, many governments had established agricultural research services and experiment stations where scientists could carry out their work under 'controlled' conditions.

Breakthroughs were soon forthcoming in plant breeding, first with the development of hybrid maize, and later with high-yielding varieties of other crops. Mechanization, improved agronomy, and the advent of chemical fertilizers set the stage by the late 1930s for a dramatic take-off in crop yields, first in the USA, a little later in other temperate-zone regions, and more recently in the sub-tropics and tropics.

This chapter provides a brief historical overview of wheat research in Pakistan, beginning with the colonial period, from 1905 to 1947. Next, wheat research in West Pakistan from 1947 to 1963—before semidwarf varieties were introduced—is surveyed. A more detailed account is then provided of the period when semidwarf wheats from Mexico were introduced (1964-70). The post-1970 period, after the separation of Bangladesh, is divided into two parts: the early and mid 1970s, when there was little national coordination in wheat research, and the period since 1978, which has seen the rise of the Pakistan Agricultural Research Council (PARC) as the major coordinating body for the nation's agricultural research system.

Colonial Wheat Research Period

British India was a pioneer in the development of organized agricultural research. In 1905 it created the Punjab Department of Agriculture and in 1906 the Punjab Agricultural College and Research Institute at Lyallpur (now Faisalabad). This research and training complex was one of the premier agricultural institutions of Colonial India.

In 1907, a botanical survey was conducted by the Punjab Board of Agriculture to collect and classify the available wheat landraces (Khan, 1987). From this survey 25 landraces were identified among three species of wheat. Selections from these landraces were released to farmers as improved cultivars. In 1911 and

1913, respectively, the cultivars T9 and T11 were approved for general cultivation. In 1914, the economic botanist R. D. Milne conducted another survey of landraces. As a result of this work, the improved cultivar 8A was released in 1919 for commercial use.

In 1926, the appointment of a cereal botanist at Lyallpur provided added stimulus for wheat improvement, and three varieties were released over the next eight years. A selection from a local landrace, 9D, was released for cultivation in 1932. In subsequent years, cross-breeding techniques were used to hybridize varieties. The first variety, C518, a cross between T9 x 8A, was released to farmers in 1933; C591 was released the following year. Two additional varieties (sister lines) were released before partition: C228 in 1941 and C250 in 1944.

The early Lyallpur wheat researchers provided Punjabi farmers with substantial benefits in the form of improved varieties throughout the first half of the 20th Century. These made the Punjab a major global granary, supplying Britain and many other countries with wheat (Table 15). While expansions in irrigated area accounted for about 75% of the total increase in output, the use of improved varieties of wheat, cotton, and sugarcane led to a 12% increase in yields on irrigated land and a 3% increase on unirrigated land, despite a drop in the yield of gram (Pray, 1984).

Table 15. Improved Tall Varieties Released in the Punjab

Variety	Year of Release	Parentage
T 9	1911	Selection
T 11	1913	Selection
8 A	1919	Selection
9 D	1932	Selection
C 518	1933	T9 x 8A
C 591	1934	T9 x 8B
C 228	1941	Hard Federation x 9D
C 250	1944	Hard Federation x 9D
C 271	1957	C 230 x IP 165
C 273	1957	C 209 x C 591

Source: Md. Aqil Khan, 1987

Pre-Semidwarf Variety Era in National Research

With the partition of British India, much of the colonial agricultural research infrastructure was located in territory belonging to India. West Pakistan inherited the Punjab Agricultural College and Research Station, the Veterinary College in Lahore, and one provincial experiment station in each of the provinces of NWFP, Sind and Baluchistan. A small agricultural college was also located in Peshawar. After partition, most wheat researchers—mainly Hindus and Sikhs—migrated from West Pakistan to India. This resulted in a serious shortage of trained manpower for wheat research in the initial years after independence.

During the first decade after independence, wheat breeding in the Punjab continued to focus on grain quality and stem rust resistance. In 1957, two tall bread wheat varieties were released for commercial use: C271 (parentage: C230 x IP165) and C273 (parentage: C209 x C591). These varieties had hard, vitreous grains with good gluten strength, which means they made excellent chapattis and had good grain storage characteristics. But, like the varieties that preceded them and to which they were closely related, these cultivars had relatively low yield potentials. In the nearly 50 years from the release of T9 in 1911 to that of the last tall variety, C273, in 1957, maximum yield potential had increased from 2,400 to 2,525 kg/ha, a gain of only 125 kg/ha in 40 years (Khan, 1987).

Despite the price premium paid for the high quality grain of the local (desi) varieties, Pakistan experienced an increasing deficit in wheat production during the 1950s, with imports averaging 800,000 tons per year during most of the decade. By the early 1960s, the government took a more active role in stimulating wheat production. The procurement price for wheat was raised, greater amounts of chemical fertilizers were imported and made available, and irrigation systems were expanded.

While wheat production grew, the lack of fertilizer-responsive genotypes limited the amount of nutrients that could be profitably used by the farmer. The threat of lodging under higher fertility or increased irrigation placed an effective limit on yield potential. Diseases were also a problem with the tall varieties, especially loose smut, powdery mildew and the rusts.

The Mexican Connection

The story of the development of HYVs in Mexico is inextricably linked to their introduction in Pakistan and several other Third-World countries.

As with many scientific breakthroughs, the HYV semidwarf spring wheat varieties were a consequence of both design and happenstance. These genotypes were the fruit of a vigorous, production-oriented wheat improvement program launched in 1944 by the Mexican government in collaboration with the Rockefeller Foundation and headed by a young American wheat scientist, Norman E. Borlaug.

During the 1940s, the Mexican wheat research program's first priority was to develop varieties with improved resistance to stem rust. Facing a farm community with little faith in agricultural researchers after suffering three disastrous stem rust epidemics in the 1939-41 period, Borlaug and his group set out to produce and release an improved, stem-rust-resistant variety as soon as possible. To speed up the germplasm development process, a shuttle breeding scheme was developed which would permit the growing of two breeding cycles per year, thus effectively cutting in half the time needed to produce a new variety. This shuttle breeding system, however, challenged the conventional wisdom in plant breeding that varieties could only be bred for and within one specific environment.

The set of Mexican locations which permitted Borlaug to grow two cycles a year were indeed radically different from each other. One was in the Yaqui Valley of northwest Mexico, an irrigated desert near the coast in the state of Sonora. The other was on the high plateau of the Toluca Valley, state of Mexico. These two sites differed in latitude by 10 degrees (1,800 km), in elevation by 2,600 meters (40 m in the Yaqui Valley; 2640 m in the Toluca Valley), and in water supply (irrigated in the north; rainfed on the central plateau). Different disease matrices prevailed at each location. Stem and leaf rust were very virulent in the Yaqui Valley, while stripe and leaf rust and Septoria leaf blotch were endemic in the Toluca Valley.

By growing wheat in the north during its relatively mild winter season (November to May) and on the central Mexican plateau during the cool, rainy summer season (May to October), Borlaug was able to expose his materials to a broad spectrum of diseases while advancing two generations per year. The result was that, by 1948, the first improved, tall, stem-rust resistant wheat variety, Yaqui 48, was released for commercial production—only four years after the first cross was made.

During the first few years that Borlaug operated the shuttle breeding system, he was roundly criticized by many of his peers, including some of his former professors. But by then he had already begun to see a whole new range of unexpected benefits from such an approach. In addition to the exposure of the breeding materials to different spectra of disease-causing organisms, the amount and regime of solar radiation at each of the sites varied considerably. Only those materials that withstood the rigors of both environments were advanced in the breeding system.

The Mexican semidwarf wheat varieties had a radically different partitioning of biomass compared with their tall predecessors. The introduction of these new varieties provoked a revolution in wheat production, first in Mexico, next in Pakistan, and later in a host of other countries.

Borlaug and his colleagues soon began to see a new type of wheat—one that was photoperiod insensitive and, therefore, adapted to different latitudes and daylengths. In addition, because of the multilocational screening system that was employed in Mexico as well as internationally, it was possible to pyramid genes for more durable resistance to the rusts and other pathogens. Since the varieties produced through this system were also capable of superior yield performance across a range of diverse environments, a smaller number of varieties would be needed to serve Mexico's farmers, an important simplification in seed multiplication and distribution for Mexico's recently established national seed industry.

Between 1944 and 1957, the Mexican wheat research team developed a number of improved tall wheat varieties with good disease resistance and broad adaptation. These materials, however, still lacked sufficient straw strength to stand up under conditions of improved soil fertility and moisture availability during grain filling, placing an effective limit on yield potential of about 3 t/ha.

In search of genotypes with stiff straw, Borlaug and his colleagues screened the entire USDA world wheat collection, but met with little success. Then Borlaug heard about a dwarf Japanese winter wheat variety, Norin-10, being used by Dr. Orville Vogel of Washington State University at Pullman in crosses with his own materials. Vogel had received Norin-10 seed from Dr. S.C. Salmon, who had discovered the material on a visit to the Norin research station (where it was bred and released in 1935) while serving as Agricultural Advisor to the U.S. Occupational Forces in Japan. One of Vogel's crosses, Norin 10 x Brevor, was obtained and crossed extensively with tall Mexican varieties to produce semidwarf spring wheats.

By the late 1950s, it was apparent that a whole new type of spring bread wheat was in the works. Initially, these new Mexican semidwarfs had problems of sterility, grain shrivelling, poor industrial quality, and extreme susceptibility to all three rusts. But the promise they showed well justified the work required to get them into shape for release. From their shuttle-bred Mexican parents, they had inherited broad adaptation and photoperiod insensitivity, and through the multilocation screening system they received superior resistance to rusts (especially stem rust) and other diseases. From their Japanese-American parents, they had inherited a short, stiff straw that permitted higher applications of fertilizer, and a new plant architecture in which a much higher amount of the plant biomass was apportioned to grain. Finally, these plants possessed an enhanced tillering capacity, thus producing more biomass per unit area than the tall genotypes.

Previously, the highest yield obtained in Mexico with the best tall variety was 4.5 t/ha, and this only by physically propping up the plant to keep it from falling over under intensive fertilization—not a very practical method to control lodging. In contrast, the semidwarf varieties yielded 6 to 7 t/ha under optimum doses of fertilizer, with virtually no lodging.

The Pakistan Connection

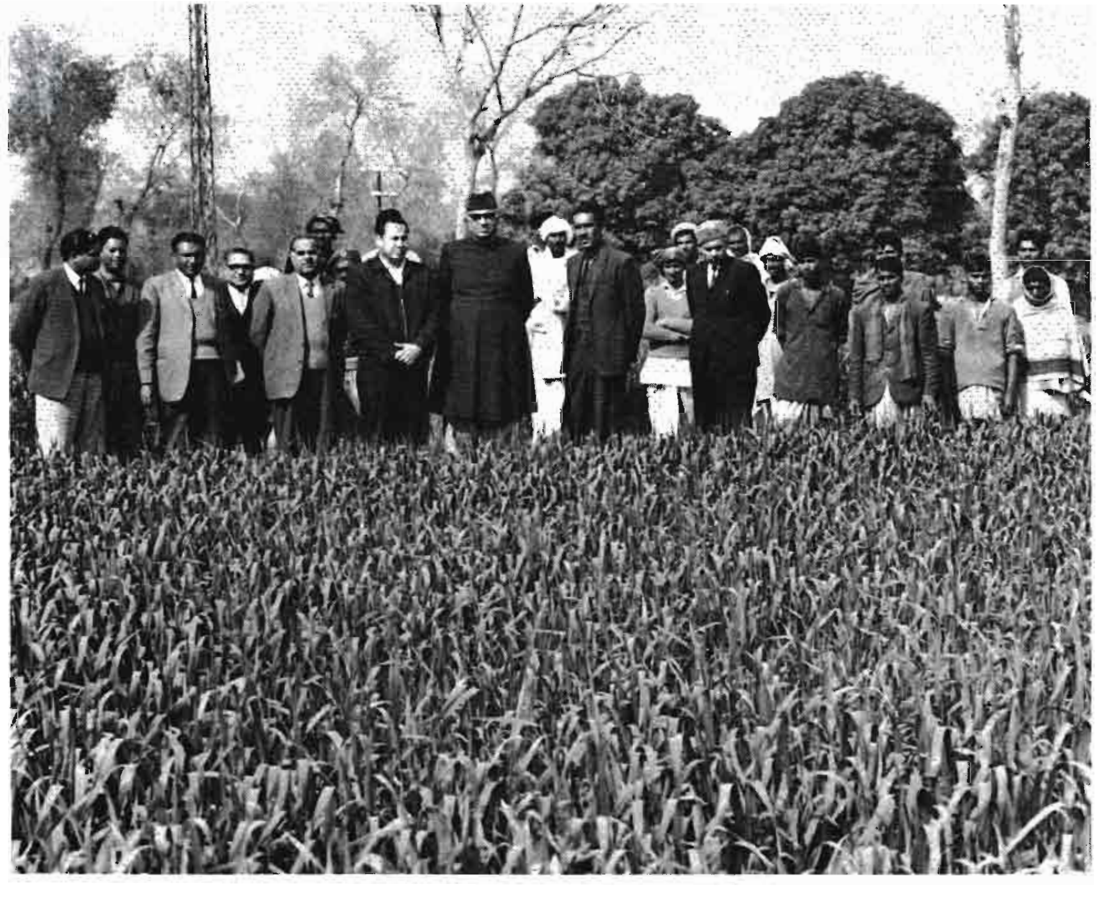
The first contact that Pakistani scientists had with Borlaug came in 1960, when he toured the country as a member of a FAO-Rockefeller Foundation team studying wheat production problems in North Africa, the Middle East and South Asia. A major recommendation of this expert team was for the practical training of regional wheat scientists in wheat improvement. FAO agreed to locate candidates for training, Borlaug offered to provide training in Mexico, and the Rockefeller Foundation agreed to put up the funds for this activity.

The first group of promising young researchers arrived for training in 1961. There was one Pakistani in the first group, Manzoor A. Bajwa, next year another, Muhammed Nur, and in 1963, two more. These young Pakistani researchers spent nine months in Mexico working alongside Borlaug and the Mexican-Rockefeller research team. The trainees were exposed to new and practical methods for improving wheat production, and all went home carrying packets of seed and the knowledge on how to use it to best advantage.

In 1963, Borlaug returned to the sub-continent as a guest of the government of India to ascertain whether the Mexican semidwarf wheat varieties could be of value there. Before making his recommendation, he decided to visit Bajwa and Nur in Faisalabad at the Ayub Agricultural Research Institute (then called the Punjab Agricultural Research Institute). Researchers there had brought back from their training program seed of many HYV semidwarf wheats for testing in Pakistan.

Borlaug's first inspection of these materials in the major experimental field was disappointing; their yields were not much different from the tall, traditional genotypes grown in the Pakistani and Indian Punjab. The problem however soon became evident: they had been grossly underfertilized. Borlaug quickly learned that his Pakistani colleagues officially were only permitted to fertilize the semidwarfs at 30 kg of N per ha—the normal dosage applied to the tall, traditional types. However, these enterprising researchers had also grown several small plots of the semidwarf wheats in an isolated corner of the station using the proper fertilizer dosage. In these plots, Borlaug found his answer about the suitability of the Mexican semidwarfs for the irrigated plains of the Punjab. The yields of the HYV lines he saw were twice that of the best tall local varieties in Pakistan and as good as in the Yaqui Valley of Mexico, their home half-way around the world.

There were many heroes of the Pakistan's Green Revolution in wheat, including Malik Khuda Backsh Bucha (center), Minister of Agriculture for West Pakistan, pictured with some of the key wheat researchers of the Accelerated Wheat Improvement Program.



Haldore Hanson, the Ford Foundation representative in Pakistan, had heard about the Mexican dwarf wheats by 1963 and was interested in assessing their value for the country. Hanson invited Borlaug to provide a demonstration of the yield potential of the semidwarf varieties at AARI in the 1963-64 season. The yields of the semidwarf wheat plots were convincing: the new HYV seed-fertilizer technology from Mexico offered the potential for a dramatic breakthrough in wheat production in Pakistan. Hanson believed he could convince the Ford Foundation to finance a program to introduce the new technology into the province of West Pakistan as quickly as possible, with Borlaug as an active participant in the project.

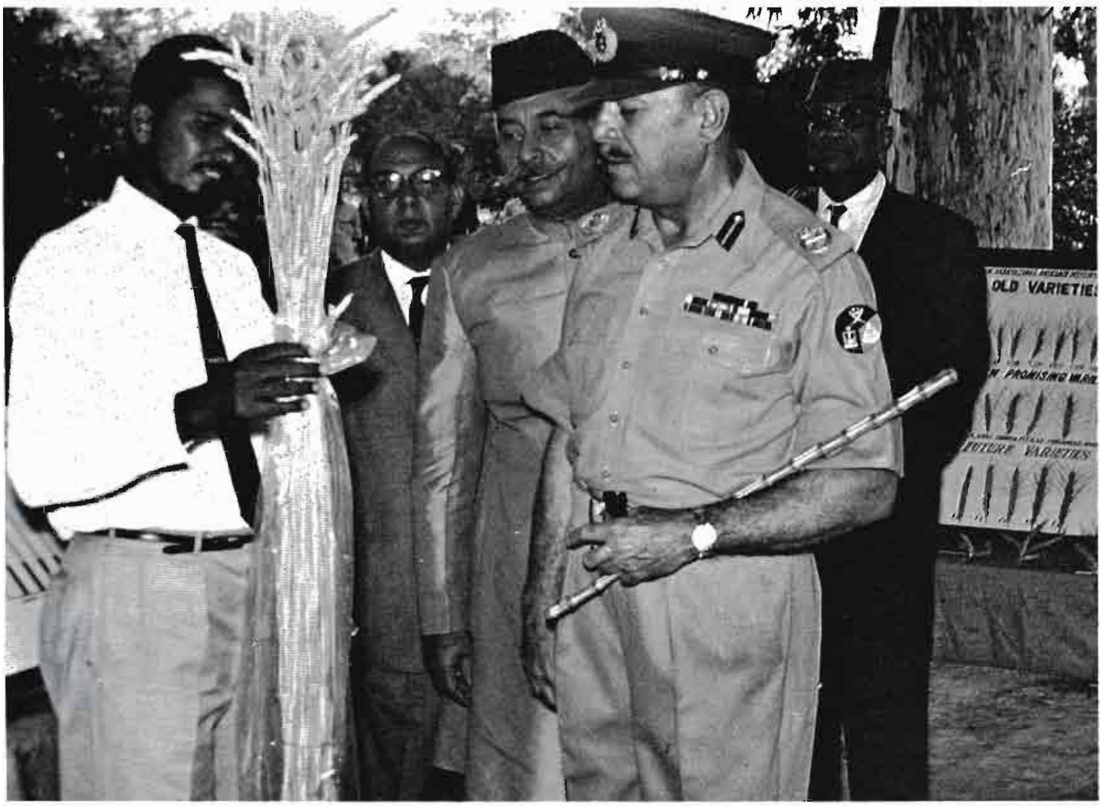
With strong support from the highest levels of the Pakistan government, the Ford Foundation made a grant in 1964 to West Pakistan to launch the Accelerated Wheat Improvement Program. Borlaug agreed to provide overall program guidance and Dr. Ignacio Narvaez, Director of Wheat Research at Mexico's National Agricultural Research Institute (INIA) during the latter part of the period when HYV technology was being developed and extended to that country's wheat farmers, agreed to serve as the resident wheat advisor. Key roles were also given to other Ford Foundation staff: Dr. Oddvar Aresvik, an agricultural economist, was assigned to the Ministry of Agriculture's planning cell, and Mr. Robert Havener, the agricultural program officer, supported the Foundation's overall agricultural program. Both were active in getting fertilizers imported and into the hands of farmers, and participated on other policy issues.

West Pakistan's Accelerated Wheat Improvement Program

West Pakistan's Accelerated Wheat Improvement Program had various features distinguishing it from previous wheat research and development efforts. First, it established joint coordinators, Dr. S.A. Qureshi and Mr. Z.A. Munshi, to work with the three wheat research institutes at Lyallpur (Faisalabad) in the Punjab, Tarnab in NWFP, and Tandojam in the Sind. The three institutes agreed to pool their breeding material, their data, and even their scientific staff in selecting and evaluating varieties. All materials developed at one institution would be shared with the others. Whatever material received from CIMMYT would be distributed to all three institutes.

A team of scientists from different disciplines was set up within each research institute to cut across section lines and merge collective talents into one research effort. Exchange visits between institutes would occur regularly and decisions for selection of varieties would be taken by the research team as a whole. Much greater emphasis was also given to getting researchers off the experiment station and onto farmers' field's, especially when evaluating promising varieties and production recommendations for farmers.

The new semidwarf wheats were demonstrated as part of a production package that included 1) increased rates of nitrogen and phosphorus fertilizer use; 2) proper irrigation procedures; and 3) improved cultural practices comprising better land preparation, proper dates for sowing each variety, good planting practices, and adequate weed control. The design of these demonstrations was simple. They were to be conducted by farmers under the supervision of the wheat researchers and extension workers. Each demonstration included two plots of sufficient size to provide the farmer with a realistic scale for comparing the new technology with the existing one. On one plot, the new recommended



President Ayub took an active interest in the Accelerated Wheat Improvement Program of West Pakistan. Pictured here is M.A. Bajwa, then a young wheat scientist and now Director General of the Ayub Agricultural Research Institute, Faisalabad, showing President Ayub the advantages of the new semidwarf wheat varieties.

varieties and production practices were demonstrated; on the other plot, the farmer-cooperator was asked to use his traditional varieties and production technology.

HYV wheat demonstration plots were planted on thousands of farms in the Punjab, Sind and NWF provinces. The differences in yields were dramatic and the new technology gained the enthusiastic support of farmers. The HYV demonstration plots also served as multiplication plots to increase availability of the still-scarce semidwarf wheat seed. This farmer-to-farmer seed production and distribution system was especially important in accelerating the diffusion of the semidwarf wheat varieties (Lowdermilk, 1972).

Special field days were held for policymakers at the research institutes and on farmers' fields. President Ayub Khan even attended some of these events to lend prestige and confirm his commitment to the program. These events also helped government officials to improve their understanding of production problems and opportunities, as well as show farmers their interest in agriculture. To ensure that officials understood what the new production package could do, Qureshi, Munshi, and Narvaez planted test plots on the farms of many top policymakers, including the President and the Minister of Agriculture.

Convinced by what they saw, politicians took key policy decisions to raise and defend the guaranteed wheat price, spend scarce foreign exchange on massive imports of seed and chemical fertilizer, and provide subsidies and credit to encourage adoption of the new technologies. Finally, the government substantially altered its previous development plans and gave high priority to developing the nation's seed and fertilizer production capacities.

Import of Mexican Seed—The initial phase of the varietal improvement program centered on massive, direct introductions of Mexican semidwarf varieties. The first big seed purchase in 1965 consisted of 250 tons of Penjamo-62 and 100 tons of Lerma Rojo-64.

The seed was to be shipped through Los Angeles on the same freighter that would carry 250 tons of Lerma Rojo-64 and 50 tons of Sonora-64 to India. Once loaded and on the high seas, war broke out between India and Pakistan, and the ship had be diverted to Singapore, where the seed for Pakistan was transferred to a ship going to Karachi.

As a result of these harrowing events, the 350-ton shipment arrived in Pakistan about a month too late for the best planting date, but was distributed throughout the wheat-growing area immediately. At this point, disaster almost struck again. Because of the delayed arrival, the seed was distributed without undergoing the usual germination tests. Once the plantings were in process, researchers discovered that, due to improper treatment in Mexico, the seed had very poor germination. To overcome this potentially disastrous situation, an urgent campaign was mounted to get growers to double the recommended seed rate, in hopes of thus obtaining an adequate plant stand. This was done, and acceptable yields—indeed spectacular ones, by tall variety standards—were achieved during the first crucial year of introduction, when many were looking to see how the semidwarfs would perform.

That first year, about 5,000 ha were planted with the new semidwarf varieties on several hundred private fields and on a number of government farms. Even with poor germination and lower-than-recommended fertilizer application rates, the average yield on these plots was nearly 3 t/ha, compared to an average yield of 1.2 t/ha for the tall, local materials. The top semidwarf yield that year was 7 t/ha, obtained on a 25 ha private field; and 38 private growers had yields above 4.5 t/ha. Pakistan's green revolution in wheat was underway.

Despite the excellent performance of the Mexican wheats under difficult circumstances, another problem soon became apparent. The first HYV introductions, Penjamo-62 and Lerma Rojo-64, had soft, red grains low in gluten strength. Consumers in Pakistan had developed a preference for white-grain varieties high in gluten strength and ideal for making chappatis. With their grain-quality limitations, it was unlikely that the first HYV introductions would gain a permanent foothold. Again, good fortune came to the rescue.

The Variety Mexipak—While in Mexico in 1961, a young Pakistani researcher, Manzoor Bajwa, now Director General of AARI, Faisalabad, had identified a medium-to-hard, white-grain line from segregating generations of the cross 8156, Penjamo x Gabo (it was also segregating into a red-grain line). The white-grain version had the preferred color and high gluten strength needed to make good chappatis; it was also very high yielding, and showed good resistance to rust and powdery mildew. He took this line back to Pakistan, and after yield tests it was released for general cultivation. Though the cross was made in Mexico, line selection was performed by a Pakistani researcher To commemorate this collaboration, the variety was named Mexipak. With Mexipak-65, Pakistan had the high-yielding wheat it needed to launch its Green Revolution in wheat production.

The next problem was seed availability. Since Mexipak had not yet been released in Mexico, there was not enough seed for commercial production. During the 1965-66 season, the roughly 200 kg of Mexipak seed available in Pakistan was planted for maximum seed production on 5 ha of land; 30 tons were harvested in the spring. Efforts to grow a second-generation seed increase in high areas of Pakistan during the summer of 1966 were not successful, and only 20 tons were available for planting by the 1966-67 season. This was supplemented by the purchase through USAID of another 50 tons of Mexipak grown by a private farmer in the Yaqui Valley of Mexico The purchase of this seed is an exciting story of bold action by the USAID advisor, Staley Pitts,

Pakistan's Green Revolution in wheat has led to a tripling in national production over the past 20 years. Today, wheat accounts for twice the economic value of the two next most important crops combined—rice and cotton.

who went to Mexico and ''unofficially'' secured the first substantial shipment of Mexipak seed. The sale was negotiated without the official sanction of either the U.S. or Mexican governments (Swegle, unpublished manuscript, 1970).

In total, 70 tons of Mexipak were thus available for planting in 1966-67, resulting in a 3,000 ton harvest. At this rate, it would have taken a number of years to build up sufficient seed. To accelerate the diffusion process for Mexipak, the government of West Pakistan decided to make a massive purchase of Mexican seed. By then, Mexipak and Indus 66 (red-grain sister line of Mexipak) had been released in Mexico as the variety Siete Cerros, and large quantities of seed, especially the red-seed version, were available.

In summer of 1967, Pakistan sent a delegation to Mexico to negotiate a purchase of HYV seed. The Pakistani government mission ended up buying 40,000 tons of Indus-66 and 1,500 tons of Mexipak-65, plus 200 tons of Sonora-64 and 20 tons of INIA-66. With this 42,000-ton transaction, they had consummated the largest seed purchase in the history of world agriculture.

The HYV seed arrived in Pakistan in September of 1967 and was quickly distributed to wheat growers. A total of 1.3 million ha was planted during 1967-68 to the new semidwarf varieties—approximately 20% of the total wheat area. West Pakistan's wheat production, which had averaged 4 million tons in the preceding six years, jumped in one year to 6.7 million tons and West Pakistan was suddenly self-sufficient in wheat again. Within four years, more than half the irrigated wheat area had been switched to semidwarf varieties grown with higher N fertilizer dosages.

National Semidwarf Wheat Breeding Research—National wheat breeders had been active in developing new materials, and there were even better semidwarf wheat lines in the pipeline. Scientists at AARI (formerly the Punjab Agricultural Research Institute) started in 1961 to cross the Mexican semidwarfs with the tall local varieties, combining the architecture of the Mexican genotypes and their broad adaptation and disease resistance with the high grain quality of local varieties such as C271 and C273. One of the first HYV semidwarf varieties to be released from this work was Chenab-70. This wheat had excellent grain quality, resistance to a new race of rust harmful to Mexipak, and a yield potential 10 to 15% above that of Mexipak, qualities which ensured its enthusiastic reception by farmers.

Other new varieties were developed to meet the needs of varying production environments; these included Barani-70, the first variety developed for barani conditions, and SA-42 and Blue silver (Sonalika), developed for the shorter-season production environments. Each improved on the performance of previous cultivars, serving specific production niches and major crop rotations more effectively.

But by 1971-72, the dramatic rise in the adoption of new semidwarf wheat varieties in the irrigated Punjab had largely run its course, and most of the initial yield gains associated with the introduction of HYVs had been exploited. Consequently, the rate of increase in wheat production began to slow, and second generation production problems started to appear with greater frequency. The improved conditions for wheat were also favorable for the development and mutation of rust pathogens. Although the semidwarfs had broader-based disease resistance than the tall local varieties, they were not immune and eventually began to succumb to new races of the rust.

HYVs with new combinations of genes for resistance to the prevailing rust races were released in 1970 and 1973 (see Tables 17-19, Chapter Four). However, shortcomings in seed production and extension education systems restricted their spread. Problems in the coordination of wheat research and production began to appear; these were aggravated during the civil strife that led to the independence of Bangladesh in 1970.

The 1970s: A Period of Drift in Wheat Research

The independence of Bangladesh led to a new constitution for West Pakistan that established a federal-provincial political structure. In this structure, the primary responsibility for agricultural research, extension and input-supply services was assigned to the provinces. The new structure disbanded the former Agricultural Research Service of the Province of West Pakistan, effectively putting an end to the Accelerated Wheat Improvement Program (Albrecht et al., 1979). Its demise came when the concept of a coordinated, production- and problem-oriented wheat research system was only beginning to be accepted and was by no means consolidated. And yet, the second generation problems in wheat production required greater research integration if they were to be tackled and solved in a cost-effective way. Meanwhile, government planners had been lulled into a sense of complacency about wheat, assuming that the nation's supply problem for this staple grain had been solved with the new HYV technology; consequently, they turned their attention to other crops and economic problems.

While future gains in wheat productivity depended upon generating technology more specifically tailored to the various wheat farming systems, the trend in research organization was toward greater specialization and isolation between research disciplines and a breakdown in communication among the new provincial wheat research organizations. Punjabi scientists from the old ARS who were assigned to other provinces returned home, leaving serious shortages of trained manpower in the wheat improvement programs of the Sind, NWFP, and Baluchistan. The national wheat research system became increasingly fragmented, with wasteful duplications of effort and a lack of coordination between the scientific disciplines and institutions involved. (Amir, 1982). There was a great sense of frustration among those who wished to maintain a national perspective.

Only in the Punjab was there a functioning wheat research program, and even here provincial scientists from different disciplines were tending toward isolation from one another and from the production problems and circumstances of the country's wheat farmers. An especially serious breakdown had developed between plant breeding and plant pathology, two disciplines that must be integrated within wheat improvement programs.

Adverse weather in 1972-73 and 1973-74 seriously affected the Pakistani wheat crop and by 1972-73, the nation was again importing wheat in pre-Green Revolution quantities, but at three times the previous price. During 1973-74, the oil crisis further squeezed production and demonstrated the dependence of HYV wheat technology on fossil fuels and their by-products. Fertilizer shortages and reduced demand due to high prices further constrained growth in production, and food prices increased sharply in 1976.

The Agricultural Research Council

While there was never any question about the need to establish a national coordinating structure for agricultural research, similar to the old Imperial Council of Agricultural Research (ICAR), pressing matters in other development sectors delayed its creation during the 1950s and 1960s. Instead, a series of interim measures were adopted to coordinate the provincial research systems of West and East Pakistan. Although the nation was composed of two physically separated provinces with very different agricultural systems, the lack of overall coordination had been less of a problem, since a consolidated research service existed in each wing. After 1970, however, the need for greater policy coordination in Pakistan's agricultural research system—now comprising four independent provincial research services—became extremely important. In 1968 and 1972, the government invited high-level teams of U.S. and Pakistani scientists to review the national research system. From this effort came a set of recommendations designed to build a mixed federal-provincial research system.

In 1974, USAID entered into an agreement with the government of Pakistan to provide the financial and technical support for a five-year project to strengthen agricultural research. There were three key elements in this development plan. One was the creation of a national policy-making board—the Agricultural Research Council (ARC)—to coordinate and manage the expenditures in agricultural research. The second key element included the development of a federal research service, with sufficient facilities and human resources to undertake a series of central research and training functions, supporting and complementing the work of provincial research organizations. The third element involved a range of institution-building activities designed to improve the overall capacity and performance of the national research system.

A centerpiece of Pakistan's new national agricultural research system was to be the establishment of a new National Agricultural Research Center (NARC), a development strongly supported by CIMMYT and the international donor community. In 1976, some 450 ha were purchased near Islamabad for NARC's future headquarters and primary research station.

The loan agreement made with USAID in 1974 also involved a novel concept regarding the status and mode of operation of the Agricultural Research Council: the Council, in representation of the government of Pakistan, was given the power to engage in research improvement programs with international agricultural research centers (IARCs), U.S. universities, and organizations such as the ARS/USDA. This gave the ARC new authority and leverage in mounting a coordinated wheat research program.

In 1974, a Coordinated Wheat Program (CWP) was reactivated under the ARC. Mr. Muhammed Tahir was appointed as the National Wheat Coordinator, and a CIMMYT wheat scientist was assigned to assist him. Under the agreement with CIMMYT, the ARC would fund the activities of the advisor. The ARC would be responsible for logistical support, and the advisor would be directly supervised by the CIMMYT Wheat Program.

In mid 1974, CIMMYT's second resident wheat advisor in Pakistan, Dr. Armando Campos, assumed his post. Tahir and Campos faced a very different institutional environment from that confronting Qureshi, Munshi and Narvaez ten years earlier. Where one agricultural research service had existed before, now there were four organizational structures, each strongly provincial in outlook. The initial efforts of the National Coordinated Wheat Program during 1974-76 focused on rebuilding the communications links between the provincial research institutes. The national wheat workers workshop was reinstated and exchange visits between scientists in different institutions were encouraged. New training opportunities, especially for advanced degrees at foreign universities, were offered. The off-season summer nursery site at Kaghan in the western end of the Himalayan mountains, which had been established by the NWFP government in 1972, was reactivated and managed as a service to the provincial wheat programs. The micro-plot trials instituted on a nationwide basis in the 1960s were re-established as the National Uniform Wheat Yield Trials. The Chairman of ARC, Malik Khuda Baksh Bucha, gave the National Coordinated Wheat Program the special charge of seeing what could be done to raise yields in rainfed barani areas, where few farmers were growing semidwarf wheat varieties.

The Wheat Rust Epidemic of 1977-78

During 1975-76 and 1976-77, wheat production increased and there were noticeable yield gains in barani areas. Although communication between provincial researchers improved and Pakistan's breeders continued to release new wheat varieties with different sources of disease resistance, the problems associated with a fragmented wheat research and production system persisted. Especially ominous was the continued use of rust-susceptible varieties and a dangerous build-up of inoculum. From 1972-73 onward, the loss of rust resistance in the major commercial varieties—Chenab-70, Mexipak, Barani-70, SA-42—was common knowledge. While the new rust-resistant varieties—Blue Silver, Lyallpur-73, Sandal, and Pari—were available for use, little of their seed had been multiplied by the provincial seed corporations, and few farmers were growing them

The research establishment had warned of the potential for a rust epidemic. In the National Coordinated Wheat Program's 1975-76 Annual Report, (released in June of 1976) the following statement was made: ".. This season, leaf rust and stem rust were a time-bomb that almost exploded...We were saved by the late arrival of primary inoculum..." The 1974-75 Annual Report of the cereal botanist from the Punjab Agricultural Research Institute also argued for the need to replace the susceptible varieties in

Within five to seven years after widespread use, improved varieties that were resistant at the time of commercial release, succumb to new races of leaf and/or stripe rust. Wheat breeders and seed production organizations, therefore, must continue to produce replacement varieties with improved characteristics, including effective new gene combinations for disease resistance, if rust pathogens are to be held in check.

widespread commercial use: ''The present new [rust] spectrum in the country demands that the commercial varieties Chenab-70, Mexipak 65, Barani-70 and SA-42 must all be replaced with resistant varieties—or at least reduced in area. The situation clearly reveals that the life of a variety should not be considered more than 6 to 7 years...''

Lacking a national perspective, breeders were reluctant to recommend that varieties which they had developed and which had become susceptible to rust in other provinces be eliminated from future seed multiplication and distribution throughout the country. Instead, rationalizations prevailed over objective analysis and little was done to pressure policy makers to take needed action. With the conditions for rust development different in various parts of the country, provincial breeders simply hoped that conditions would not become favorable for a serious rust attack in their area.

By the early 1970s, Borlaug and his deputy, the late R. Glenn Anderson, had become very alarmed by the rust build-up. They convinced agricultural policy makers to undertake an urgent program of varietal diversification and replacement. In view of a lack of seed of new varieties in Pakistan and a poorly functioning national seed industry, CIMMYT recommended that Pakistan import from Mexico 6,000 tons of the varieties Nuri, Yecora and Pavon, sister lines of Sandal and Pari. This decision offended the professional pride of Pakistan's wheat breeders, who were highly vocal in expressing their displeasure. Nevertheless, seed imports of these varieties were made as a stop-gap measure until sufficient seed of resistant Pakistani wheat varieties could be multiplied and distributed.

Yecora and Nuri seed from Mexico arrived for the 1976-77 season. However, the lack of a strong local commitment to distribute these two varieties resulted in the major wheat acreage being sown to rust-susceptible varieties in 1976-77 and 1977-78. In this last season the rust came early and weather favored its development. As a result, the disease was widespread and severe, with leaf rust in the Punjab and Sind, and stripe rust in the north. Because of the damage to the wheat crop, Pakistan in 1978-79 had to spend US$ 200 million to import nearly 2 million tons of grain (Nagy, 1984). In contrast, on the Indian side of the Punjab where varietal replacement had occurred, a record wheat crop was harvested in 1977-78.

The PARC Period

The rust epidemic of 1977-78 became the catalyst for the establishment of a federal research service whose responsibilities cut across provincial boundaries. Out of the wake of this production disaster, a reorganized ARC emerged in 1978 under the leadership of its first full-time Chairman, Dr. Amir Muhammed, and the new masthead of PARC—the Pakistan Agricultural Research Council—with new means and authority to coordinate national research efforts for the major crops.

PARC has a semi-autonomous legal status, and its Chairman serves as the Secretary of the Federal Agricultural Research Division, participating in national policy and resource-allocation decisions. The PARC Governing Board, with about 40 members, is broadly constituted and represents various governmental and private sector organizations and interests concerned with agriculture and related research.

PARC was given a charter and a set of directives to coordinate and promote agricultural research within the country. A guiding principle in the development of its Federal Research Service has been to undertake those activities which support and complement the work of provincial research institutions. During its first decade of operation PARC completed several major construction projects, namely NARC's multi-institute research and training facility in the Islamabad Capital Territory and PARC's headquarters building in Islamabad. In addition to its 30-odd nationally coordinated research programs, PARC has also established several specialized national research institutes —the Crop Diseases Research Institute (CDRI), the Arid Zone Research Institute at Quetta, and the Farm Machinery Institute at NARC—to address specific agricultural research and development objectives. Finally, strengthening the human resource capacities of national researchers (federal and provincial) through a range of training opportunities (in-service and advanced-degree) has been a major PARC objective since its inception.

Strengthening Wheat Pathology Research—One of the first steps taken by PARC after the rust epidemic of 1977-78 was to establish a national wheat pathology research system and integrate this research with plant breeding. (Amir, 1978). In recent years, CDRI has been strengthened in staff and facilities. Disease screening work was intensified and the results of this work were more fully integrated in the variety evaluation process.

More disease inoculum was provided to the provincial wheat improvement programs, markedly improving on-station disease screening. Varieties and lines in the National Uniform Yield Trials were also included in the disease screening nurseries, and information on disease reactions was integrated more quickly into the yield trial results. CDRI was also given additional resources for disease surveillance, including farm-level surveys and trap nurseries. Through the NCWP, work is being encouraged to develop wheat varieties with tolerance to heat and moisture stresses, and saline/sodic soil conditions, as well as resistance to diseases other than the rusts (e.g., karnal bunt).

Greater Emphasis on Improved Crop Management—The increasing awareness that wheat is grown within various, often complex farming systems led PARC to promote multidisciplinary research efforts, including more active and effective programs of on-farm experimentation and technology validation. New crop management research activities have been undertaken by NARC in several of the major irrigated cropping systems (rice-wheat, cotton-wheat). An expanded program of agronomic research for barani areas was also launched, emphasizing tillage experiments and fertilizer management.

The recently established Agricultural Economics Research Units (AERUs) provide an invaluable complement to crop management research in the irrigated and barani cropping systems. The active participation of agricultural economists in on-farm research teams has added a ''farming systems perspective'' to wheat production research in Pakistan.

Technology Transfer—PARC has stressed the synthesis of research results on agricultural commodities into integrated production technologies for different agroecological zones of the country. Although agricultural extension is a provincial responsibility, PARC undertakes research on extension methodologies to determine the best ways of validating and communicating improved production technologies to users. In addition, PARC has the extension responsibility for the Islamabad Capital Territory and for verifying and extending improved technology under the outreach components of its various programs in selected areas (PARC, 1987). Among its wheat-related technology transfer efforts are the Crop Maximization Program and the Barani Agricultural Research and Development Project.

Expanded International Cooperation—PARC plays a pivotal role in negotiations with various bilateral and multilateral donor agencies committed to agricultural progress in developing countries. In 1986-87, donor organizations were providing Rs. 219,370 million, with a foreign exchange component of Rs. 142,227 million, in support of several national agricultural research projects. These projects often provided strong technical assistance components through various agricultural development organizations.

PARC also plays an important role in international research organizations such as the Consultative Group on International Agricultural Research (CGIAR). PARC leaders have frequently served on the Technical Advisory Committee of the CGIAR, and as trustees of international centers. Pakistan's national research collaboration with various international agricultural research centers and the Indian Council of Agricultural Research (ICAR) is coordinated by PARC.

The PARC/CIMMYT Collaborative Program has launched innovative research studies involving the rice-wheat rotation, a cropping system practiced on millions of hectares in Pakistan and other parts of South Asia. Research has focused on developing improved technologies in land preparation, pest and weed control, and fertilization. Concern for optimizing the farmer's total return in environmentally sustainable ways guides this research thrust.

The National Wheat Research System

Most of the wheat research in Pakistan is financed and carried out by the provincial governments. As would be expected, the largest and most comprehensive wheat research program is conducted in the Punjab Province by the Ayub Agricultural Research Institute (AARI). Wheat research is given considerable priority in NWFP at the Cereal Crops Research Institute (CCRI), Pirsabak, Nowshera, and at the Wheat Research Institute (WRI), Tandojam, in the Sind Province. In the Baluchistan Province, the primary research concern is high-value irrigated cash crops, such as fruits and vegetables, and livestock and range management.

At the federal level, wheat research is conducted mainly by PARC organizations. Wheat research activities at NARC are designed to complement and support provincial wheat programs. Emphasis is given to germplasm introductions and evaluations, pathology research and disease epidemiology work, milling and baking quality studies, and management research for the major crop rotations in which wheat is grown. The agricultural institutes operated by the Pakistan Atomic Energy Commission (PAEC), comprising the AEARC, Tandojam, the NIAB, Faisalabad, and the NIFA, Tarnab, also engage in basic research on cytology and mutation breeding for wheat and triticale, in addition to some conventional wheat breeding work.

Research on fertilizer use is conducted by the provincial research institutes, the PARC institutes, and by the adaptive research stations of the Punjab Department of Extension. In addition, there is a Rapid Soil Fertility Survey and Soil Testing Institute at Lahore, which has a network of soil and water testing laboratories throughout the Punjab Province and provides advisory services to farmers. The Federal Government (Food and Agriculture Division) Soil Survey of Pakistan and the Water Quality and Soils Monitoring Directorate of WAPDA, both headquartered in Lahore, also conduct soil and water use research with a bearing on wheat production.

Pakistan's provincial agricultural universities—the University of Agriculture, Faisalabad; Sind Agriculture University, Tandojam; and the NWFP Agricultural University (now merged with provincial research institutes), Peshawar—are considered primarily as teaching institutions. Faculty are given full teaching loads; therefore, only limited funds or staff time are allocated for research-related activities beyond supervision of graduate student thesis projects. However, there is growing support in some public circles for increasing the amount of faculty time and funding devoted to research activities at these universities.

Pakistan's national wheat research system stresses plant breeding and research conducted on station at the provincial institutes. Crop management research programs (agronomic studies) are not well established, especially at the provincial level. They lack trained manpower, a conceptual framework for conducting research, and adequate budgets, vehicles and organizational structure. In the multi-crop research institutes, the integration between wheat-breeding groups and researchers engaged in disciplinary research programs such as pathology, soils, weeds, economics, is often weak.

The National Coordinated Wheat Program
A major function of PARC is to undertake, aid, promote, and coordinate agricultural research in the nation and to expedite the utilization of the results. To further these objectives, PARC sponsors some 30 national crop research programs, including the National Coordinated Wheat Program (NCWP). The NCWP is the oldest and largest of these programs, predating the establishment of PARC itself. Since 1980, the NCWP Coordinator has been Dr. N. I. Hashmi, who also heads the NARC wheat program.

The principal objective of the NCWP is to bring together wheat research workers from provincial and federal institutions and agricultural universities to plan and carry out a coordinated national program. The NCWP sponsors various activities designed to link provincial, federal and international centers of wheat research and to enhance the exchange of genetic materials, research methodologies and results, and scientific information. The NCWP has eight cooperating institutes formally associated with it and informal collaborative links with various other PARC-sponsored programs. The participating members in 1987 were:

- Ayub Agricultural Research Institute, Faisalabad
- Atomic Energy Agricultural Research Center, Tandojam
- Agricultural Research Institute, Tandojam
- Agricultural Research Institute, Sariab, Quetta
- Cereal Crops Research Institute, Pirsabak, Nowshera
- University of Agriculture, Faisalabad
- Kaghan Cereals Summer Nursery Station
- NARC, Islamabad

The NCWP serves as 1) a funding conduit for various wheat research and manpower development activities at the provincial level and 2) a coordinator of country-wide networking activities designed to improve co-operation and effectiveness in national wheat research activities. The NCWP, however, does not have direct control over the activities of participating provincial institutes nor of the PAEC research institutions

To bolster the human resource capacity in specific disciplines, NCWP provides funding for 35 staff positions (grades 17-19) at the four major provincial agricultural research institutions and NARC Smaller grants for research equipment and scientific literature are provided to participating NCWP organizations. In addition, the operating budgets for the various NCWP activities are provided through PARC

PARC's National Coordinated Wheat Program is the unifying thread that brings together the work of provincial and federal wheat research programs with that conducted by the international agricultural research centers and national institutions in other countries. Pictured here are Dr. Amir Muhammed, PARC Chairman (center), Dr. M. Yousuf Chaudhri, Director General, NARC (left), and Dr. Naeem Hashmi, NCWP Coordinator (right).

Germplasm Introductions—The NCWP serves as a germplasm clearinghouse for new introductions from CIMMYT, ICARDA, USDA, FAO, and national wheat research programs in other countries. In addition to the coordination and distribution of international nurseries, the NCWP also provides individualized germplasm services for participating agencies. These include special germplasm searches and requests for materials from various wheat germplasm banks around the world, as well as from the collections of wheat research programs in Pakistan.

PARC Observation Nursery—At NARC, one set of all international nurseries received from CIMMYT, ICARDA, and other cooperating institutions is grown. These materials are screened and approximately 300 of the best lines/varieties are assembled, together with germplasm from provincial programs, in the PARC Observation Nursery distributed to NCWP cooperators. This program reduces germplasm entries to a number that is manageable for many of the smaller wheat improvement programs.

National Uniform Yield Trials—The National Uniform Yield Trials (NUYTs), in operation for nearly a decade, were designed to provide a neutral forum for the national evaluation of promising wheat cultivars. (Neither PARC nor any of its research institutions themselves release varieties and hence, have no vested interests in promoting specific lines for national release). The NUYTs include the candidate lines for varietal release developed by the wheat breeders of different participating NCWP institutions. These entries are coded and tested for their yield potential, adaptation, disease reaction, and other characters of economic performance. The nurseries are conducted annually as 250 replicated and non-replicated trials at about 100 locations nationwide, in research stations and on farmers' fields.

The NARC wheat program staff multiply, assemble and distribute the seed of entries from participating programs, and even plant some of the trials. In 1986-87, the seed of 46 entries in the five NUYT trials was multiplied and 250-300 nursery sets prepared for distribution to NCWP collaborators. NARC staff visit most trial sites, process the results, provide the data to the cooperators, and conduct milling and baking evaluations of the materials.

The NUYTs give breeders from the various institutions an opportunity to assess the performance of their advanced breeding materials across a broad range of climatic, agronomic and disease conditions. They provide an objective assessment of the yield response, breadth of adaptation, and disease reaction of advanced lines being considered for varietal release in the provinces. They also serve as part of an on-farm, variety testing system to help breeders compare new, promising lines with currently grown commercial materials. Since the inception of the NUYTs, more than 30 HYVs have been released by provincial breeding programs after going through this uniform yield trial system.

There are five types of NUYTs:
1) NUWYT-regular (Bread wheats with regular maturity)
2) NUWYT-early (Bread wheats with early maturity)
3) NUWYT-rainfed (Bread wheats for rainfed areas)
4) NUDTYT (Durum wheat and Triticale)
5) NUBYT (Barley)

The data from these trials forms the basis of recommendations by the National Wheat Variety Evaluation Committee (VEC) to Provincial and National Seed Councils regarding the approval and release of new cultivars. The NCWP Coordinator is a member of the VEC, an advisory board without the authority to force or stop the release of a variety. Even so, the VEC's recommendations wield considerable influence over provincial varietal registration authorities.

The NUYTs, however, have not been effective in streamlining the varietal release system. Provincial breeding groups still conduct uniform wheat yield trials (called micro-plot trials) for two years before materials enter into the NUYT system. Thus, as presently organized, the provincial-federal systems duplicate efforts, delaying the process of varietal evaluation. The NCWP has recommended that promising cultivars from provincial programs be tested concurrently in provincial micro-plot trials and within the NUYT system. In addition, it has been recommended that the number of NUYT locations be reduced to a few key sites in each of the major agroecological zones. In this way, better site management, as well as more reliable and complete data, could be achieved.

One of the important events sponsored by the National Coordinated Wheat Program is the annual travelling seminar. Over a three week period, provincial and federal wheat researchers travel throughout the wheat-growing areas of Pakistan, reviewing national wheat varietal trials and the conditions of the commercial wheat crop.

Wheat Travelling Seminar—For many years, the NCWP has sponsored an annual travelling seminar for provincial and national wheat researchers. The seminar allows national wheat breeders to assess the yield potential, disease reaction and distribution of varieties in different agroecological zones. NUYT trials are visited and data are collected by breeders and pathologists on the disease reaction of candidate varieties in different parts of the country. The seminar also permits researchers to observe the present wheat crop in farmers' fields. Finally, a better understanding and exchange of ideas among the various wheat scientists of the country is fostered during the informal discussions which occur

At the end of the trip, a detailed report is prepared which summarizes research findings, makes policy-related recommendations and provides a preliminary assessment of the wheat crop and likely production levels. The report is an extremely valuable document for agricultural policy makers.

Training Programs—The NCWP has hosted a number of short courses and in-service training programs, usually in collaboration with international and national wheat research organizations from abroad. Courses have been offered on wheat disease research methodologies, weed control, statistical analysis of agronomic data, on-farm research survey techniques, and the use of micro-computers in data processing and analysis. The course coordinator is also responsible for advising PARC on potential candidates for wheat research training at foreign and national institutions.

Summer Nursery Service—The off-season Kaghan Cereal Nursery station in the mountain area of NWFP was established in 1972 to screen for stripe, leaf and stem rust, and to permit Pakistani breeding programs to advance breeding materials two generations per year. The nine-hectare station, located at 2,039 meters elevation, is operated by the NCWP as a service to its institutional cooperators.

Wheat Research in the Punjab

Wheat research in the Punjab is conducted by AARI at the Agricultural University of Faisalabad (mainly wheat breeding), and several other organizations within the provincial ministries of agriculture and water resources. AARI is composed of 13 monocrop/single-discipline research institutes and 35 research sections scattered throughout the province. AARI has more than 500 scientists in grades 17-20—approximately 350 located in Faisalabad—involved in plant breeding for wheat and other major food and fibre crops including tobacco, sugarcane, fruits and vegetables. In addition, AARI's disciplinary departments and institutes conduct research on soils, fertilizers, biochemistry, food technology, agronomy, plant physiology, plant protection, and agricultural economics.

In its Annual Report for 1984-85, AARI listed 476 wheat-related research studies (out of 2,300 total) under way in its programs. (AARI, 1987a). AARI has made outstanding contributions over its history and continues to produce excellent new varieties (Table 16). Its dependencies include the Wheat Research Institute in Faisalabad, the Bahawalpur Agricultural Research Station, the Rawalpindi Agricultural Research Sub-station, and the Barani Agricultural Research Institute, Chakwal.

Table 16. Semidwarf Bread Wheat Varieties Released in Punjab

Variety	Year of Release	Parentage
Mexipak-65	1965	Penjamo 'S'/Gabo
Indus-66	1966	'' ''
Chenab-70	1970	C271/W1 (E)//Son64
Barani-70	1970	Pit/Gb//C271
SA 42	1971	$C271^2$//LR64/Son
Blue Silver	1971	II 53 388/An//Pit64/3/LR64
Lyallpur-73	1973	Bb/Nor67
Sandal-73	1973	Cno67//Son64/K1.Rend/3/MxP
Pari-73	1973	'' '' '' ''
SA-75	1975	Nai/CB151/S949/3/MxP
Punjab-76	1976	'' '' ''
LU-26	1976	Blue Silver/Khushal
Indus-79	1979	Bb/15 13 5/Son64
Chenab-79	1979	Pb76/Ch70
Bahawalpur-79	1979	Cno'S'/LR64/Son64/Son(Amb)
Punjab-81	1981	Inia/3/Son64/P4160(E)//Son64
Kohinoor-83	1983	Ore F1158/Fdl//Mexifen'S' /$Tiba^2$/3/Coc75
Faisalabad-83	1983	Fury//Kal/Bb
Barani-83	1983	Bb/Gallo/3/Gto/7C//Bb/Cno
Punjab-85	1985	Kvz/Trm/Bb/Ana
Faisalabad-85	1985	Fury//Kal/BB
Chakwal-86	1986	Forlani/Acc//Ana
Sutlej-86	1986	Cmt/Yr/Mon'S'
Rawal-87	1987	Maya/Mon'S'//Kvz/Trm

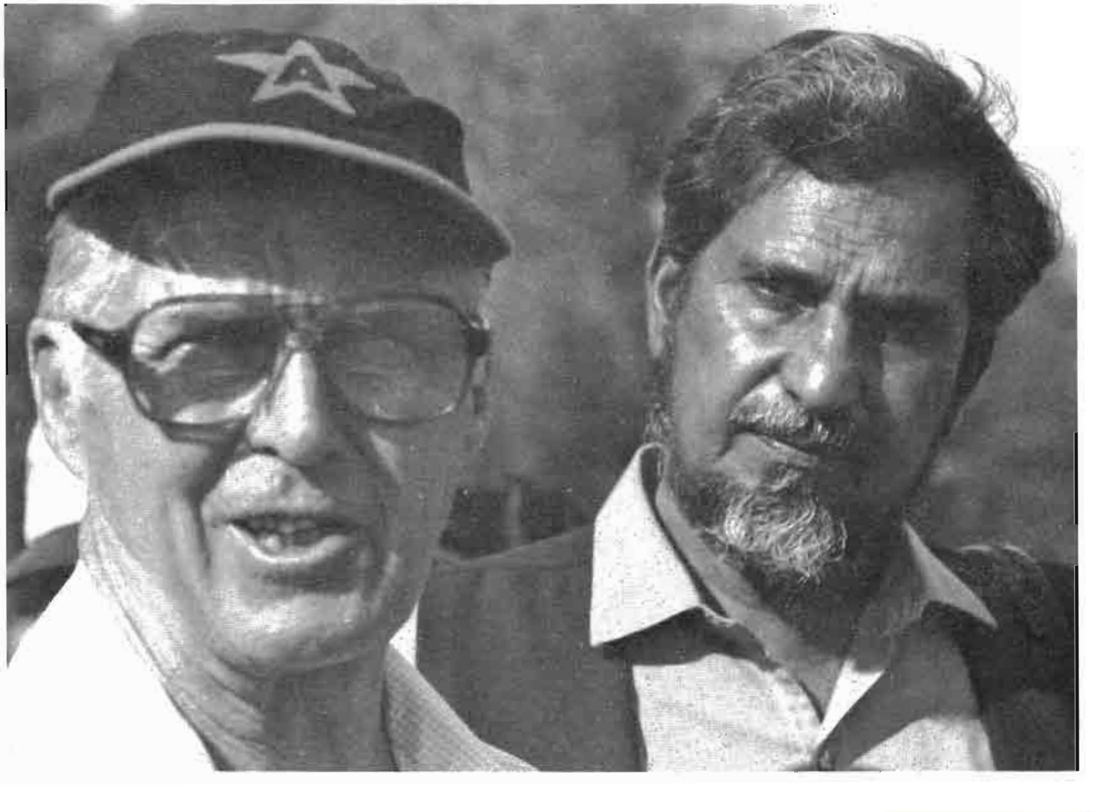
Source: National Cooperative Wheat Program, PARC

The focal point for AARI's wheat research is its Wheat Research Institute (WRI), located at Faisalabad, which has a staff of 39 scientists. WRI is primarily involved in breeding research on bread wheat, durum wheat, triticale and barley. (AARI, 1987b). WRI listed the following bread wheat breeding objectives in 1986-87: 1) breeding varieties with high yielding ability, good quality and durable resistance, especially short-cycle wheats; 2) breeding for stress conditions such as diseases, sudden high temperatures, cold/frost, low-moisture and saline-sodic soils; 3) making spring x winter wheat crosses to broaden the genetic base; 4) developing ''efficient'' genotypes with lower input requirements; and 5) improving yield components that may provide another breakthrough in wheat productivity (WRI, 1987b).

Varietal development work at WRI is increasingly focused on overcoming the production constraints of the major rotations in which wheat is grown, namely cotton/wheat and rice/wheat, which account for 75% of the Province's irrigated wheat area. In these intensive cropping systems, wheat is a secondary crop often planted later than the optimal time, and substantial yield losses result. (Bajwa, 1986). To overcome this problem, WRI is developing earlier-maturing varieties with high yield potential and rust resistance, and increasing the heat tolerance of the later-maturing high yielding varieties with good disease resistance.

Another important production problem facing wheat in irrigated areas is the build-up of soil and water salinity and sodicity While wheat already has considerable tolerance to these conditions, the development of varieties with enhanced salt tolerance is an important priority in the work carried out by the Salinity Research Institute and WRI. Screening for salt-tolerant varieties will be conducted until 1990. Selected lines will be crossed with other desirable varieties, and those combining salt tolerance with good agronomic type will be carried forward into subsequent selection generations.

Two-long time colleagues, Drs. Norman Borlaug and Muhammed Bajwa. In 1963, Dr. Bajwa was the first Pakistani to train with Borlaug in Mexico. It was Bajwa who, as a young trainee, selected the advanced line 8156 for Pakistan. This high-yielding, white grain line was named Mexipak, which sparked the Green Revolution in wheat in Pakistan. Today, Dr. Bajwa is Director General of AARI, Faisalabad.



Efforts to attain more durable resistance to leaf and stripe rust and to develop resistance to karnal bunt are still major objectives at WRI. In 1984-85, breeders and pathologists began pyramiding known genes for leaf rust resistance into commercial wheat varieties through backcrossing with resistant sources over several cycles to develop ''multiline'' versions of popular commercial wheat varieties. Resistant lines from these backcrossed commercial varieties will be yield tested, and the most outstanding will be grouped into several multiline varieties. Ultimately, the multiline varieties will be comprised of 4-7 lines phenotypically similar to the original commercial variety but with different sources and combinations of resistant genes. In this way, it is hoped that more durable resistance to leaf rust can be obtained.

WRI scientists are trying to develop a more diversified base of breeding materials. At present, they depend heavily on CIMMYT for bread wheat germplasm, and approximately three-fourths of the cultivars and lines in the CIMMYT breeding program, as well as the main commercial varieties in Pakistan, are spring x winter genotypes that contain the 1B/1R chromosome translocation. It appears that the main genes for resistance in these genotypes are Lr 26 for leaf rust and Yr 9 and Yr 7 for stripe rust. The fear is that if these resistant genes succumb to new races of rust pathogens, then most of Pakistan's commercial varieties and breeding materials would become susceptible—a potentially disastrous situation.

Considerable research attention is also being devoted to containing the spread and damage of karnal bunt (*Tilletia indica*), the most important disease after the rusts in localized pockets of the Punjab. So far, virtually all of the bread wheat germplasm in the crossing blocks has shown susceptibility to karnal bunt (KB). Lines with possible sources of KB resistance have been provided by CIMMYT for evaluation. In addition, bread wheats are being crossed with durum wheats, which are generally resistant to KB.

AARI's Barani Agricultural Research Institute (BARI) in Chakwal, northern Punjab (and its substation at Rawalpindi), and the Agricultural Research Station (ARS) at Bahawalpur in southern Punjab, also conduct wheat breeding research. BARI develops varieties for barani production areas. Germplasm development priorities include long-duration genotypes that permit early planting using residual monsoon moisture and that have tolerance to drought stress and resistance to shattering. Priorities in pathology research are resistance to leaf and stripe rust, and loose and flag smut. ARS/Bahawalpur concentrates its research work on developing improved varieties for the cotton/wheat zone of the Punjab. Emphasis is on the development of short-duration varieties with leaf rust resistance and tolerance to heat during grain-filling.

WRI also conducts plant breeding research on durum wheat, triticale and barley. Experimental germplasm of each is routinely received from CIMMYT and ICARDA and evaluated each year. High-yielding varieties of durum wheat (Wadanak-85) and barley (Jau-83) have been released by the provincial government for commercial use in the Punjab. Interest in durum wheat has increased in recent years at WRI because of three factors: 1) the resistance of durum wheats to karnal bunt; 2) the apparently higher maximum yield potential of durum wheat compared with bread wheat, and 3) the possibility of exporting quality durum grain and/or semolina to Middle Eastern countries.

There are probably another 125 to 150 AARI researchers engaged in some form of wheat-related research. Soil studies are conducted by five different groups, agronomy work by three groups, environmental stress research and breeding by four groups, plant pathology by two groups, and pest control by three different groups. Most of these researchers are looking at soil fertility and agronomy (245 studies), and plant protection (56 studies). Most of the production-oriented studies are routine agronomy experiments that often have limited economic relevance for the farmer. Missing is a clear sense of why certain experimentation is being undertaken and how it relates to the real priority problems and production circumstances of farmers. Little recognition of the increasing intensification in wheat cropping patterns is evident in the production agronomy research agenda.

In addition to these disciplinary divisions, wheat research is also conducted at more than a half-dozen stations and institutes in other parts of the province. Since 1985, AARI has set up sub-stations to support on-station and on-farm agronomic research in four agroecological zones with different cropping systems: Sialkot (rice/wheat), Khanewal and Multan (cotton/wheat), and Leiah (sandy soils). This multiplicity of research groups makes the task of coordination substantially more difficult. Furthermore, the separation of wheat research along disciplinary lines makes the integration of results into viable production recommendations much more difficult.

Wheat Research in the Sind Province

Provincial wheat research in the Sind Province is carried out by the Agricultural Research Institute (ARI) under the direct management of its recently formed Wheat Research Institute (WRI), and the Sind Agricultural University. ARI and the University are both located in Tandojam; WRI headquarters are found in the Nawabshah district of central Sind (a cotton/wheat zone) with sub-stations at Tandojam and Dokri. ARI also has two research stations in Sakrand and Kotdiji which devote part of their resources to wheat. Rice research stations at Dokri and Thatta are used to screen wheat materials.

The dominant wheat varieties grown in Sind—Pavon, Blue Silver (Sonalika), and WL711—were originally developed and released by national programs in India and Mexico and are based on CIMMYT material. Several varieties have been released by ARI and the AEARC in Tandojam, although none have been grown in significant proportions (Table 17).

Efforts to expand Pakistan's irrigated area are being countered by losses of existing agricultural lands to waterlogging and soil salinization/sodification. These problems must be addressed through research to develop improved water management strategies and through engineering solutions to improve drainage systems in many areas.

Table 17. Semidwarf Bread Wheat Varieties Released in the Sind Province

Variety	Year of Release	Parentage
Pak-70	1970	C-271/Willet Dwarf/Sonora 64
ZA 77	1977	(WOR 67-7C)II 30367-1M-0Y)
Pavon	1978	Vcm//Cno''S''/7C/3/Kal/Bb
Sind-81	1981	Norteno/Mexipak
Tandojam-83	1983	Head Selection, Nacozari
Sind-83	1983	Tzpp/P1//7C
Sarsabz	1985	Pi/Frond//Mxp/3/Pi/Mazoe /79-75-76

Source: National Cooperative Wheat Program, PARC

WRI has 39 authorized positions for wheat research, which are funded by PARC through the NCWP. Besides limited on-station agronomic research, germplasm development priorities cover:

- Leaf and stem rust resistance
- Tolerance to heat at juvenile and late stages
- Tolerance to salinity
- Drought tolerance
- Intermediate-to-early maturity
- Resistance to shattering

Problems which hamper WRI activities include poor pathology research capacities and the fact that a considerable number of WRI positions were vacant in 1987.

Wheat Research in the Northwest Frontier Province
Wheat research in the NWFP has been conducted by the Cereals Crop Research Institute (CCRI), Pirsabak, Nowshera since 1979, and formerly at the Agricultural Research Institute (ARI), Tarnab, founded in 1912. (CCRI originally was the Maize and Millets Research Institute.)

There are 20 authorized positions for wheat research at CCRI, seven of which are funded by PARC through the NCWP; a considerable number of vacancies currently exist and the program is seriously understaffed. In 1986, the NWFP Agricultural University, CCRI and ARI were merged into one organization in hopes of integrating their agricultural instruction, research, and extension work.

CCRI's wheat program has concentrated on breeding in bread wheat and barley, although a modest on-farm research program also exists with assistance from the PARC/CIMMYT Collaborative Program. (CCRI, 1987). The CCRI wheat program makes extensive use of CIMMYT nurseries and the PARC Observation Nursery. Various types of yield trials are conducted, including NUYT and microplot (normal and short duration) trials.

All disciplines involved in wheat research at CCRI report to the same director; thus, breeders and pathologists work in an integrated fashion. Breeding work is carried out for both the irrigated and barani areas of the province. CCRI posts wheat breeders at D.I. Khan, Serai Narang, Kohat and Tarnab to test materials across several environments in the province. Wheat-related research on soil fertility and plant protection (mainly weed science) also takes place at ARI, Tarnab.

Table 18. Semidwarf Bread Wheat Varieties Released in NWFP

Variety	Year of Release	Parentage
Khushal-69	1969	2193-Chapingo 53/Andes Sib/3/Yaqui 50/C271
Tarnab-73	1973	Unknown
Khyber-79	1979	Wren/Cno'S'/Gallo/3//C271
Pak-81	1981	Kvz/Buho//Kal/Bb
Sarhad-82	1982	Au//Kal/Bb/3/Wop'S'
Pirsabak-85	1985	Kvz/Buho'S'//Kal//Bb
Khyber-87	1987	Lira'S'

Source: National Cooperative Wheat Program, PARC

A number of semidwarf bread wheat varieties have been released by this program for commercial production (Table 18). In most cases, these are direct selections or reselections from CIMMYT's advanced lines and cultivars. Recently, CCRI has released a new barley variety, Frontier-87, based on the French variety, Lignee-527, supplied through the ICARDA/CIMMYT International Barley Yield Trial (IBYT).

Research priority is given to developing normal and short-season materials, as well as genotypes with drought tolerance and resistance to leaf, stripe and stem rust, powdery mildew and karnal bunt. Work has recently been started on cold/frost tolerant wheats for high-elevation areas, but this line of development still needs more support.

CCRI also engages in crop management research with the PARC/CIMMYT program. On-farm surveys of farmer practices, circumstances, and production constraints have been carried out in the Peshawar and Mardan Valleys in the irrigated areas. Experimentation has focused specifically on land preparation systems, weed control, and fertilizer use recommendations.

Wheat Research in the Baluchistan Province

Provincial wheat research in Baluchistan is performed by the Agricultural Research Institute (ARI) at Sariab, Quetta, through a program established in 1972. There are 12 sanctioned positions for wheat research, five of which are financed by PARC through the NCWP. Wheat is not a priority crop, especially on the high elevation plots, where limited irrigation is used for higher value fruits, vegetables and fodder crops.

The ARI wheat breeding program is designed to develop wheats for two distinct agroecologies: 1) the irrigated plains of southern Baluchistan, with problems similar to those of the Sind rice/wheat area, e.g. late planting, heat stress, heavy leaf rust incidence; and 2) the upland areas where torrent flood and rainfed conditions prevail; here stripe rust, cold and drought stress are the major stress problems, and fodder production is an important consideration. ARI has released two wheat varieties for commercial production: Zargoon-79 (Cc/Inia/3/Tob/Cfn//Bb/4/7c), a late-maturing, cold-tolerant variety, and Zamindar-80 (Ron/Cno//Bb/Nor67), a early-maturing variety. Neither is grown commercially to any extent.

There are no sub-stations in the province, apart from Sariab, and wheat is grown in small pockets over a large area; this makes travel difficult for the small, but well-trained group of wheat improvement scientists. At present, the major weakness of the program is a lack of crop management research.

National Agricultural Research Center

The National Agricultural Research Center (NARC) is the main institution of the PARC system. NARC is a multi-discipline research and training institution located on 585 ha of land southeast of Islamabad and whose goal is to conduct interdisciplinary research on topics of national importance that are not being adequately addressed. The agricultural production problems of barani areas have been especially identified for NARC attention.

Wheat, Triticale, and Barley Program—Although various groups within NARC perform research related to wheat, the primary responsibility for this activity is assigned to the Wheat, Barley and Triticale Section, which is part of the Crop Sciences Institute. Wheat program staff collect, evaluate and characterize germplasm for use by other research institutes, conduct on-farm and farming systems research in barani areas and other important wheat zones, and carry out seed multiplication of promising varieties for testing in different agroecological zones through the national uniform yield trials. The wheat program provides special operational support for the various NCWP network activities and services mentioned previously.

A large crossing block of wheat, triticale and barley materials is maintained by the NARC wheat program for screening and utilization in developing improved cultivars. At present, this crossing block consists of about 3,000 lines/varieties drawn from international as well as national breeding programs. These lines are classified into sub-groups according to specific disease resistances, agronomic traits, maturity, grain quality, yield potential, etc. Crosses are made and outstanding progeny are supplied to provincial programs.

Station-based crop management research involves the following activities: ongoing evaluations of several materials for phytotoxicity to different herbicides; physiological studies under controlled conditions of stress problems such as drought; planting date trials; and mustard/wheat intercropping studies. An on-farm research program with a farming systems perspective is conducted in several of the major cropping systems in which wheat is grown. The NARC wheat program has taken the lead on a number of long-term agronomic studies in wheat-based barani systems involving an interdisciplinary research team. Long-term soil fertility and tillage trials are being performed to determine the effects of chemical fertilizer and mechanized tillage practices on soil productivity.

The on-farm research methodology used in the program involves informal and formal surveys to determine farmer problems, researchable issues, and quantify important characteristics of wheat crop management. On-farm experiments are then conducted to develop and verify new technological components for specific cropping systems. At present, the NARC program is concentrating its efforts on the barani areas of Northern Punjab, the irrigated rice/wheat areas of Punjab, and the maize/wheat irrigated areas of NWFP. (Some work has also been started in cotton/wheat areas.) The results of this work are reported in Chapter Six.

Farm Machinery Research Institute—Mechanization of wheat production activities is occurring at a rapid rate in Pakistan. Most farmers prepare their land with tractors and use stationary threshers to thresh their grain. Other wheat production activities are becoming mechanized because of labor costs and shortages, and government promotions. In particular, there is a need to reduce the time required for land preparation and completing harvesting operations. The Farm Machinery Research Institute (FMI) located at NARC, Islamabad, is engaged in mechanization research and product development, as well as testing and standardization of farm machinery. FMI is turning out and testing zero-till planters and cutter-binders for wheat harvesting. Growing use of combine harvesters is occurring in Pakistan, and FMI is looking at prototypes for a nationally-produced combine harvester.

Crop Diseases Research Institute—Another major service of PARC to national wheat improvement efforts is provided by the Crop Diseases Research Institute (CDRI) with installations in Murree, Islamabad and Karachi. This plant pathology institute is concerned with several crops, although wheat research is the center's dominant activity. Its program looks at host-parasite genetic relationships, and monitors changes in the virulence of fungi that cause rusts in wheat. It assays modes of resistance inheritance and identifies pathogenic variation in the fungus. CDRI provides disease inoculum to provincial and federal wheat breeding programs, works with plant breeding groups to identify new sources of resistance to rust, powdery mildew, septoria, and smut, and conducts seed health testing to detect seed-borne diseases. Finally, it provides in-service training and short-courses in pathology research methodologies.

As part of its program of work, CDRI prepares and distributes a National Wheat Diseases Screening Nursery (NWDSN) to other wheat research organizations. The NWDSN comprises 300 to 400 entries, including widely grown commercial varieties and advanced lines from national breeders. Ordinarily, the nursery is planted at a dozen or so sites throughout the country, where artificial inoculations are performed to place heavy disease pressure on the breeding materials. This nursery helps to identify new sources of resistance to the prevalent and new races of rusts, and to evaluate breeding materials from various Pakistani wheat programs for their disease reactions. CDRI also prepares and distributes the Wheat Rust Trap Nursery (WRTN) each year. This nursery includes commercial varieties and lines with single genes for resistance to leaf and stripe rust. It is planted at 30 to 40 sites and is used to monitor and trap the natural virulences of each race of rust prevalent in the country.

PARC's Social Science Research
During 1984-86, PARC also established Agricultural Economics Research Units (AERUs) at NARC, Islamabad; AARI, Faisalabad; ARI, Tandojam; ARI, Tarnab; and ARI, Quetta. The general mandate of the AERUs is to undertake research in collaboration with physical and biological scientists to promote the development and diffusion of appropriate technology in the Pakistani farm community. Because of the small number of staff assigned to each unit (two to three), their work has been restricted to research on the major cropping patterns. A large part of the work of the AERUs, especially in Punjab, NWFP and NARC, has been conducted on wheat-related issues in close collaboration with CIMMYT economists. On-farm surveys of production practices and constraints have been carried out in the major cropping systems in which wheat is grown. These surveys have then served to identify the priorities for on-farm crop management experimentation.

PARC's Crop Maximization Program
PARC is concerned with promoting the expeditious use of research results to improve agricultural productivity. Its Crop Maximization Program (CMP), conducted with Italian technical assistance, is improving the productivity of wheat, rice and maize through large-scale testing and demonstration of improved technology, including more efficient use of tractors and farm machinery. Technical assistance and training is provided to participating farmers and extension workers. The CMP has had very impressive yield results in its field demonstrations. The major criticism of the CMP has been the costs of the recommended technologies: high NPK application rates, mechanized planting, chemical weed control, and combine harvesting. Improved linkages between the program and crop management researchers

(biological and social scientists) could help ensure that the technologies recommended are appropriate to the circumstances of representative farmers.

Provincial Agricultural Universities

The three agricultural universities are outgrowths of previous colleges and faculties of agriculture. The University of Agriculture, Faisalabad, was established in 1961 by the separation of the Punjab Agricultural College and Research Institute (which became AARI). The University of Agriculture at Faisalabad is the nation's largest academic institution in agriculture. It has a faculty of 345 and a student body of 3,400 undergraduate and 600 graduate students. The Sind Agricultural University, Tandojam, was established in 1977 by upgrading the Sind Agricultural College. It has a faculty of 190 and a student body of 1,450 undergraduate and 350 graduate students. The NWFP Agricultural University, Peshawar, was established in 1981 by the separation of the Faculty of Agriculture from the University of Peshawar. It has a faculty of 85 and a student body of 500 undergraduate and 125 graduate students.

Collectively, the agricultural universities constitute a large pool of scientific manpower. Little of this manpower, however, is harnessed directly for agricultural research. Lacking are operational research budgets and access to experiment station facilities. Furthermore, the current heavy teaching loads make it difficult for many faculty members to conduct an ongoing program of agricultural research. Even so, contributions have been made by faculty members at the various universities. The greatest amount of wheat research is conducted at the University of Agriculture, Faisalabad. The current Vice-Chancellor, Dr. Rahman, developed the variety LU 26, a cross between Mexipak and Khushal, which was released in 1976. Though highly susceptible to rust, LU 26 is still grown today by some Pakistani farmers for its grain quality. Research on wheat varieties with greater salt tolerance is also underway at the University under the direction of Dr. Raizzuddin Qureshi.

The need to capitalize more fully on Pakistan's scientific human resource base has resulted in a movement to merge the agricultural universities with the provincial research institutes. This movement has gone furthest in NWFP, where a formal merger between research and teaching occurred in 1986. In the Sind

Province, greater cooperation between the research institute and the Agricultural University is also being sought. In the Punjab Province, the University of Agriculture and AARI have a joint research planning committee designed to pool the scientific talents of both organizations. Though a formal merger of these two organizations is unlikely, ways are being explored to strengthen their collaboration.

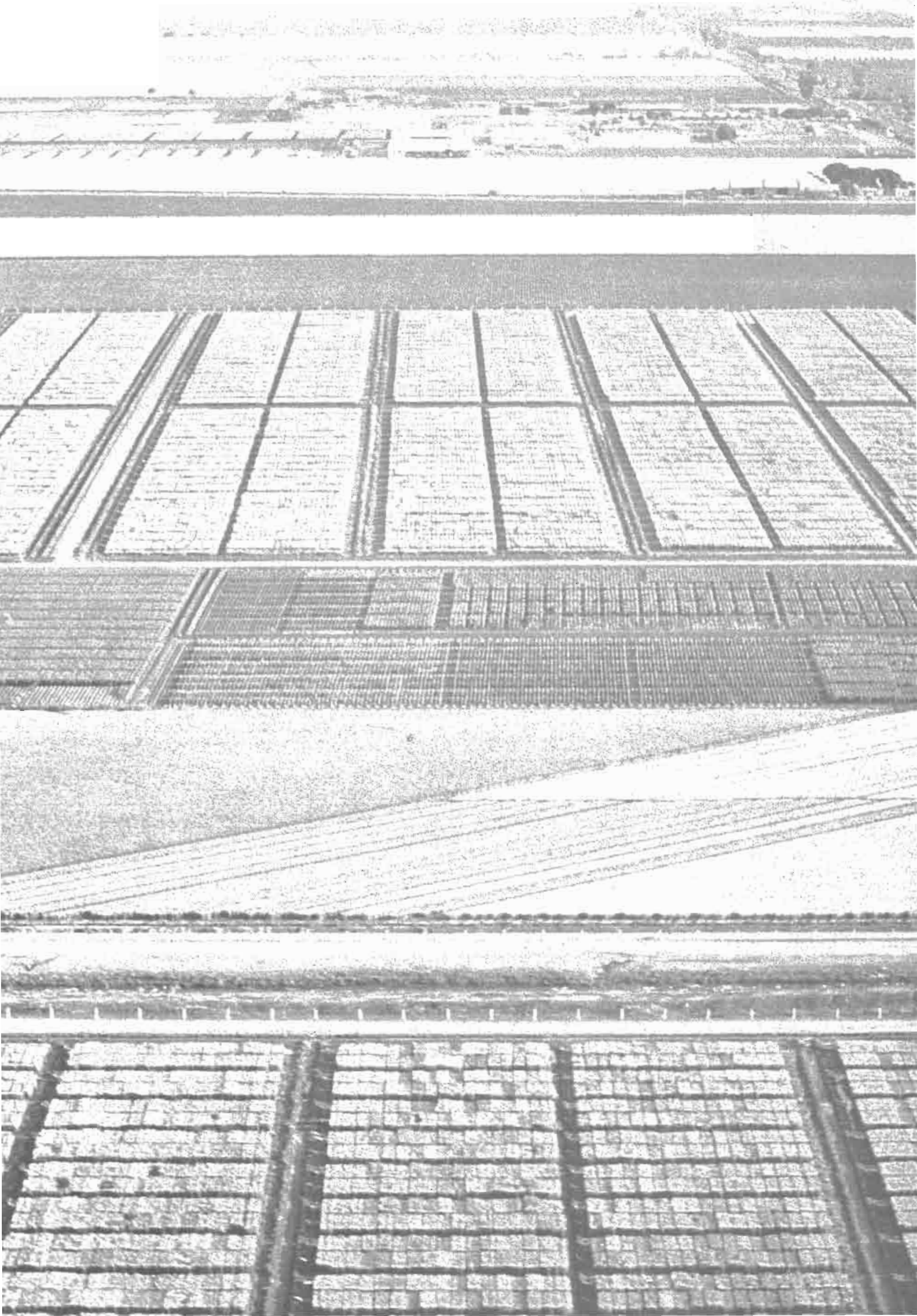
The Punjab Provincial Government, however, did merge AARI's Barani Agricultural Research Institute at Chakwal with the Ministry of Agriculture's Barani Agricultural College at nearby Rawalpindi.

PAEC Agricultural Research Centers
The Atomic Energy Commission (PAEC) has three nuclear institutes for agricultural biology research located in Faisalabad, Tandojam, and at Tarnab, adjacent to the provincial agricultural research institutes. These well-equipped, basic research institutes were established to develop peaceful applications of nuclear technology, (especially radiation-induced mutations for crop improvement) and to study various life processes with radioactive markers. The director general of each institute has considerable autonomy in decision making.

At the Atomic Energy Agricultural Research Center (AEARC), Tandojam, basic studies on wheat cytology are carried out and interspecific and intergeneric crosses between bread wheat and wild relatives are made. (AEARC, 1987). Both mutation and conventional breeding techniques are used in the bread wheat varietal development program. An active research program is underway to develop bread wheat varieties with greater salt tolerance. Available germplasm of bread wheat, durum wheat, triticale, and wild relatives, such as Aegilops, are being screened for salt tolerance. Developing high-yielding wheat cultivars with improved protein quality is also an important thrust. The AEARC in Tandojam has released several wheat varieties: Jauhar 78 was developed through mutation breeding and Sind 81 and Sarsab 86 were developed through conventional breeding techniques. In 1987, Dr. Khushnood A. Siddiqui, Head of the Genetics Division of AEARC, was awarded the Third Annual Norman E. Borlaug Prize for his outstanding contributions to agricultural research in Pakistan.

The Nuclear Institute of Agriculture and Biology (NIAB) is also engaged in mutation and conventional breeding with wheat, triticale and several wild grasses. NIAB's major research contribution in breeding has been an early-maturing, high-yielding cotton variety, NIAB 78, which has improved productivity in the cotton/wheat rotation. Mr. Siddique Sadiq, a NIAB researcher, has performed triticale breeding studies and wide crosses to confer greater salt tolerance to wheat. In 1985, NIAB's triticale variety, T-183, was submitted to the VEC for potential release in the Punjab. This triticale was selected from a cross of NIAB T-77 (Maya II/Arm'S') and NIAB T-103 [(T. durum x Spp. *polonicum*) x (*T. persicum* x rye 10 KR)]. In 1987, NIAB's work in triticale breeding and salt tolerance was shifted to AEARC, with the reposting of Mr. Siddique Sadiq to that institution.

The Nuclear Institute for Food and Agriculture (NIFA), at Tarnab, Peshawar, NWFP, began in 1987-88 to screen wheat lines, with emphasis on rust resistance. Though not officially a participating institution, it receives germplasm from NCWP, CIMMYT, and ICARDA.



CIMMYT'S Wheat Research Collaboration

CIMMYT, the second of the IARCs to be established, was created to speed up the generation and transfer of productive maize and wheat technologies to Third World farmers. It is one of 13 organizations supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR, in turn, is sponsored by the Food and Agriculture Organization of the United Nations (FAO), the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Program (UNDP). In 1987, the CGIAR coordinated funding from some 45 donor countries, international and regional organizations, and private foundations.

CIMMYT and its predecessor organization in Mexico, the Mexican Government-Rockefeller Foundation Cooperative Agricultural Program, have had a close collaborative relationship with Pakistani wheat research institutions for nearly 30 years. Two principal donors have financed this bilateral collaboration: the Ford Foundation from 1964 to 1976, and USAID from 1976 to 1987.

By the time CIMMYT was officially constituted in 1966, Pakistani wheat research institutions, especially those in the Punjab, had been collaborating with the Mexican wheat program for more than five years. The Mexican Government-Rockefeller Foundation wheat research program had already developed a considerable number of high-yielding semidwarf wheat varieties along with the accompanying agronomy to grow them, at least in irrigated areas. A half dozen Pakistani researchers had been to Mexico as trainees, and there were close personal ties between the Pakistani and Mexican wheat research staff. After CIMMYT's creation, the Rockefeller Foundation transferred its wheat staff in Mexico to the new international center and Norman Borlaug continued to serve as the Director of the Wheat Program. Since Borlaug was the wheat leader for 35 years, for the purposes of this report, the activities of CIMMYT and its predecessor organization will be treated as part of the same institutional effort.

CIMMYT's Products and Services

Research support to Pakistan—the third largest wheat-producing country in the developing world—has always figured prominently in CIMMYT's priorities, and can be classified under five general headings:

1) improved genetic resources adapted to the major wheat production environments of the developing world;

2) efficient methods for plant breeding, crop management research, and research planning;
3) training of agricultural scientists;
4) scientific information services; and
5) consultation services to national wheat research programs.

CIMMYT sees its role in wheat research as that of a producer of intermediate products—technological components—that are broadly useful to national wheat programs. The similarities between Pakistan's wheat-producing environments and those in Mexico (irrigated Yaqui Valley, Sonora), where CIMMYT conducts much of its wheat breeding research, has meant that the germplasm developed by CIMMYT is well-suited to Pakistan.

During the past five years, CIMMYT's research agenda has given more weight to the challenges presented by the more marginal production environments. (CIMMYT, 1987). These environments are characterized by such limiting factors as a high incidence of disease, drought, acid soils, saline soils, or excessive heat or cold. Millions of farmers live and work in these unforgiving environments and CIMMYT, along with Pakistani wheat research institutions, is devoting more resources to the development of germplasm and to identifying production practices appropriate for these harsher environments.

Genetic Resources—CIMMYT has conducted a vigorous germplasm development and exchange program with Pakistan since the early 1960s. Pakistan was a pioneering partner in the development of this international wheat testing program and has been an active contributor of germplasm for testing. Each year, from 50 to 70 international nurseries containing thousands of advanced lines, segregating early generation material, and commercial varieties released by national programs in other countries are supplied through the NCWP to Pakistan's wheat research organizations (Table 19).

The international germplasm testing and exchange networks that CIMMYT's predecessor organization helped to establish nearly 40 years ago marked the beginning of a new age in wheat breeding. This mechanism has helped to introduce genetic diversity into national breeding programs and has served as the unifying thread for the work of thousands of wheat researchers and hundreds of organizations worldwide.

Table 19. Distribution of CIMMYT International Wheat, Triticale and Barley Nurseries to Pakistan

Year	Bread Wheat	Durum Wheat	Triticale	Barley**	Total
1977	20	18	23	13	76
1978	15	13	17	11	56
1979	36	13	16	11	76
1980	21	12	16	14	63
1981	20	5	6	11	42
1982	29	5	13	10	57
1983	38	1	11	15	55
1984	37	12	9	6	64
1985	28	8	10	11	77*
1986	36	5	8	12	80*

* Includes a new class of nurseries containing materials from special germplasm development activities, such as specific disease research, wide crosses, yield components

** Since 1984, barley nurseries distributed by ICARDA/CIMMYT Program in Mexico

Source CIMMYT Wheat Program files

The most popular wheat varieties in Pakistan during the late 1980s are derived from spring x winter crosses. The most popular commercial variety in Pakistan, called Pak-81, is derived from the spring x winter line, Veery, developed in Mexico by Dr. S. Rajaram, leader of the CIMMYT Bread Wheat Program. Worldwide, some 30 varieties based on Veery have been released in 24 countries; these varieties are commercially grown today on more than 4 million ha.

International testing ushered in a new willingness to share advanced-generation, un-named lines as well as early-generation materials. This in turn accelerated the introduction of materials with genetic variability into national breeding programs. It became accepted policy that any line tested internationally could be used by the collaborating scientist for breeding purposes or commercial release, providing acknowledgement of the source of the material was given.

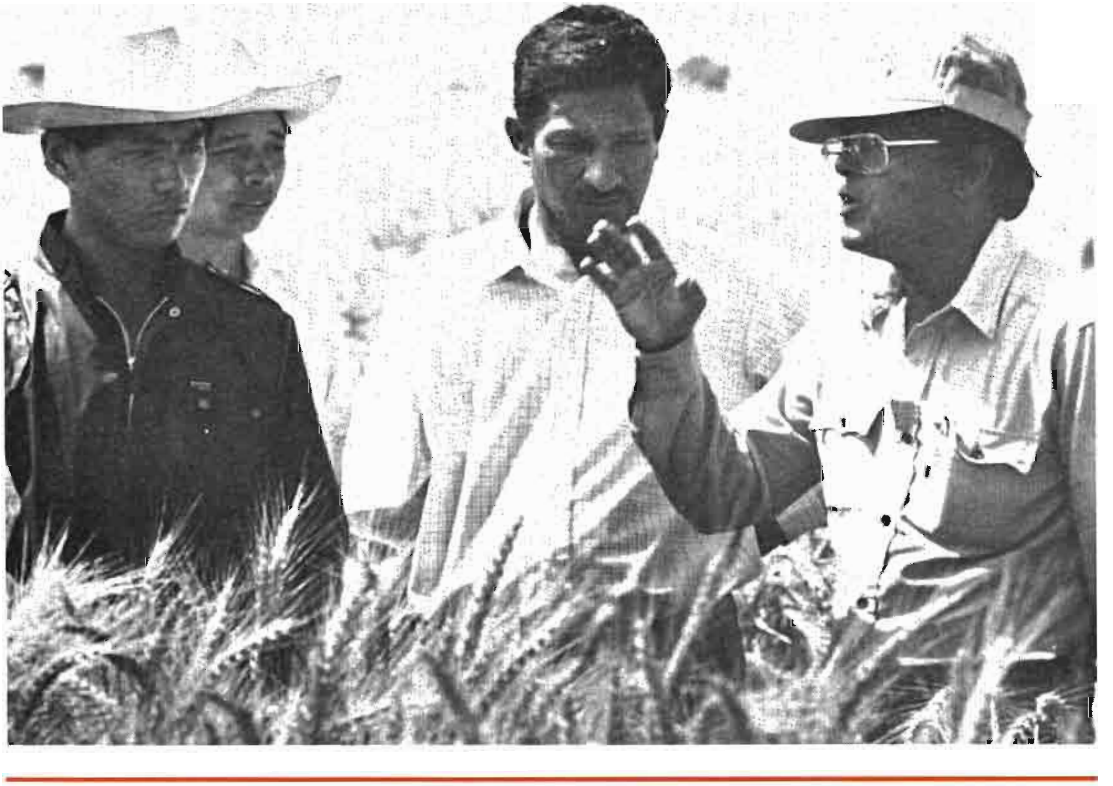
CIMMYT's international wheat testing program has served the practical needs of Pakistan wheat breeding organizations in various ways. Within the best lines of these international nurseries, Pakistan's wheat breeders have selected individual plants which are better adapted to local conditions than were the partially selected or bulk populations, permitting the opportunity for crop improvement with minimum time and expense. The international testing program has also provided Pakistani wheat scientists with a worldwide screening mechanism to observe the adaptation and performance of national wheat materials to widely differing conditions in other parts of the world.

For some, the continued dominance of CIMMYT materials carries a negative connotation with regard to the expertise of local plant breeders. This impression is both unfortunate and mistaken First, Pakistani researchers form an integral part of the international wheat testing program coordinated by CIMMYT and contribute superior germplasm for use by other national wheat programs. Furthermore, the screening observations about commercial varieties from other countries that are made in Pakistan help to guide international network decisions to advance or reject the germplasm undergoing improvement. The success of the so-called "CIMMYT" wheat improvement program has been due to its access to a broad range of genetic diversity provided by national collaborators and because of the large multilocational testing program operated each year by these participating wheat research institutions around the globe. It is the total effort of this network of collaborators that has made the international wheat testing program so successful.

Of course, more specific attributes are required for the varied environments that make up Pakistan's 5.5 million ha of irrigated wheat-growing area, and these germplasm requirements are being attended to by the nation's wheat research institutions. In addition, differing varietal pre-requisites exist for the rainfed plains and the higher mountain valleys. More closely-tailored combinations of resistance to diseases are required, as are a range of maturity periods in wheat varieties, to fit different cropping systems. It is in these areas that national efforts have, quite appropriately, been focused

Training Programs—CIMMYT's founding in 1966 was predicated upon the high returns that come from establishing production-oriented, well-focused wheat and maize research programs in the developing world. This approach has made the Center a leader in strengthening the wheat research capacities of national institutions. CIMMYT has pursued this objective in partnership with Pakistani wheat research institutions, 1) by developing applied in-service training courses, 2) through in-country training on a special needs basis, 3) through the efforts of bilateral and regional program staff, who spend much of their time working side-by-side with Pakistani wheat research colleagues, and 4) by sponsoring especially promising young scientists in their pursuit of advanced degrees.

In-Service training of Pakistani researchers, such as the one pictured here (center), has been a major component of CIMMYT's collaboration with the national wheat research system. More than 75 Pakistani researchers have attended CIMMYT's in-service wheat courses in Mexico on breeding/pathology, production agronomy, cereal technology, and experiment station management.



To date, CIMMYT's primary training activities have been the in-service training courses (Table 20). These courses are designed to impart practical skills to mid-level research staff who have only recently completed their university studies, and focus on operational research issues in plant breeding, plant pathology, production agronomy, cereal technology and experiment station management. While Pakistan has sent wheat researchers to all of the courses, most have attended the wheat improvement (breeding and pathology) and production agronomy courses, with cereal technology and experiment station management accounting for much smaller numbers.

Table 20. Pakistani Alumni of CIMMYT In-service Wheat Training, by Course Concentration 1966-86

Origin	Breeding/ Pathology	Produc. Agronomy	Cereal Tech.	Exp. Sta. Mgmt	Total
Punjab	15	9	3	0	27
Sind	4	3	1	0	8
NWFP	9	4	1	1	15
Baluchistan	5	3	0	0	8
Federal	8	4	2	2	16
AJK/FATA	2	2	0	0	4
Total	43	25	7	3	76

Source: CIMMYT Training Program files

The typical Pakistani who attended these in-service courses in the 1960s and early 1970s had a B.Sc. degree, had been employed by his research institute for 3 to 5 years and was under 30 years of age. The idea was that in-service training in Mexico was the first step in a training path that would often include future leaves of absence for the most outstanding research workers to pursue MSc and PhD degrees. As such, in-service training in Mexico was seen as a screening mechanism to identify the best, brightest and most motivated research workers for future training and advanced degree studies. This is no longer an accurate stereotype of the typical trainee from Pakistan. (Gant, 1986). Those being nominated today tend to be much older, often having worked for 10 to 15 years in wheat research. Clearly CIMMYT's in-service training courses were not designed for such individuals.

In recent years, there has been a decline in the interest of Pakistani wheat research workers in CIMMYT's in-service training courses. First, in-service training in Mexico often competes directly with the opportunity for advanced degree training. Obviously, most will opt for a scholarship for graduate university studies, especially if such studies are at a foreign institution and result in an advanced degree. Second, Pakistan's research leaders believe that they can provide the type of in-service training offered by CIMMYT through local wheat research institutions. As a corollary, they believe that CIMMYT should replace its current offerings for Pakistanis with more specialized and advanced forms of training in new techniques.

In well-established national wheat research programs such as those of Pakistan, there is now a need to finish more advanced and specialized training in new research techniques and equipment and provide collaborators on sabbatical leave from their research institutions with a suitable environment for special research studies. Visiting scientist programs are generally tailored individually and often involve trips to Mexico during the Ciudad Obregon wheat improvement cycle that begins in November and ends in May. These visits center around discussions with the CIMMYT wheat staff and selection of specific germplasm from the breeding plots. New types of visiting scientist fellowships are also being offered in which the scientist can make use of CIMMYT's specialized training facilities, such as the microcomputer training center, and its expanded scientific information and data processing services.

Technical Information Services—CIMMYT has greatly increased the extent of its information services dealing with wheat research. The number of wheat-related titles published annually has increased from an average of 5 publications a year in the 1960s and 1970s to an average of 20 publications a year during the 1980s. These include the results of the international wheat and triticale nursery program, biannual wheat program reports, proceedings of CIMMYT-sponsored wheat research conferences, manuals on research procedures, and field identification and scoring guides for wheat diseases.

In 1987, some 150 individuals and libraries from Pakistan were included on the CIMMYT mailing list and were thus able to receive, free of charge, one copy of any CIMMYT publication. In addition, CIMMYT jointly publishes a Wheat, Triticale & Barley Abstracts Journal with CAB International. Fifteen subscriptions to this Journal—which contains abstracts of approximately 5,000 articles from refereed journals—are provided to Pakistani libraries and wheat research institutes free of charge.

CIMMYT's resident staff in Pakistan are also involved in joint publishing with national wheat scientists. More than a dozen research reports, including the Travelling Seminar Report, and various working papers on the on-farm survey and field experimentation work have been published as part of the PARC/CIMMYT Collaborative Program

Research Consultation—CIMMYT's senior staff and Pakistan's wheat research leaders have had long-standing professional relationships and friendships, beginning nearly 30 years ago with Norman Borlaug and the Pakistani researchers who went to Mexico for training. This sense of camaraderie was further strengthened in Pakistan during the Accelerated Wheat Improvement Program. The project culminated in Borlaug being awarded the 1970 Nobel Peace Prize, which he accepted on behalf of all those involved in the development of the Green Revolution wheat technologies, especially Pakistani researchers and farmers. Frequent contact has been maintained—especially by Borlaug—with the Secretaries and Ministers of Agriculture, Governors, Prime Ministers and the nation's Presidents.

CIMMYT headquarters and regional wheat staff frequently visit Pakistani wheat scientists at key periods during the crop cycle. Pictured here is Dr. Jesse Dubin, a pathologist assigned to the Asian regional program, discussing wheat disease reactions with a Pakistani wheat scientist, Mr. Farzand Ali Khan.

The late Dr. Glenn Anderson, Borlaug's deputy and later successor as Wheat Program Director, visited the wheat research plots and fields every year between 1971 and 1981. His counsel and support of national wheat researchers was deeply appreciated. The subsequent Wheat Program Directors, Dr. Byrd Curtis and Dr. Arthur Klatt, have visited Pakistan frequently, as have many of the headquarters-based wheat staff.

CIMMYT's regional pathologists over the last two decades— Drs. E.E. Saari, J. M. Prescott, and H. J. Dubin—have provided key backstopping to the efforts of Pakistan's wheat pathologists. On average, CIMMYT staff not based in Pakistan have spent another 60 person-days a year in visits to wheat research organizations around the country.

Resident Staff Activities in Pakistan

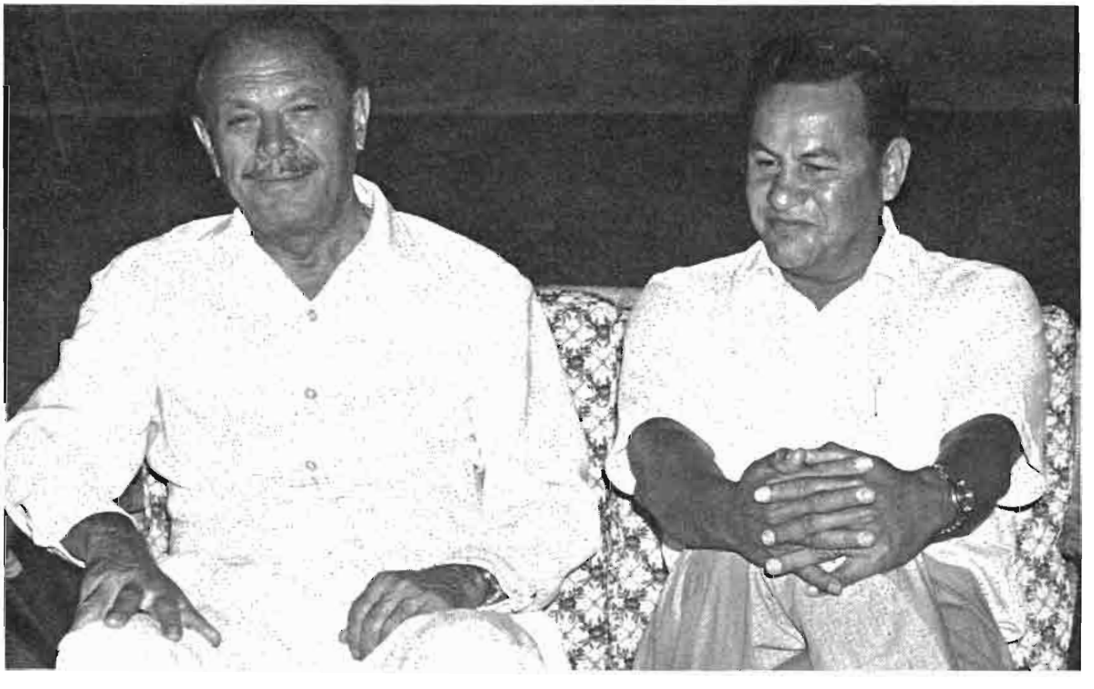
Since 1964, CIMMYT has posted four resident wheat advisors in Pakistan for a total of 17 man-years. These resident advisors have had some tasks in common as official Wheat Program representatives in the country. They have been spokesmen for, as well as the eyes and ears of CIMMYT headquarters' wheat program in Mexico. These resident wheat advisors have helped to 1) coordinate the distribution of international nurseries, 2) process applications for in-service training in Mexico, 3) conduct in-service training events within Pakistan, 4) provide information and advice on research and production issues, and 5) support special research projects of Pakistani wheat research institutions.

The CIMMYT wheat advisors have always been attached to nationally coordinated wheat research programs: first, the Accelerated Wheat Improvement Program, and later the National Coordinated Wheat Programs sponsored by ARC/PARC. All of the resident wheat advisors have been concerned with production-oriented research issues, and most have done their PhD training in agronomy. In the mid 1960s, the first concern was the introduction of semidwarf wheat varieties and high-yield production technologies. It was very much an activist period in which the resident advisor, Dr. Ignacio Narvaez, was involved in many policy matters of seed and input delivery. Increasingly, more attention was paid to strengthening the national breeding programs so that a steady stream of improved varieties with new sources of disease resistance could be released for commercial production.

After the departure in late 1968 of Dr. Ignacio Narvaez, five years went by in which CIMMYT had no resident wheat staff assigned. The second advisor, Dr. Armando Campos, was appointed in June, 1974 and held this position for two years. Dr. Campos was involved in establishing a new National Coordinated Wheat Program, the first attempt at mounting a coordinated program with the new federal structure and four provincial research institutions. Dr. Campos was attached to the Agricultural Research Council, which lacked its own research facilities and programs.

The third CIMMYT wheat advisor, Dr. Homer Hepworth, was posted to Pakistan in 1977 under the auspices of PARC. His tenure in Pakistan coincided with the establishment of NARC and its new research station near Islamabad. Dr. Hepworth was actively involved in station development work at this site. He helped to establish the Travelling Seminar, which has been an ongoing activity of the NCWP for seven years. Dr. Hepworth also paid special attention to wheat production agronomy in barani areas, emphasizing tillage and weed control research. Various in-service training programs were offered in Pakistan, with teaching assistance provided by various CIMMYT staff.

Dr. Ignacio Narvaez, CIMMYT's first resident advisor in Pakistan, played a major role in the introduction of the semidwarf wheat varieties and improved production technology into the country. At the end of his 4-year assignment, Dr. Narvaez was personally honored by President Ayub Khan for his outstanding contributions.



The fourth CIMMYT wheat advisor, Dr. Peter Hobbs, has continued the agronomy focus of his predecessor, but has concentrated more on conducting on-farm research with a farming systems perspective. His work has been facilitated by the presence of CIMMYT economists who have collaborated closely in on-farm research programs in wheat. Several of the major cropping systems have been selected for this work: the irrigated rice/wheat area of the Punjab, the irrigated maize or sugarcane/wheat area of NWFP (Mardan), and the rainfed barani wheat production areas in the northern part of the country.

Dr. Hobbs has shown a special concern for tillage-related problems. Improved land preparation practices, such as zero till and deep tillage, have been investigated as ways to increase yields, reduce time-of-planting conflicts between wheat and other crops grown in rotation, and lower production costs. Dr. Hobbs has also supported important work on weed control, more balanced N and P fertilizer use, and research issues related to the long-term sustainability of wheat production systems. He has been instrumental in introducing micro-computers as research tools for data processing and analysis in wheat research programs.

CIMMYT posted its Regional Economist for South Asia, Dr. Derek Byerlee, in Pakistan from 1983 to 1987, where he spent approximately 50% of his time supporting wheat-related research activities, especially those of the PARC's Agricultural Economics Research Units (AERUs). Dr. Byerlee helped develop the use of social scientists as part of on-farm research teams. He has been extensively involved in setting the research agenda for the AERUs and in a wide range of collaborative research projects with Pakistani researchers. During 1985-87, a second economist, Dr. Paul Heisey, was added to the resident staff. In his wheat research, Dr. Heisey has helped to design and conduct surveys on wheat varietal use and the rationale of farmer decision making in changing to new varieties.

Future Collaboration with Wheat Research Organizations
With the termination of the PARC/CIMMYT Collaborative Wheat Program in 1987, CIMMYT will rely on its two regional wheat staff (a pathologist/breeder and an agronomist) assigned to South Asia (office in Kathmandu, Nepal) to provide the principal research liaison with provincial and federal wheat research institutions in

Pakistan. In addition, CIMMYT's bilateral Economics Program with PARC will finish collaborative research support and institutional links with Pakistani wheat research organizations.

The PARC/CIMMYT Collaborative Wheat Program in Pakistan has been markedly strengthened through the addition of economists to the research team. Pictured here is CIMMYT's regional economist for South Asia, Dr. Derek Byerlee (far right), reviewing on-farm agronomic experiments during 1987 with Dr. Peter Hobbs (far left), CIMMYT's resident wheat advisor.

Continued collaboration is envisioned in both wheat improvement and crop management research. In wheat improvement, increasing research emphasis at CIMMYT is being given to the varietal requirements for sustainable production in intensive cropping patterns. Work to develop drought-tolerant and heat-tolerant wheats will be especially helpful to Pakistani wheat programs concerned with the rainfed barani areas. CIMMYT's continuing quest to develop more durable resistance to leaf and stripe rust, and its more recent work to develop sources of resistance to karnal bunt, are also extremely important research

thrusts for Pakistan. Efforts by CIMMYT to broaden the genetic diversity of its germplasm base through improved characterization of these materials for different traits can also be important for Pakistani breeding programs.

The extent of CIMMYT's work on wheat-based crop management will obviously decline with the reassignment of the resident wheat agronomist, Peter Hobbs, to a regional position for South Asia headquartered in Kathmandu. In this position, Dr. Hobbs will focus primarily on the crop management problems of rice/wheat rotations throughout the region, including Pakistan. CIMMYT's remaining resident advisor in Pakistan, Dr. James Longmire, an economist who assumed the post of resident advisor in February 1988, will assist the AERUs staff in conducting on-farm surveys on wheat production circumstances and constraints, issues of importance to the nation.

Current Wheat Technology and Constraints to Production

Agroecological Zones of Wheat

The Soil Survey project of Pakistan has developed a report titled, ''Crop Ecological Zones of the Indus Plains'' which delineates 17 major agroecological zones in the country. (Rafiq, 1971; 1976). Wheat is grown in 15 of these major agroecological zones. However, only 11 zones are really considered to be suitable for wheat production. (Figure 12, page 100; Table 21).

Wheat production in Pakistan is concentrated on the plains of the Indus basin. Most of this area is semi-arid to arid and 80% of the nation's wheat area depends on irrigation for production. The rainfed areas are found mainly in the high plains, foothills and mountain valleys of the northern and northwestern regions of the country. Of the rainfed areas, approximately 650,000 ha have rainfall above 500 mm annually and 850,000 ha are low-rainfall areas with 350 to 500 mm of precipitation annually.

Table 21. Wheat-Producing Agroecological Zones of Pakistan

Zones	Province(s)	Wheat Area ('000 ha) Irrig.	Rain.	Total
Zone 1- Thatta	Sind	18	0	18
Zone 2-Hyderabad	Sind	282	0	282
Zone 3-Sukkur	Punjab/Sind	2346	52	2,398
3a. Multan-Khairpur	Punjab/Sind	(2065)*	(34)	(2,099)
3b. Jacobabad-Dadu	Sind	(281)	(18)	(299)
Zone 4-Faisalabad	Punjab	1544	12	1,566
Zone 5-Gujranwala	Punjab	828	11	839
Zone 6-Peshawar	NWFP	121	79	200
Zone 7-Thal	Punjab	337	87	424
Zone 8-W. Piedmont	Various	50	35	85
8a. Kachhi	Baluchistan	(8)	(8)	(16)
8b. D.I.-D.G. Khan	Punjab/NWFP	(42)	(27)	(69)
Zone 9-Gujrat	Punjab	5	200	205
Zone 10-Rawalpindi	Punjab/NWFP	22	276	298
Zone 11-Talagang	Punjab	47	187	234
Zone 12-Murree-Swat	NWFP/Punjab	58	223	281
Zone 13-Chitral	NWFP	18	2	20
Zone 14-Quetta/Lorelai	Baluchistan	90	98	188
Zone 15-Makran-Jhalawan	Baluchistan	7	22	29
Zone 16 & 17-Tharparkar/Cholistan	Punjab/Sind	2	0	2
Grand Total		5773	1283	7,056

* Figures in parentheses are the partial areas of a zone.
Source: PARC/CIMMYT Collaborative Program

Pakistan's wheat-producing land can be divided into three types: primary wheat-producing zones, secondary wheat-producing zones, and minor or non-wheat-producing zones. The Appendix to this chapter gives a general agroecological description of each wheat-producing zone and the key constraints to increased productivity there.

There are three primary agro-ecological zones in which wheat is grown in Pakistan. These are located in the Punjab and Sind provinces and account for 4.8 million ha, nearly 70% of the country's total wheat area; collectively, they produce nearly 10 million tons of grain. Depending upon soil type and summer humidity/rainfall, wheat is grown maily in rotation with cotton, two types of rice, sugarcane, maize, pulses or fodder. The dominant cropping patterns by far are the cotton/wheat rotation and the rice/wheat rotation.

Secondary wheat-producing zones border the primary zones to the west and north. These include lower-rainfall barani areas, torrent flood areas, smaller irrigated areas, and some of the high-elevation mountainous areas. Collectively, these zones account for 1.8 million ha, 25% of the national area. Major impacts on yields could be made in these zones through well-focused research and extension programs.

The remaining agroecological zones are either minor or the non-wheat producing areas in deserts or barren mountain lands. Collectively, the minor wheat-producing zones account for about 135,000 ha.

Estimating the Yield Gap

It is generally reported that wheat yields in Pakistan are currently at only one-third of their potential, given available technology. In various reports, a yield gap of 70% has been quoted. Such reports contend that with "optimum" management practices, the average national yield could be 5.4 t/ha and that 38 million tons could be produced on the 7 million ha currently devoted to wheat production. While a substantial yield gap does exist in Pakistan, it is considerably less than those figures suggest. Based upon dozens of on-farm experiments, "economic" yield potentials were calculated for several major wheat cropping systems (Table 22).

Table 22. Comparison of Wheat Yield-Gap Assessments

	Irrigated				
	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	Punjab Mixed Wheat	NWFP Maize/ Wheat	Punjab Barani Wheat
Area, 000 ha	1,010	2,560	1,062	130	440
Official Current Yield, t/ha	1.7	1.9	2.0	1.5	1.1
Official Yield Potential	5.0	6.0	6.0	4.5	4.0
Official Yield Gap, %	66	68	67	67	72
Estimated Current Yield, t/ha	1.8	2.1	2.1	2.5	1.7
"Economic" Yield Potential, t/ha	3.5	3.3	3.5	4.5	3.0
Economic Yield Gap, %	49	36	40	44	43

Source: PARC/CIMMYT Collaborative Program data

The optimum economic yield in these calculations is estimated by assuming the farmers' perspective of wheat as one crop, albeit a very important one, in his cropping pattern, where management conflicts and compromises have to be made. Thus this figure takes into consideration the total productivity of the cropping pattern within a realistic economic environment. As can be seen, there are considerable discrepancies in the apparent "yield gaps" in wheat. However, even with the lower set of yield-gap estimates, it is clear that there are substantial opportunities to increase wheat yields within existing cropping systems.

Status of Technology in Major Cropping Systems

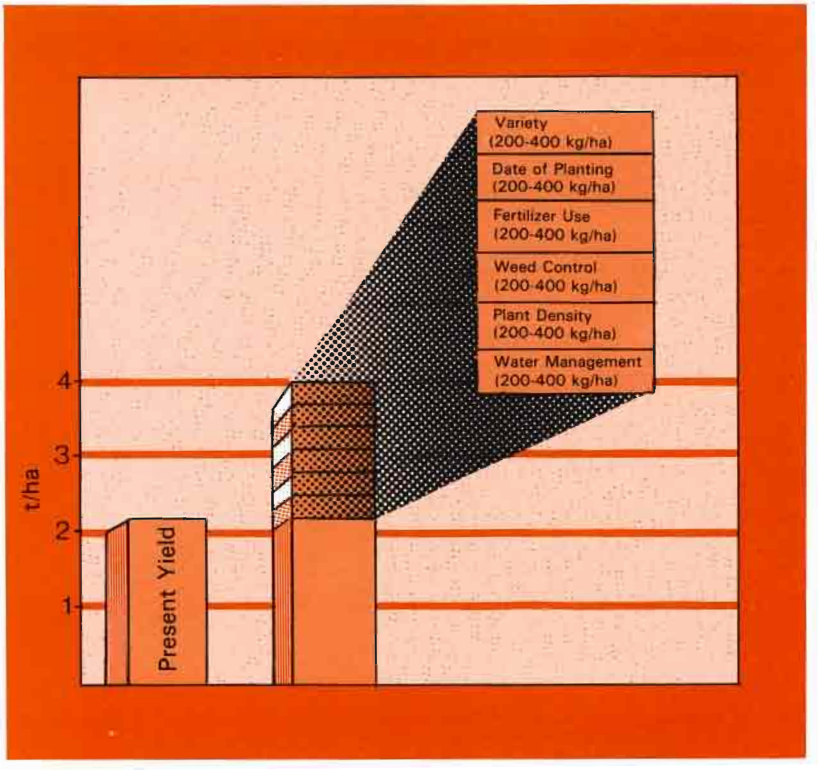
The high-yielding wheat varieties currently available in Pakistan have a maximum genetic yield potential of 6-9 t/ha. This theoretical yield potential, however, is not the economic yield potential in which conflicts in the cropping systems, economic constraints at the farm level, and the lack of information on the part of farmers result in suboptimal production practices in land preparation, stand establishment, fertilizer use, and weed control. In the irrigated areas, especially, the cropping intensity during the last two decades has increased sharply, placing pressure on wheat in these systems. Results of on-farm surveys and experiments have led to the identification of a series of production problems in the context of the major cropping systems.

While there are many different cropping patterns, the dominant irrigated crop rotations are cotton/wheat, rice/wheat, diversified kharif crops/wheat, maize/wheat and sugarcane/wheat. The dominant barani systems are in the high-rainfall plains areas and certain mountain zones. On-farm research conducted by PARC/CIMMYT and provincial wheat researchers provides reliable information on the current production constraints and yield gains possible from the introduction of improved management practices within the reach of representative farmers.

Wheat yields in Pakistan will be increased through improvements in a number of production practices (Figure 8). These include 1) the use of newer, higher-yielding varieties, 2) observance of optimum planting dates, 3) improved planting methods, 4) improved fertilizer use and management, 5) improved weed control and 6) improved water management. When any one of these technological components is at suboptimal levels, yield losses from 200 to 400 kg/ha may be expected; under generally poor management, they can collectively account for a 1,200 to 2,400 kg/ha reduction from potential yields.

The use of farm machinary plays an important role in the scheme of wheat production; if adequate it can both raise yields and lower costs, especially in land preparation and harvesting.

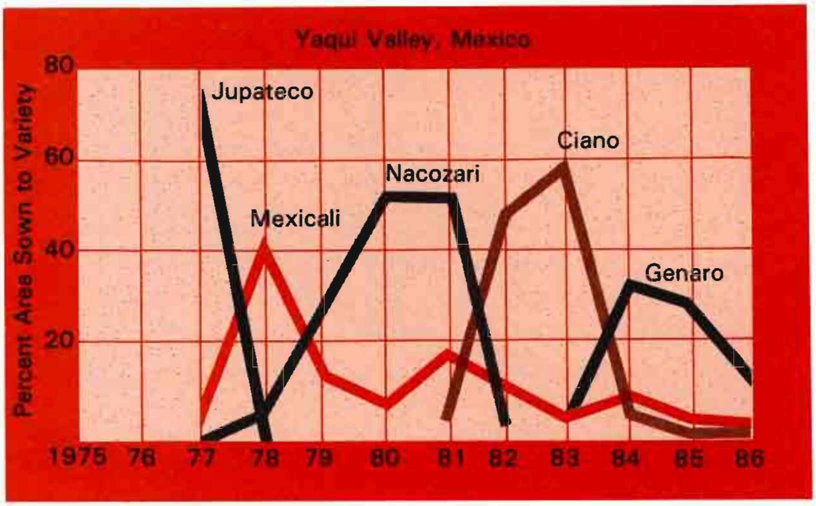
Variety—Since 1965, more than 30 HYVs have been released by the provincial research services of Pakistan. These materials fall into two maturity groups: full-season and short-season. They are generally white-grain types with high gluten strength. Stem and leaf rust resistance are needed in all growing areas, resistance to stripe rust in areas north of Faisalabad. There is also a need for resistance to some bunts and smuts. Resistance to stem rust has held up, but leaf and stripe rust resistances have been more ephemeral. Most varieties have lost their resistance to these two types of rusts within four to six years of release. In some cases, resistance has been lost before or shortly after release.

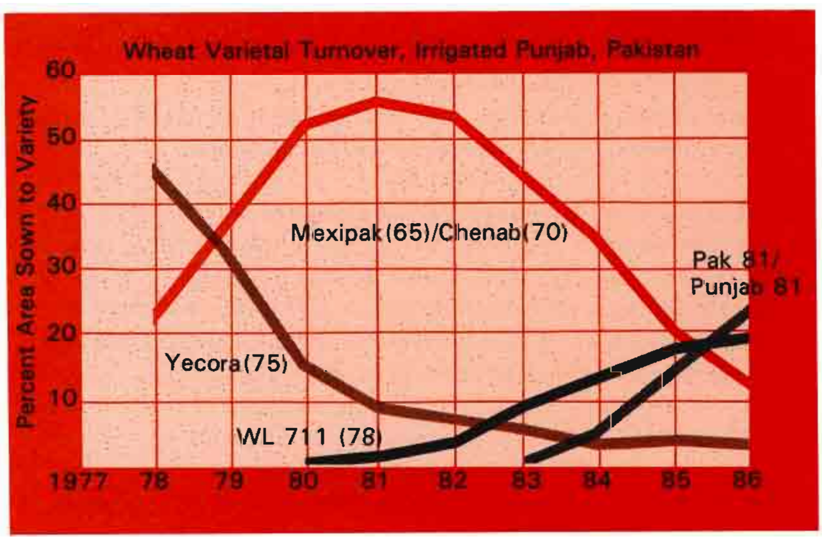


Source: PARC/CIMMYT Collaborative Program data

Figure 8. Present and Potential Wheat Yields in Irrigated Areas Based on On-farm Research Information

Pakistan's wheat research systems have released a continuing stream of improved semidwarf HYVs since 1965. On average, the yield potential of the these new HYVs has increased at about 60 kg or 1% per year (Byerlee and Heisey, 1989) during 1965-85. Despite these gains in yield potential, the commercial introduction of these new varieties has been slow. Average age of varieties (from time of release to peak coverage) ranges from 6 to 9 years; replacement takes over 10 years. Since the introduction of the first HYVs in the late 1960s, commercial use patterns for the HYVs have only changed when rust epidemics have put heavy pressure on farmers to switch to new varieties. Replacement of rust-susceptible varieties with higher-yielding resistant ones takes six to eight years in Pakistan, a rate so slow as to almost ensure an alarming proportion of commercial wheat areas planted to rust-susceptible varieties. This situation contrasts with those of Mexico or India, where the turnover is much quicker (Figure 9).





Source: Heisey et al., 1987

Figure 9. Comparison of Wheat Varietal Turnover in Mexico and Pakistan

Wheat Diseases—In 1986-87, 64% of the cotton/wheat zone, 52% of the rice/wheat zone, and 60% of the irrigated zone of NWFP were planted to either banned or old varieties susceptible to rust pathogens. At present, the old variety, Pavon-76 (a "slow-rusting" genotype) is the only wheat variety with resistance to leaf rust that is being multiplied by the Sind Seed Corporation, and Pak 81 is the sole leaf and stripe rust-resistant variety being multiplied in any quantity by the Punjab Seed Corporation, despite the availability of at least a half-dozen newer HYVs (Kohinoor 83, Faisalabad 83, Faisalabad 85, Punjab 85) with resistance to leaf and stripe rust. In the case of Sind, all of the newer HYV wheat varieties currently promoted by ARI and AEARC are showing susceptibility to leaf rust.

Approximately 50 to 60% of the country's total wheat area is planted to varieties that are susceptible to rust attacks (Table 23), often because these varieties are preferred by farmers for eating purposes. Apart from the threat of a rust epidemic, on-farm experiments have consistently shown the superiority of the newly released varieties under farmer conditions. In over 50 experiments planted between 1983 and 1985, Pak 81, for example, provided an average yield increase of more than 20% over the variety Yecora, and a 5-10% advantage over WL-711, depending on planting date. And yet, this variety has been slow to be adopted.

Though the proportion is decreasing, the continued planting of rust-susceptible varieties (still grown on 40 to 50% of the national wheat area) poses a serious threat to stable wheat production in the country. The failure to distribute newly released varieties in a timely way exposes the country to an agricultural time bomb, in a scenario ominously similar to the events leading up to the 1977-78 rust epidemic. Luckily, 1986/87 was not a "rust" year; the rusts came late and only caused a 3% reduction in total production. Another problem with the continued use of susceptible varieties is that it increases the chances of a new mutant race developing to attack presently resistant varieties.

There are other potentially serious disease problems looming over wheat production in the country. Stripe rust, more serious in the cooler northern parts of the country, could also explode into an epidemic under favorable conditions. Seed-borne diseases, principally loose smut, flag smut, and karnal bunt are also serious in certain locations. Karnal bunt, in particular, is on the rise and was observed in the 1986/87 season in both the rice/wheat tracts of Punjab and in the Peshawar valley. This disease reduces the quality of wheat and produces a black seed mass that makes the grain unsuitable for human consumption. A survey is needed to detect the hot-spots and develop a suitable research strategy for control measures.

Table 23. Percent Area Under Different Wheat Varieties in the Irrigated Rice and Cotton Zones of Punjab and the Irrigated Maize Zone of Peshawar

Varietal group	Rice Zone Punjab		Cotton Zone Punjab		Irrigated Maize Zone Peshawar	
	1985-86	1986-87	1985-86	1986-87	1985-86	1986-87
New recommended:						
Pak 81	26.3	38.4	6.2	10.9	19.5	19.1
Punjab 81	-	-	9.0	5.4	-	-
Bahawalpur 79	-	-	12.3	9.1	-	-
Faisalabad 83	0.2	1.4	0.5	-	-	-
Kohinoor 83	0.1	0.8	0.1	1.5	-	-
Pirsabak 85	-	-	-	-	0.1	0.3
Indus 79	-	-	-	-	0.5	-
New don't know	4.7	7.2	3.2	8.9	5.7	20.4
Total	31.3	47.8	31.3	35.8	25.8	39.8
Old recommended:						
B. Silver/Sonalika	10.4	11.3	21.2	21.6	6.8	2.5
Sandal	5.7	5.3	0.6	0.8	1.7	.7
Pari-73	4.1	3.4	0.1	-	-	-
Lu-26	1.4	1.6	0.1	0.2	-	-
Lyallpur 73	4.3	1.8	0.7	0.4	8.3	1.6
Total	25.9	23.4	22.7	23.0	16.8	4.8
Banned:						
Punjab 81*	17.4	7.3	-	-	-	-
Bahawalpur 79	0.2	-	-	-	-	-
WI 711 "India"	2.3	0.4	37.2	28.9	9.9	12.3
Yecora	10.5	7.8	1.0	1.3	-	-
SA 42 "Torlashi"	-	-	-	-	14.0	14.8
"Mex.Pak"	-	-	-	-	25.8	20.7
Old don't know	12.4	13.3	7.8	11.0	7.7	7.5
Total	42.8	28.8	46.0	41.2	57.4	55.3

* Punjab 81 and Bahawalpur 79 banned for rice zone but not cotton zone

Source: Data from Surveys by Agricultural Economics Research Units, Faisalabad and Tarnab, and CIMMYT

Some problems can be effectively controlled through the use of the chemical seed treatments, as recommended by the wheat research service. Such chemicals should be supplied by the seed corporations at the time of purchase (certified seed is not chemically treated because of fear of people eating it as grain). While this means of chemical protection will increase seed costs somewhat, such treatment could delay infections past the critical period for epidemic development.

Planting Date—In double cropping systems there are often difficulties in planting at the optimal time, and wheat crops seem to be planted increasingly later (Table 24). In Pakistan, wheat yields are quite sensitive to late planting dates because of the risk of high temperatures in the flowering and grain-filling stages. Analysis has shown that this late planting of wheat is a rational practice, given the farmer's current technology and the economic environment he faces: the farmer favors his basmati rice and cotton crops in the rotation because they pay more money. However, it is estimated that for every day's delay in planting wheat after November 20, wheat yields, on average, decline 1% (Figure 10). The problem is most pronounced in the cotton/wheat area, where 20% of the fields are planted in January (with an average loss of 1 t/ha of wheat grain due to this practice). (Akhtar et al., 1986). In basmati rice areas, 20% of the fields have traditionally been planted very late (in early January) although this situation has recently improved. The adoption of the earlier-maturing, high-yielding cotton variety, NIAB 78, and the basmati rice variety, Basmati 385, are helping to alleviate the problem of late planting. In particular, the early-maturing Basmati 385 variety

Table 24. Distribution of Wheat Planting Dates in Irrigated Areas

Planting Date	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
	% of fields		
Recommended (before Dec 1)	60	29	66
Somewhat late (Dec. 1-15)	30	29	19
Very late (after Dec. 15)	10	41	15

Source Byerlee et al , 1986

is having a marked impact on wheat yields by allowing farmers to plant 10-15 days earlier. As rice and cotton farmers take up new, earlier-maturing varieties of these summer crops, timely planting of wheat can increase yields by 500 to 800 kg/ha.

Another set of solutions lies with the wheat crop itself. It has been assumed that early-maturing varieties solve the problem of late planting. However, recent evidence indicates that some of the wheat varieties of later maturity have enhanced tolerance to heat stress, and perform even better than early maturing varieties, when planted late. Examples are Pak-81 and WL-711, both very popular with farmers. Such genotypes provide the farmer with additional flexibility while allowing higher yields in seasons with more favorable growing conditions. This yield dependability is an example of the value of "wide adaptation" in wheat. Short-season varieties to replace the popular but rust-susceptible Blue Silver/Sonalika are also urgently needed.

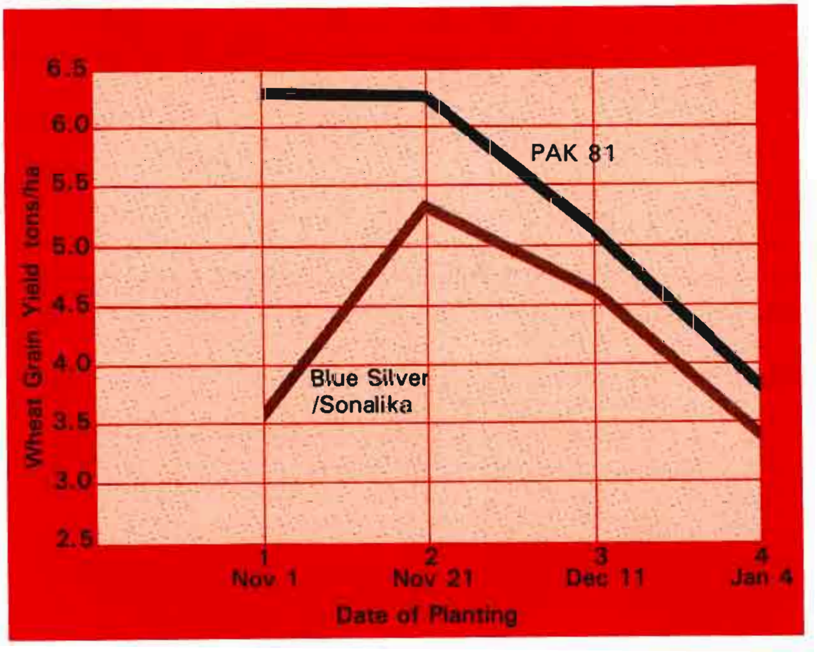


Figure 10. Effect of Planting Date on the Grain Yield of Wheat at Khanewal Seed Farm, Punjab, Pakistan 1982-85

Land Preparation and Planting Methods—Land preparation practices appear to be an important constraint in the rice/wheat area, especially where basmati rice is grown. Here the farmer typically performs six cultivations before planting wheat after rice (Table 25). Even so, the resulting seedbed is often not in good enough shape to achieve a good stand of wheat, due to the difficulty of working the puddled, compacted soils and incorporating plant residues from the previous rice crop. In addition, the time required to carry out so many tillage operations contributes to late planting.

Table 25. Land Preparation and Planting Methods in Irrigated Wheat Areas

	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
Average number of tillage operations	6.1	4.8	3.3
Average seed rate, kg/ha	98	110	113
% who broadcast seed	98	98	92

Source: Byerlee et al., 1986

An exciting research development in this area is zero-tillage, especially for the basmati rice/wheat zone, but probably also for other zones. This technology permits the direct drilling of seed into the undisturbed soil surface with simultaneous fertilizer application. It results in improved stand establishment, more uniform spread of fertilizers, improved weed control (because dormant seed are not brought to the surface), and saves time and money. With zero-tillage, the traditional land preparation costs of Rs. 750/ha can be reduced appreciably. Current data indicate that wheat planted after rice using zero-till direct seeding can achieve an average yield increase of 20 to 30% with a 20% reduction in production costs to boot.

In barani areas, shallow cultivation has also resulted in a hard plow-pan layer 20 to 30 cm below the surface followed by compacting beneath that. This limits root growth and reduces yields by 30 to 40%. Agronomic trials conducted during 1984-87 indicate that deep tillage with a moldboard plow can overcome the current problems of soil compaction and thus substantially improve yields (Table 26).

Table 26. Effects of Tillage Treatments on Wheat Grain Yields in the Rainfed Area of Rawalpindi and Islamabad Districts

Year	No. of Experiments	Grain Yield, t/ha Cultivator (Shallow)	Grain Yield, t/ha Moldboard (Deep)	% Yield Increase
1984-85	16	2.1	2.9	36
1985-86	35	4.1	5.1	27
1986-87	13	3.6	4.1	14
Average	68	3.4	4.3	25

Source: Hobbs et al., 1987

* Unpublished data, P.R. Hobbs

Soil Fertility—Fertilizer has made a major contribution to increased wheat production in Pakistan. Nitrogen fertilizer use is now at moderate-to-high levels in the irrigated and well-watered production areas. In many areas, however, insufficient phosphorus is applied (Table 27).

Table 27. Fertilizer Use in Irrigated Wheat Areas

	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
	kg/ha of nutrient		
Average dose N	77	97	97
Average dose P	44	46	32
Total nutrients	121	145	129
	% farmers who...		
Apply P	83	85	47
Use farmyard manure	9	4	38

Source. Byerlee et al., 1986

Researchers have traditionally provided one fertilizer recommendation for all irrigated areas, with little economic justification. Differential responses to fertilizer by crop rotation relate in part to the effect of carryover fertility from the previous crop. A four-year series of on-farm experiments has looked at differential responses to fertilizer recommendations for relatively homogeneous groups of farmers, classified according to the crop rotations and using realistic cost estimates and rates of return on capital (Table 28).

Table 28. Fertilizer Recommendations for Wheat Grown in Different Cropping Patterns Compared to Farmers' Practices

Rotation	Farmers average use		Official Recommend.		Economic Recommend.	
	N	P	N	P	N	P
	kg/ha					
Maize-wheat NWFP	91	27	136	57	103	82
Sugarcane-wheat NWFP	112	37	136	57	137	82
Rice-wheat Punjab	77	44	136	111	155	49

Source: Byerlee et al., 1986

The results show considerable discrepancy with officially recommended dosages. In the irrigated maize/wheat areas of NWFP, there appears to be little basis for the recommendation of a 2.5 to 1 ratio of N to P. On-farm trial data show that farmers could benefit from higher levels of P than currently recommended on wheat planted after sugarcane. In the Punjab, on the other hand, wheat planted after rice would appear to benefit from higher doses of N. While increased amounts of N and P fertilizer use are still profitable in most of the major zones, the relative balance in the application of these nutrients is an especially important consideration. With current cropping intensities, deficiencies of secondary and micro-nutrients will constrain yields and negate investments in nitrogen and phosphorus.

Weed Control—Few Pakistani wheat farmers use chemicals to control weeds (Table 29), despite the fact that weeds are a serious yield-limiting factor in the rice/wheat area and the maize/wheat area of NWFP. Figure 11 shows the impact of weeds in NWFP. (Hussain et al., 1986). The problem of grassy weeds is directly linked to the number of years of continuous rabi season wheat planting. In fields that are alternated with row crops or with fodder crops in the rabi season, the grassy weed problem is less severe.

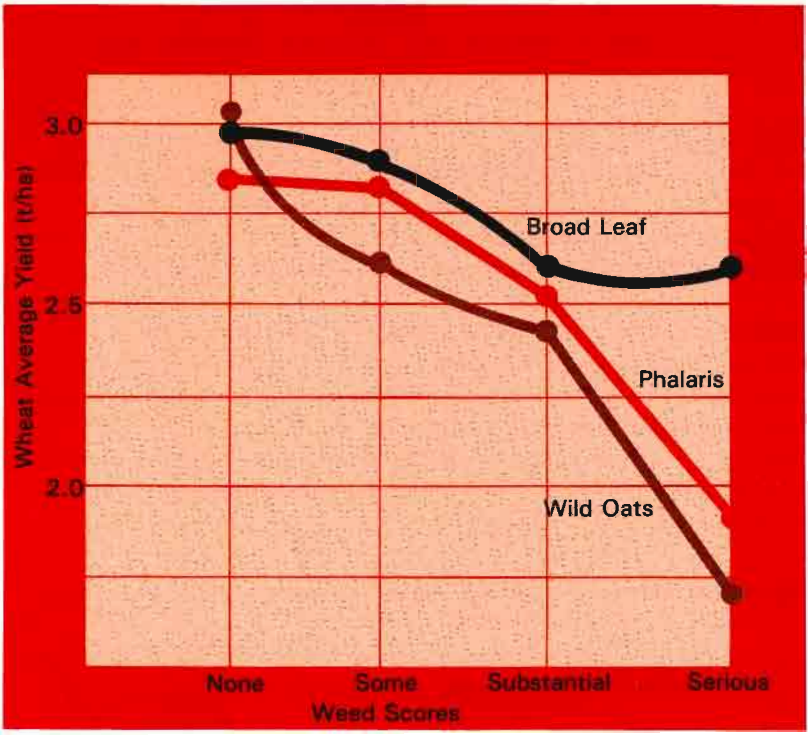
Table 29. Weed Control Methods and Weed Problems in Irrigated Wheat Systems

	Punjab Rice/ Wheat	Punjab Cotton/ Wheat	NWFP Maize/ Wheat
% of farms with weed problem			
- broadleaf weeds	13	13	35
- Phalaris	28	1	11
- Wild oats	6	3	9
% farmers using weed control method:			
- hand weeding	7	17	19
- herbicide	3	-	4
- none	90	83	77

Source: Byerlee et al., 1986

A possible solution for the weed problem is herbicides. In the maize/wheat area, experimental data have shown very attractive rates of return (240%) for the use of phenoxy herbicides to control broadleaf weeds. After convincing farmers of the profitability of using herbicides in cotton production, private companies are now starting stronger herbicide marketing efforts for improved weed control in the rice/wheat area.

Mechanization—The mechanization of Pakistani wheat production has proceeded at an accelerated rate. Now that the country has, for all practical purposes, a mechanized wheat production system, there is a need to optimize returns from these investments. In particular, there is a need for a research and development program to manufacture a range of improved implements for wheat production, including deep-tillage plows, zero-till drill/planters, cutter/binders, and improved threshing equipment.



Source: Byerlee et al., 1986

Figure 11. Average Wheat Yield According to Weed Scores, Maize/Wheat Area, NWFP

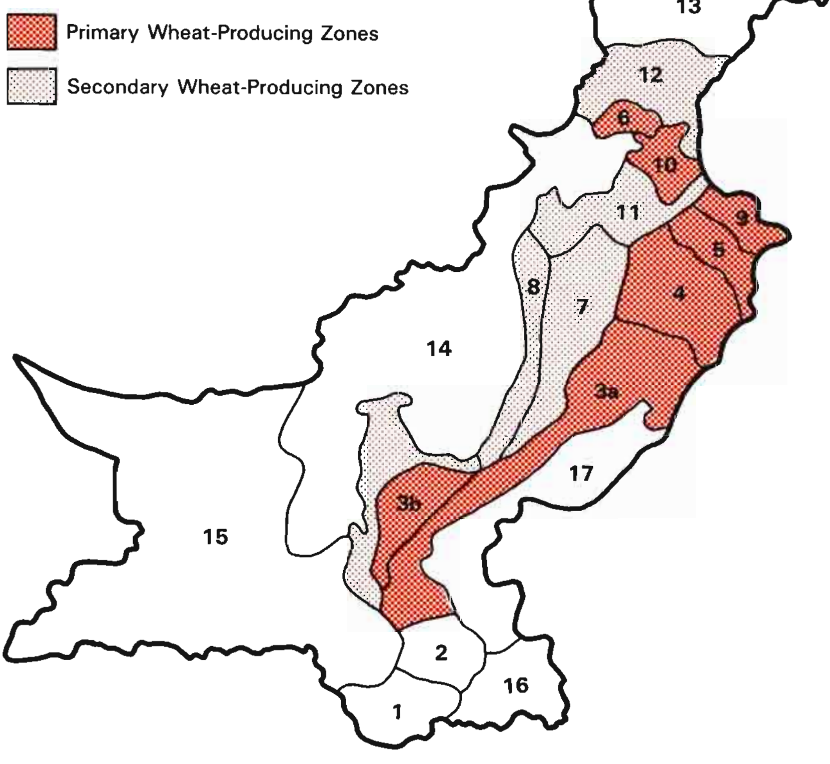
Increased mechanization of harvesting operations can reduce the time required for these operations which, in turn, can reduce grain losses due to late harvesting (as in the 1986-87 season, when rains seriously affected traditional harvesting operations). Also, increased mechanization can reduce the traditional costs for cutting, threshing and transportation (up to 30% of the crop is currently sold to pay for these operations). Self-propelled combines now harvest over 100,000 ha in the rice/wheat area alone. While many parcels may be too small for efficient combine harvesting, the wheat area handled this way is expected to grow substantially in future years. However, a significant shift toward greater mechanization in harvest operations would also result in labor displacement.

Water/Moisture Management—Research issues in water management are complex. The problems of timing of irrigation, salinity, sodification caused by rising water tables and waterlogging all affect the yield potential and sustainability of production systems. Although the issues are complex, improved water management is a high priority research area.

While wheat is a relatively salt-tolerant species, its productivity can decline seriously under extreme conditions. The development of adequate drainage systems to control sodification and salinization should not be discounted, but improved tolerance to these conditions can also be achieved through plant breeding.

Another source of concern in irrigated wheat production is the cost of diesel powered tubewells, which is 10 times more than canal irrigation and 3 times more than electric powered tubewells. The current plans to expand the rural electrification grid will alleviate this problem, although some analysts believe that the real price of electricity should be increased to maximize social benefit in Pakistan.

Figure 12. Wheat-Producing Agroecological Zones of Pakistan



Wheat-Producing Zones of Pakistan

(See Table 21, page 85)

Zone 1: Thatta—This is the delta area of the Indus River where only 18,000 ha of wheat are grown. It is not an important wheat-growing area because of its short season. Rice and sugarcane are the major summer crops and pulses and mustard are the major winter crops. The principal soil problems are waterlogging, salinity and heavy texture.

Zone 2: Hyderabad—This zone covers 282,000 ha and includes areas of the Sanghar, Tharparkar, Hyderabad, and Dadu Districts. Its northern boundary represents the limit of the frost-free zone of Pakistan. Sugarcane and cotton are the major summer crops, pulses and wheat the major winter crops. The wheat season is short with planting in late November and harvest in mid-March. Rust usually occurs late in the season and is not a problem. There is a need for short season varieties with heat tolerance during grain filling. Wheat yields in this zone are 2.2 t/ha, 17% above the national average.

Zone 3: Sukkur—This zone is the major wheat-producing area of Pakistan. It covers nearly 2.4 million ha in the arid part of the Indus plains with less than 200mm of rainfall. The zone is characterized by very hot summers with low humidity and mild winters where frost occurrence is rare. Because of significantly different soil types, two sub-zones exist, each with distinct cropping patterns.

3a sub-Zone: Multan-Khairpur. This sub-zone covers 2.1 million ha where cotton/wheat is the major rotational pattern. It is located east of the Indus river in northern Sind and southern Punjab, stretching from Multan District in the north to Khairpur District in the south. Soils are mainly silty loams with some clays also found. The water table is generally deep. Salinity in some areas, however, is problematic. It is some of the best wheat-producing land in the country. Cotton is the most suitable summer crop and wheat is the most suitable winter crop, although gram is also produced. Wheat is harvested in April and May. It is often sown late, especially in the northern part of the zone, due to the preceding cotton crop cycle. Heat stress during grain filling is a widespread problem and varieties with either heat tolerance during grain filling or early maturity are required. Leaf rust attack can be very serious. *Chenopodium* and *Convoluvulus* are potentially the most damaging weed species, but do not cause serious yield losses at present. Nitrogen use is approaching optimum and therefore phosphorus deficiencies are showing up. The average wheat yield in this sub-zone is 2.2 t/ha, 16% above the national average.

3b sub-Zone: Jacobabad-Dadu. This sub-zone covers roughly 300,000 ha where rice/wheat is the major rotational pattern. The area is located west of the Indus river in the Jacobabad, Larkana Shikarpur, and Dadu Districts. It has clayey soils and a high water table that causes major problems. Considerable waterlogging and salinity exist. Rice is the major summer crop (mostly IRRI-type varieties). Wheat, gram, pulses, and fodder are the major winter crops. For wheat, late planting and crop stand establishment are major production constraints. On-farm irrigation management is a major problem. There is a need for short-season varieties with heat tolerance during grain filling. Many farmers still grow local (desi) wheat varieties susceptible to rust. Weeds (broadleaf and grassy) are becoming more serious as increased fertilizer is used. More balanced N and P fertilizer dosages are required. Very little wheat research is done in this area. Water management is also a problem. The average wheat yield for the zone is 1.7 t/ha, 11% below the national average. This irrigated wheat area is one of the lowest-yielding in the country.

Zone 4: Faisalabad—This zone covers almost 1.6 million ha and is located in the central part of Punjab. Wheat is the principal crop in the Rabi season and a diversified range of crops in the Kharif season. It includes land in Faisalabad, Okara, Sahiwal, Kasur, Sargohda, Jhang, and T.T. Singh Districts. Soils are mostly silt loams, with some clays. Weather is characterized by hot summers, cool-to-cold winters with frost a possibility, and low rainfall in winter. Wheat is the most suitable winter crop. Higher humidity in summer makes the zone less suitable for cotton production (250,000 ha nonetheless are grown) and this has resulted in diversified summer cropping patterns that include sugarcane, rice, cotton, maize, fodders, and pulses. Some areas have high water table and salinity problems. Depending upon the previous crop, late planting in wheat can be a problem. The weeds *Phalaris* and wild oats are the major species causing yield losses. Leaf and stripe rust attack can be severe in this area; loose smut is also a problem. Hot temperatures during grain filling require varieties with heat tolerance. Land preparation systems which allow a quicker turnaround between crop rotations are needed. Increased use of P fertilizers is required. The average wheat yield for this zone is 2.4 t/ha, 20% above the national average.

Zone 5: Gujranwala—This rice/wheat zone covers more than 800,000 ha in the sub-humid part of the Indus plains in the Gujrat, Gujranwala, Shiekhupura, Sialkot and Lahore Districts of the Punjab Province. It is characterized by hot summers and cold winters. Rainfall is in the 400 to 700 mm range. Soils are clay loams and silt loams. Salinity, saline-alkalinity, and waterlogging are major soil problems. Basmati rice is the major summer crop, wheat is the major winter crop. Poor stand establishment due to poor soil structure, poor land preparation, and rice residues limit yield potential. The structure of soil following puddled rice and the shallow plow pan needed to resist water percolation in rice are other factors detrimental to wheat production. Weeds are a problem in this zone. *Phalaris, Avena fatua, Lolium, Chenopodium*, and *Rumex* are the major weed species reducing yields. Zero tillage offers considerable promise for reducing production costs and shortening the turnaround time between crop rotations, allowing for more timely planting of wheat. Leaf and stripe rust can cause serious production losses. Karnal bunt can be a problem in wet years. Winter rains can either help or hurt the crop, depending on when they come. Early rains help in stand establishment and early plant growth; late rains in March and April can cause serious grain damage during harvest. Frost can affect short-season varieties planted too early. Average wheat yields in this zone, at 1.9 t/ha, are equal to the national average.

Zone 6: Peshawar—This zone covers 200,000 ha and is made up mostly of the irrigated areas of NWFP in Peshawar, Mardan and parts of Swat and Malakand Districts, an area with hot summers and cold, rainy winters. The zone is characterized by complex cropping patterns, with maize and sugarcane being the major summer crops, and wheat, sugarbeet, fodder and tobacco being the major winter/spring crops. Frost is a likely occurrence during 2-4 weeks of the winter cycle. Weeds are a major problem, including many temperate broadleaf weeds and the grassy weeds *Phalaris, Avena fatua*, and *Lolium*. Leaf and stripe rust are serious disease problems. Karnal bunt can be serious in a wet year. Varieties should have frost tolerance. When wheat is planted late, e.g., following sugarcane, grain is often shrivelled due to hot, dry winds in late April and early May. More balanced N and P fertilizer use is required for higher yields. Mechanized tillage practices have caused hard plow-pan layers to develop at shallow levels. Official yield statistics in this zone are erroneous. The official average yield of this zone is 1.46 t/ha; a more realistic estimate is 2.5 t/ha, some 70% higher than indicated in the official statistics.

Zone 7: Thal—This zone covers 424,000 ha, 337,000 ha of it irrigated. The area is only marginally suitable for wheat production although the crop is grown on a considerable area, especially when supplementary irrigation is available. The cotton/wheat rotation is common with irrigation. The zone is located between the Indus and Jhelum rivers and has sandy soils and sand ridges. Climate is similar to Zones 3 & 4: summers are hot, winters are generally cool and can occasionally get cold. Frost is possible during two weeks. Rain is common during the winter season and the area is suitable for gram production. Little wheat research has been done in the area. The average wheat yield in this area is 1.5 t/ha, 21% below the national average.

Zone 8: Western piedmont—This 85,000 ha strip of piedmont on the west bank of the Indus river is an arid area with little rainfall but torrent floods from the runoff of nearby mountains. Two sub-zones are delineated:

8a sub-Zone: Kachhi plains—Located in Kachhi and Larkana Districts. Hottest area year-round in Pakistan. Cropping depends upon torrent water in the riverain areas. Soils are loamy near hills in the northern area but clayey in the southern areas; all are strongly calcareous. Sorghum and millet are usually grown in the summer, gram in the winter. Cotton is also moderately suitable. Some wheat is also produced using tall local varieties. Fertility is good.

8b sub-Zone: D.I. Khan and D.G. Khan—This mixed irrigated/rainfed sub-zone covers 69,000 ha and is located in D.I. Khan and D.G. Khan, and Rajanpur Districts. It has higher rainfall (100-250 mm) than found in sub-Zone 8a; otherwise the climates are similar. Loamy soils predominate. Some canal irrigation exists in D.I. Khan where the major crops are rice, cotton, and sugarcane in summer, and wheat in winter. Wheat production problems include late planting, poor stand establishment, and weeds (in irrigated areas). Diseases are not very important. Short-season varieties with heat tolerance are needed because of hot winds in April. Average wheat yield in this sub-zone is 1.3 t/ha, which includes 1.7 t/ha for irrigated and 0.7 t/ha for rainfed land.

Zones 9 and 10: Gujrat and Rawalpindi—This zone covers 503,000 ha and is located in parts of Rawalpindi, Sialkot, Mianwali and Gujrat Districts. These are the higher rainfall barani production areas with 500 to 1,000 mm of annual rainfall. Wheat is the main winter crop and 70% is grown in association with brassica, which is taken off the field as fodder in January and February to feed livestock. Summer crops are maize, millets, sorghum, and pulses for fodder and grain purposes. Frost frequently occurs and can affect short-season varieties that are planted early. When rainfall is adequate yields in this zone can exceed those in irrigated areas if farmers use moderate levels of N and P along with recommended varieties. Soil compaction occurs in some areas but deep moldboard plowing is a suitable solution to this problem. Wheat is often grown following fallow and late planting is usually not a problem. Soil moisture at time of planting can be limited and cause problems in stand establishment. Seed must be drilled to get good stands; planting depth should be at least 10 cm to find moisture. There is a need for varieties that can emerge from deeper planting. Erosion is also a problem. Zero or minimum tillage systems may be important innovations in the future, both for soil management (minimize reformation of compacted soil layer), conservation (erosion control), and reducing production costs (much lower land preparation costs). Leaf and stripe rust can be serious. Flag smut and dryland root rot can also be problematic. Average yields in zones 9 and 10 are 1.1 and 1.4 t/ha, respectively, considerably below the national average. With increased and well-focused research, substantial yield gains are possible in the near term.

Zone 11: Talagang—This zone covers 234,000 ha and is located in the Bannu, Jhelum, Mianwali, Kohat, Attock, and Karak Districts. It is the semiarid area of the Pothowar uplands and is south of zone 10. Soils are mostly loams with a sandy texture. Annual rainfall is in the 300-500 mm range and crop failure can occur. Irrigation is available in pockets. Cattle production and grazing are important. Some wheat and gram are grown during winter. Little research has been done in this area. Poor plant stand and root rot are problems. Yields are very dependent on rainfall and residual moisture present in soil. Average wheat yield is slightly less than 1.0 t/ha, about half the national average. Although wheat production is risky, increased research attention could substantially improve wheat yields and their dependability.

Zone 12: Murree-Swat—This zone covers 281,000 ha and comprises the Swat, Mansehra, Abbottabad, and Malakand Districts. Sub-humid and humid highlands ranging from 1,000 to 1,500 m in elevation and with 500 to 1,400 mm of rainfall. The summer is mild and the winter cold. Fodder for livestock is very important. Some wheat is grown in winter after summer maize; a very long growing season is required in these areas. The zone is similar to Zones 9 & 10 with less chance of failures due to moisture inadequacies. Phosphorus is very important for balanced fertilization. Weeds are a problem because of higher rainfall. Little wheat research or extension work is done in the zone. Early-maturing varieties with cold tolerance are needed. Leaf and stripe rust and powdery mildew resistance are also required. Wheat yields can be very good, although very low rates of fertilizer generally constrain yields. The average wheat yield is reported to be 1.0 t/ha. The yields of wheat grown in the lower elevations are at least twice the reported average.

Zone 13: Chitral—This is a semi-arid, high-elevation area with 150-250 mm of rainfall. Wheat is grown where irrigation is available from glacial melt. The wheat growing season is long, beginning in October with harvest in June. (Wheat is also grown as a summer crop in a limited part of the area.) There is a need for facultative winter-wheat types or cold-tolerant, early-maturing spring types. Stripe and leaf rust can be serious. Common bunt can also be a problem on the local varieties. Fodder is very important and wheat bhusa (straw) is highly valued as an animal feed. Farmers use organic manure for the most part, although chemical fertilizer is now being adopted. Limited wheat is currently grown in the zone. The long growing season should produce good wheat yields with proper management. Little research is done on wheat.

Zone 14: Quetta-Lorelai—This zone is mountainous with isolated valleys. Moisture ranges from 350 to 400 mm. Wheat is frequently grown under torrent flood conditions; as in Zone 8, this affects fertility and dates of planting. Most farmers still grow tall, local varieties. There is a need for cold-tolerant materials. Fodder production for animals is important. Stripe rust and bunt are major wheat diseases. Some areas have kareze underground irrigation systems; fruit, vegetables and fodder are usually grown on these lands. Erratic rainfall can cause crop failure.

Zone 15: Makran-Jhalawan—This is a huge plateau and an adjacent hilly area in southern Baluchistan lying between 500 and 1,000 m elevation. Rainfall is between 50 and 300 mm and soils are primarily calcareous loams. The zone is used mostly for livestock grazing. Some areas use torrent flood, riverain agriculture and some area have kareze underground, oasis-type irrigation where wheat can be grown; but results are erratic. In kareze areas, wheat is grown under date palms. Wheat is not an important crop except to meet home consumption needs.

Zones 16 & 17: Tharparkar and Cholistan desert—Arid area, with sand ridges and little rainfall. Little wheat is grown (2000 ha irrigated). Tharparkar is mainly a cattle-raising zone with 200 to 300 mm of rainfall. In Cholistan, seasonal grazing also occurs.

Maintaining Growth in Wheat Production

For no other crop in Pakistan are the issues of research and extension more important than wheat. Pakistan's wheat research system is the nation's largest, oldest and best-developed crop research program. It is arguably the most successful. Expenditures on wheat research and extension have paid handsome dividends over the years. Nagy (1984) calculated that between 1965 and 1981, the internal rate of return to investments in wheat research and extension was 64%. Pray (1983) has argued that this rate of return would have been even greater had there not been under-investments in the overall wheat research and extension infrastructure which weakened the linkages between agricultural education, research, extension, and seed supply organizations.

While investments in wheat research and extension during the past 25 years have paid high returns, what about the future? Can the growth in wheat production experienced in the past be maintained? Will the country maintain self-sufficiency? Will it join the handful of countries that are wheat exporters?

Estimates of Future Wheat Demand

Future estimates of wheat supply and demand were recently calculated in the IFPRI wheat study done by Hamid et al. (1987). The study predicts a future for the wheat economy in which demand—driven by rapid urban growth—increasingly outpaces supply. The study estimates potential wheat deficits ranging from 1 and 6 million tons by the year 1999/2000, depending on the scenarios used.

IFPRI's demand projections appear to be on the high side due to overestimated population growth rates, while the supply projections are probably on the low side. An average net supply level of 10.8 million tons for 1983/84 and 1984/85 was used to establish the base number on current supply potential for Pakistan. Since yields during these two years were below the trend line, the supply projections in the IFPRI study are, in our view, overly pessimistic.

Using the low, medium, and high demand projections of the IFPRI wheat study—and a 13 million-ton annual wheat production level that appears to be a more realistic estimate of the wheat economy's current production potential—the annual growth rates in production necessary for Pakistan to achieve self-sufficiency in wheat by the year 2000 are somewhere between 3.2. and 4.7% (Table 30).

Table 30. Estimates of Consumer Wheat Demand to the Year 2000 and Production Requirements To Maintain Supply Self-Sufficiency

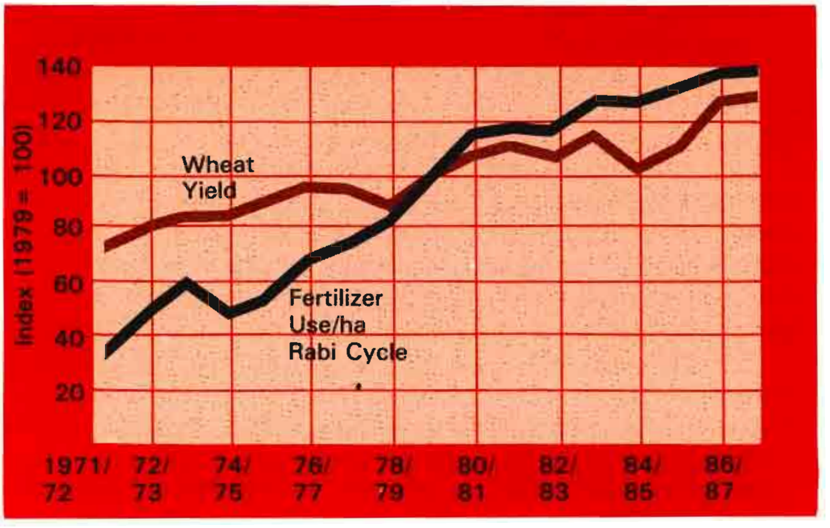
	Low	1999/2000 Medium	High
		million tons (mt)	
Projected Consumer Demand[1]	17.7	19.1	21.3
Required Increase in Supply[2]	6.7	8.2	10.7
Annual Rate of Growth Required in Supply, %	3.2	3.8	4.7

1 From Hamid et al., 1987
2 Current supply = 13 million tons minus 10% for seed, feed and waste = 11.7 million tons net supply available for human consumption

Future growth in wheat production will depend—even more than in the past—on obtaining higher yield levels on lands currently in production and, in all likelihood, under greater agroecological stresses. An apparent tapering off in the growth of wheat yields has raised the question of whether production growth will keep pace with demand (Figure 13). The needed gains in yield will come from more efficient use of available HYVs and other production inputs within ever-more complex farming systems. To achieve these gains, the Pakistani wheat farmer must become more knowledgeable and capable of managing more costly input systems. In addition, wheat producers will have to contend with losses of farmland to urban uses, and serious problems of environmental degradation reducing the productivity of the nation's farmland. While plant genetics may be able to further increase the tolerance of wheat to salinity, such soil and water problems are basically engineering issues which require improved drainage and land amendment solutions for their amelioration.

The Production Challenges Ahead

Wheat production in Pakistan has clearly moved into a ''post-Green Revolution'' phase (Byerlee, 1987). Improved varieties have come to occupy more than 90% of the total wheat area and nearly all farmers apply fertilizer, with the national average total dosage on wheat above 90 kg/ha of total nutrients. Irrigation



Source: Byerlee et al., 1986

Figure 13. Indices of Wheat Yield and Fertilizer Use/ha,

development—canal based systems and tubewells—has intensified crop production. Today, many of the irrigated wheat areas and some of the rainfed areas are double cropped annually.

Efforts to expand the irrigated area through new dams and additional tubewells are being countered by losses of existing agricultural lands to waterlogging and soil salinization/sodification. They have also led to compromises in wheat crop management, such as late planting, in order to accommodate other crops in the rotation. Waterlogging and salinity are unsolved problems that merit much more research and remedial action, including improved drainage systems in many areas.

Although 10% of the nation's wheat-producing areas still grow tall, traditional varieties, it is clear that yield gains from HYV introductions, per se, will no longer be a major production factor in the future. Furthermore, the initial growth in fertilizer use has slowed down, and is not likely to speed up again, since subsidies are being removed from fertilizer prices. There is, however, much scope for increasing yields through the development of better agronomic and crop management practices.

Maintaining the Gains Already Achieved

The most visible product of the wheat research system has been the improved semidwarf wheat varieties developed and extended to farmers during the last 25 years. This steady stream of HYVs has served to catalyze production. Plant breeding research must be kept active and dynamic. It is an axiom of experience in plant breeding that if you stop, you regress. The natural enemies of the wheat crop are themselves active and evolutionary. Rusts and other pathogens mutate, insects develop resistance to chemical control, and economic policies can affect the components of agricultural practices.

Pakistan's wheat breeding programs attempt to identify and develop cultivars with genetic protection against a broad spectrum of virulences and to build higher concentrations of genes for disease resistance. In the case of stem rust, resistance has held up worldwide for more than 25 years. Generally good progress has also been made with stripe rust, although the resistance life of a variety is much shorter. Resistance to leaf rust has been the most precarious character, despite the fact that the level of resistance was high in most Pakistani varieties when first released. Although the Pakistani wheat breeding programs have many materials with good leaf rust resistance, neither they nor anyone else in the world has been able to bring together in a single variety sufficiently large numbers of genes to provide stable and long-term protection. Most of the high-yielding varieties released over the past 25 years have succumbed to new races of leaf rust within three to four years after widespread commercial production. When leaf rust becomes endemic, it can cut average yields by 10 to 40% over large areas in a relatively short time.

Varietal Diversification

Though Pakistani research institutions have produced a continuing stream of improved wheat varieties, they have been slow in promoting the use of these new genotypes. Ways to speed up the adoption of recommended new varieties is an area requiring urgent attention by policymakers. Effective promotional programs are needed to inform farmers of new varieties and to educate them on the dangers of using disease susceptible varieties. At present, the system for varietal recommendations and replacement lacks sufficient authority to avert the occurrence of rust epidemics.

One possible model for promoting new varieties is the mini-pak seed program in India carried out by Ludhiana University. This program has been very successful in bringing about orderly changes of the wheat varieties in commercial use. It employs a system of field days organized jointly by the extension service and seed corporations and attended by thousands of farmers who are given small packets of seed (5 kg) of new varieties to take back to their villages for multiplication and sale to neighbors.

More effective seed marketing in Pakistan can be achieved through a program of market development research. Current profit margins for dealers, terms of wholesale seed sales, and dealer training in seed marketing are all issues requiring serious attention. Farm-level seed-use surveys conducted in the Punjab by the PARC/CIMMYT Collaborative Program indicate that extension education about the advantages of new varieties and the dangers of old ones must be substantially improved (Heisey et al., 1987). While seemingly a small matter, it appears that the tendency to repeat the names of varieties and differentiate only by year of release (e.g., Chenab-70, Chenab-79, Faisalabad-83, Faisalabad-85) adds confusion for the farmer about what variety he is actually growing. Wheat breeding and variety release organizations could help to improve variety recognition by assigning clearly identifiable names to new releases.

A dynamic varietal diffusion program not only protects against disease epidemics but also maintains growth in national wheat yields. On-farm varietal experiments have consistently shown the 20% yield advantage of Pak-81 over older varieties still in commercial use. And yet, it has taken five years since commercial release for Pak-81 to be grown on a significant area. Such increases in yield potential must be capitalized on more quickly and extensively.

Before leaving the discussion of disease problems in wheat two final comments need to be made. Most of the recent new semidwarf wheat varieties released in Pakistan are based on spring x winter crosses from CIMMYT, the majority of which carry the same 1B/1R translocation in their genetic make-up (Pak 81, Sarhad 82, Kohinoor 83, Pirsabak 85, Punjab 85, Faisalabad 85, and Chakwal 86). This translocation is at least partially responsible for the rust resistance of these varieties. There is concern among national as well as international wheat scientists that if the rust resistance conferred by 1B/1R breaks down, all of the nation's best varieties could become susceptible.

Pakistani breeders are well aware of the need to diversify their germplasm sources and to reduce their dependence on genotypes with the 1B/1R chromosome translocation. The NCWP has gone on record as urging the provincial programs to develop and release replacement varieties without the 1B/1R chromosome translocation for the major production zones. There is apparently widespread agreement among breeders that this should be done.

Given the yield potential and pervasiveness of the varieties carrying this translocation in the Pakistan and CIMMYT breeding programs, more should also be learned about the sources of rust resistance in the 1B/1R genotypes. There is evidence that beneath the resistance conferred by 1B/1R there are other sources of rust resistance. However, these genes should be identified as soon as possible, so that any needed modifications in the crossing programs to diversify resistance sources can be made.

Replacements are still needed for the very popular short-season variety, Blue Silver/Sonalika, released in 1972 and now highly susceptible to leaf rust. This variety is still grown on approximately 10% of the rice/wheat area and 22% of the cotton/wheat area. Not only does it have the early-maturing characteristic sought by farmers in short-season production areas, but it also has a bold white grain type that is excellent for chappatis. While a number of new lines been developed (e.g. Faisalabad-83) with the same maturity as Blue Silver/Sonalika and with resistance to the prevailing races of rust pathogens, these have yet to gain a foothold in commercial production.

A more efficient system of varietal development and introduction would raise national wheat yields, especially in the intensively cropped irrigated zones requiring shorter maturity and heat-tolerant varieties, and in the lower-moisture barani areas requiring drought-tolerant varieties. (Heisey et al., 1989).

Crop Management Research

Despite continuing opportunities for yield impact through specific varietal development work, most of the yield gains in Pakistani wheat production will come through the development and transfer of improved crop management practices. Many of the constraints to increased wheat production in Pakistan are the result of "management" conflicts and compromises with other crops and agricultural enterprises in the farming system.

The expansion of irrigation, especially farmer-managed tubewell systems, has markedly increased cropping intensity in Pakistani agriculture and clearly affected wheat yields adversely. In both the cotton/wheat and basmati rice/wheat zones (accounting for more than 3.5 million ha), farmers give preference in their crop management decisions to their higher valued cotton and basmati rice, harvesting these crops late to achieve maximum yield The widespread commercial use of the shorter-season, high-yielding cotton variety, NIAB 78, and the recent release of a shorter-season high-yielding basmati rice variety, Basmati 385, are important developments for correcting late-planting practices in wheat.

There are substantial gains to be made through an active crop management research and extension program to improve wheat productivity in rainfed areas. Traditionally, rainfed (barani) production areas have been neglected in favor of the dominant irrigated agroecological zones. Pictured here are Dr. Peter Hobbs, CIMMYT resident advisor, and Mr. A. Razzaq, an NARC agronomist, harvesting an on-farm agronomic trial in a barani area of NWFP.

The work on zero-tillage/direct seeding appears to offer many advantages for overcoming the yield reductions caused by late planting in the rice/wheat areas. It offers the potential of considerable cost-savings for the farmer by eliminating the intensive land preparation practices needed in the rice/wheat areas. Possible drawbacks of zero-tillage need to be determined by researchers as well. (Byerlee et al., 1984). The longer-term effects of zero-till planting on soil structure, on control of the rice stem borer, and on weed populations are all researchable issues. Given the potential productivity gains to be made through zero-till, research on this topic should be given high priority. (Aslam et al., 1989).

In the cotton/wheat rotation—the dominant cropping system in Pakistan—the prospects for significant near-term increases in productivity are not as encouraging. The spread in the use of the earlier-maturing cotton variety, NIAB-78, has allowed for somewhat more timely planting of wheat than before. However, part of this gain has been cancelled by greater pesticide use on the cotton, delaying harvest. Additional ways to shorten the turnaround time between cotton harvest and wheat planting are still needed; zero/minimum tillage systems and direct drilling of seed are promising technologies for overcoming this constraint. (Byerlee et al., 1987a).

There are also substantial yield gains to be made through an active research and extension program in barani areas, employing an on-farm research methodology with a farming systems perspective. Barani production areas have historically been neglected by the research establishment, which has focused its attention on the dominant irrigated agroecological zones. In fact, there has sometimes been an explicit down-playing of the appropriateness of HYV technology in these risky environments, despite the spread of such technology there.

NARC and BARI are well-situated to carry out expanded on-farm research programs on barani lands. Breeding work needs to focus on developing varieties for earlier planting using residual monsoon moisture; such varieties require longer coleoptile length and vigor for deeper seeding. More appropriate varieties in combination with improvements in land preparation (deep plowing), fertilizer management (especially P use) and moisture conservation are needed. Effective input delivery systems (especially for seed and fertilizers) in which the private sector plays a greater role will be crucial to getting improved technology to the farmer.

Research Organization

Because of the intensity of Pakistan's farming systems, future efforts to develop recommendations for the major wheat-based systems will depend upon the development of crop management research programs involving various disciplines (biological and social science). Problems associated with land preparation, stand establishment, water/moisture management, weed and insect control, fertilizer management, and labor-use efficiency all require study. Furthermore, the longer-term effects of intensive production practices must be monitored and corrective actions identified. Finally, crop management research must be conducted with a farming systems perspective, e.g., with a view from the farmers' fields (Byerlee et al., 1986). Thus crop management research on wheat production must also take into account the other enterprises involved in the system.

In recent years, much has been said about the farming systems perspective and how related research should be organized. While there are many interpretations of what farming systems research should entail, there is general agreement that this research concept can help scientists to visualize the complex interactions (biological, physical and socioeconomic) among the components of a farming system. However, a program of on-farm research requires mobility, operational funds for fuel, inputs and travel-related costs of staff, and organizational incentives for research staff to engage in such work. Too often vehicles and operational funds are not available, and program heads and station based directors and staff frown upon the extended absences of on-farm researchers from the experiment station.

Reaching the Farmer with Improved Technology

Inefficiency in Pakistani wheat production—the difference between farmers' production levels and economic yield potentials—currently ranges from 30 to 50% (Byerlee et al., 1986). To overcome this problem, farmers must be better informed. The current low literacy rates greatly complicate extension education efforts.

Reaching the farmer with improved wheat technology in today's post-Green Revolution era presents new challenges. Researchers and extension agents must learn to combine the insights that farmers have about their production environments with new technologies. The short- and long-term effects of increased cropping intensity and the rapidly changing technical and economic environment for wheat production will continue to add further complexity to farm management (Byerlee, 1987b)

Increased emphasis on adaptive, farmer-oriented research with a farming systems perspective, and reforms in extension and rural education represent the beginnings of needed institutional developments for maintaining productivity growth in Pakistan's post-Green Revolution wheat economy. The appropriate institutional arrangements to accommodate these changes are still evolving, and are made more difficult to achieve by the

Considerable mechanization has occurred in Pakistani wheat production during the past two decades. Today, virtually all farmers use tractors for land preparation and threshers for grain harvesting. New forms of mechanization are anticipated in the future, including seed drills and combine harvesters, as wheat production systems continue to be modernized.

bureaucratic divisions between research organizations, research and extension, and by the lack of communication between the public and private sectors.

More Effective Input Supply Systems—The achievement of higher and sustainable productivity levels in wheat, however, will depend on more than well-focused wheat research and extension programs. The availability of the right kinds and amounts of inputs—seed, fertilizers, pesticides—is indispensable if farmers are to increase the productivity of their resources.

Provincial research organizations charged with producing breeder and pre-basic seed must ensure that sufficient quantities of quality seed of the right varieties are provided to seed producers in a timely way. Effective seed production systems must also be integrated with effective seed distribution systems so that variety diversification and replacement are unhampared. (Chaudhry and Heisey, 1988). Efforts to develop a mixed public-private sector national seed industry are also under way (ICD, 1987).

Improvements in the fertilizer-production sector can also increase the productivity of resources devoted to wheat. Pakistan is self-sufficient in nitrogen production but still relies primarily on imports for phosphorus, potassium and other nutrients. The range of nutrients required to sustain higher-yielding wheat production continues to grow. At current levels of nitrogen use, phosphorus has become a limiting plant nutrient. With the shift away from ammonium sulfate and single superphosphate to higher analysis formulas which no longer contain sulfur, this nutrient will likely become a more serious production constraint in the future. In the double-cropped wheat lands, deficiencies of other secondary and minor elements can also be expected to increase. Changing soil fertility requirements in wheat production signal the need for a more sophisticated fertilizer sector capable of supplying the right kinds and amounts of fertilizer products.

Increased Role for the Private Sector—In the past, most private agribusiness activity in Pakistan has concentrated on farm machinery and irrigation equipment supply, involving both nationally manufactured and imported equipment. Pakistan's private sector agribusiness base is now expanding, with encouragement from the government. There has be a marked rise in the number of private contractors engaged in mechanized land preparation and harvesting operations. One example is the growth since 1985 in the number of private organizations engaged in contract harvesting operations using large, self-propelled combines. Increased private sector activity in the production and/or distribution of fertilizers and farm chemicals is also occurring. These agribusinesses are also providing technical advice on crop management.

Growth in private sector agribusiness can be a very positive force for development in Pakistan. It can lead to a much higher level of investment in agricultural development than would be possible through the public sector alone. Furthermore, greater private sector activity would add critically important management capabilities in the adaptive research and technology transfer phases.

While an important component of the modernization of Pakistan's wheat economy, the private sector is not likely to be a major force in wheat varietal improvement in the foreseeable future. However, in other areas of wheat industry development, especially farm machinery research, agronomic research, seed marketing, extension and communications, considerable potential exists for private sector involvement. There is much scope for innovative collaboration between public and private researchers in the future and the private sector will complement the public sector in many activities, thus strengthening the overall development of the wheat sector of Pakistan.

Data Tables: Wheat Production, Area, Yield, HYV Adoption, Trade

Table 1. Wheat Production in Pakistan, by Province, 1964-65 to 1985-86 ('000 t)

Crop year	Province				
	Punjab	Sind	NWFP	Baluchistan	Pakistan
1964-65	3,570	553	367	101	4,591
1965-66	2,978	542	309	87	3,917
1966-67	3,399	560	288	87	4,334
1967-68	5,046	845	395	132	6,418
1968-69	5,268	859	387	104	6,618
1969-70	5,641	1,139	381	133	7,294
1970-71	4,948	1,121	331	76	6,476
1971-72	5,291	1,081	440	77	6,890
1972-73	5,694	1,096	584	69	7,442
1973-74	5,665	1,246	607	111	7,629
1974-75	5,786	1,144	613	131	7,674
1975-76	6,572	1,321	660	138	8,691
1976-77	6,808	1,479	712	146	9,144
1977-78	6,090	1,427	689	161	8,367
1978-79	7,324	1,680	738	209	9,950
1979-80	7,914	1,849	863	231	10,857
1980-81	8,350	1,946	939	238	11,473
1981-82	7,962	2,062	962	318	11,304
1982-83	8,935	2,067	998	414	12,414
1983-84	7,623	1,946	860	454	10,882
1984-85	8,315	2,079	872	437	11,703
1985-86	10,432	2,172	907	413	13,923

Sources: Agricultural Statistics of Pakistan (1985;1986); Stastistical Bulletin on Wheat in Pakistan (1983)

Table 2. Wheat Area in Pakistan, by Province, 1964-65 to 1985-86 ('000 ha)

Crop year	Province				
	Punjab	Sind	NWFP	Baluchistan	Pakistan
1964-65	3,788	722	625	182	5,318
1965-66	3,685	683	586	202	5,154
1966-67	3,870	735	580	159	5,344
1967-68	4,292	846	612	233	5,983
1968-69	4,552	826	607	174	6,160
1969-70	4,477	939	626	188	6,230
1970-71	4,390	837	590	161	5,978
1971-72	4,225	780	593	195	5,797
1972-73	4,367	771	684	150	5,971
1973-74	4,413	840	692	167	6,113
1974-75	4,216	756	695	146	5,813
1975-76	4,472	797	707	135	6,111
1976-77	4,598	927	716	148	6,390
1977-78	4,601	906	696	157	6,360
1978-79	4,806	1,009	705	168	6,687
1979-80	4,952	1,027	758	188	6,924
1980-81	4,978	1,030	789	185	6,982
1981-82	5,054	1,026	813	216	7,110
1982-83	5,167	1,009	825	280	7,398
1983-84	5,248	1,011	794	291	7,343
1984-85	5,166	1,030	786	277	7,259
1985-86	5,343	1,031	782	248	7,403

Sources: Agricultural Statistics of Pakistan (1985;1986); Stastistical Bulletin on Wheat in Pakistan (1983)

Table 3. Wheat Yield in Pakistan, by Province, 1964-65 to 1985-86, kg/ha

Crop year	Province Punjab	Sind	NWFP	Baluchistan	Pakistan
1964-65	941	766	590	553	830
1965-66	802	793	526	434	756
1966-67	876	766	498	553	812
1967-68	1,171	996	646	563	1,070
1968-69	1,153	1,042	636	590	1,070
1969-70	1,254	1,208	609	710	1,171
1970-71	1,125	1,337	563	470	1,079
1971-72	1,254	1,383	738	406	1,190
1972-73	1,300	1,420	858	452	1,245
1973-74	1,282	1,485	876	664	1,245
1974-75	1,374	1,513	885	904	1,319
1975-76	1,467	1,568	932	1,204	1,420
1976-77	1,481	1,595	993	986	1,431
1977-78	1,324	1,575	990	1,029	1,316
1978-79	1,524	1,666	1,046	1,244	1,488
1979-80	1,598	1,802	1,139	1,229	1,568
1980-81	1,677	1,889	1,191	1,284	1,643
1981-82	1,541	2,009	1,183	1,472	1,568
1982-83	1,691	2,049	1,211	1,481	1,678
1983-84	1,452	1,925	1,083	1,560	1,482
1984-85	1,610	2,019	1,110	1,576	1,612
1985-86	1,953	2,107	1,160	1,672	1,881

Sources: Agricultural Statistics of Pakistan (1985;1986); Stastistical Bulletin on Wheat in Pakistan (1983)

Table 4. Irrigated Wheat Area in Pakistan, by Province, 1969-70 to 1985-86 ('000 ha)

Crop year	Province Punjab	Sind	NWFP	Baluchistan	Pakistan
1969-70	3,340	790	225	123	4,478
1970-71	3,380	707	230	89	4,406
1971-72	3,327	661	265	94	4,347
1972-73	3,455	651	274	82	4,462
1973-74	3,454	685	294	87	4,521
1974-75	3,356	733	277	91	4,457
1975-76	3,558	677	285	75	4,593
1976-77	3,682	782	284	64	4,811
1977-78	3,721	809	278	73	4,881
1978-79	3,914	906	286	94	5,200
1979-80	4,063	983	249	111	5,455
1980-81	4,061	988	304	112	5,466
1981-82	4,252	984	305	157	5,699
1982-83	4,322	970	307	161	5,760
1983-84	4,369	972	293	169	5,795
1984-85	4,303	990	304	167	5,765
1985-86	4,495	991	305	172	5,962

Source: Agricultural Statistics of Pakistan (1985; 1986); Statistical Bulletin on Wheat in Pakistan (1983)

Table 5. Rainfed Wheat Area in Pakistan, by Province, 1969-70 to 1985-86 ('000 ha)

Crop year	Province Punjab	Sind	NWFP	Baluchistan	Pakistan
1969-70	1,136	144	401	65	1,752
1970-71	1,009	130	360	72	1,571
1971-72	902	119	329	101	1,450
1972-73	911	120	410	67	1,509
1973-74	959	155	398	81	1,592
1974-75	860	22	418	55	1,356
1975-76	914	121	422	60	1,517
1976-77	916	145	433	85	1,579
1977-78	881	97	417	84	1,479
1978-79	892	103	418	74	1,487
1979-80	889	44	459	76	1,469
1980-81	917	42	485	73	1,517
1981-82	915	42	508	59	1,524
1982-83	963	38	518	119	1,638
1983-84	888	38	501	121	1,549
1984-85	862	40	481	110	1,494
1985-86	849	40	477	76	1,441

Sources. Agricultural Statistics of Pakistan (1985;1986); Stastistical Bulletin on Wheat in Pakistan (1983)

Table 6. Irrigated Wheat Yields in Pakistan, by Province, 1969-70 to 1985-86, kg/ha

Crop year	Province Punjab	Sind	NWFP	Baluchistan	Pakistan
1969-70	1,537	1,303	1,000	710	1,427
1970-71	1,357	1,454	789	717	1,330
1971-72	1,470	1,499	1,140	618	1,435
1972-73	1,522	1,532	1,221	689	1,489
1973-74	1,504	1,626	1,293	781	1,495
1974-75	1,578	1,535	1,312	1,178	1,547
1975-76	1,687	1,686	1,403	1,443	1,665
1976-77	1,705	1,719	1,439	1,645	1,691
1977-78	1,490	1,640	1,373	1,601	1,510
1978-79	1,679	1,741	1,425	1,807	1,678
1979-80	1,746	1,838	1,606	1,713	1,754
1980-81	1,839	1,925	1,731	1,766	1,847
1981-82	1,698	2,050	1,731	1,809	1,764
1982-83	1,849	2,088	1,760	1,901	1,886
1983-84	1,588	1,966	1,698	2,031	1,670
1984-85	1,775	2,059	1,725	2,022	1,828
1985-86	2,111	2,150	1,758	2,056	2,098

Sources: Agricultural Statistics of Pakistan (1985;1986); Stastistical Bulletin on Wheat in Pakistan (1983)

Table 7. Rainfed Wheat Yields in Pakistan, by Province, 1969-70 to 1985-86, kg/ha

Crop year	Province				
	Punjab	Sind	NWFP	Baluchistan	Pakistan
1969-70	448	735	390	—	462
1970-71	358	712	416	173	392
1971-72	445	761	420	170	448
1972-73	478	883	610	170	528
1973-74	488	847	669	539	546
1974-75	568	821	599	446	577
1975-76	675	916	605	501	642
1976-77	857	926	700	494	739
1977-78	621	1,030	734	536	675
1978-79	844	1,007	788	535	824
1979-80	924	989	834	537	877
1980-81	959	1,046	854	544	908
1981-82	812	1,045	855	569	823
1982-83	980	1,031	881	913	945
1983-84	789	896	724	904	780
1984-85	787	1,025	721	897	780
1985-86	1,114	1,050	777	780	983

Sources: Agricultural Statistics of Pakistan (1985;1986); Stastistical Bulletin on Wheat in Pakistan (1983)

Table 8. Percent Adoption of High-Yielding Semidwarf Wheat Varieties, by Province, 1964-65 to 1985-86

Crop year	Province				
	Punjab	Sind	NWFP	Baluchistan	Pakistan
1964-65	0	0	0	0	0
1965-66	0	0	0	0	0
1966-67	1	1	0	0	1
1967-68	26	24	10	2	20
1968-69	42	35	19	22	38
1969-70	47	46	22	7	43
1970-71	53	62	36	16	52
1971-72	58	68	47	14	57
1972-73	58	68	45	10	57
1973-74	59	67	44	9	57
1974-75	65	82	49	15	57
1975-76	67	71	61	23	66
1976-77	75	77	59	18	72
1977-78	75	85	62	18	74
1978-79	77	87	65	39	76
1979-80	83	88	64	39	81
1980-81	83	91	67	42	82
1981-82	85	96	65	62	84
1982-83	89	96	68	45	86
1983-84	92	96	69	56	88
1984-85	93	96	70	66	90
1985-86	94	96	70	71	91

Sources: Agricultural Statistics of Pakistan (1985;1986); Stastistical Bulletin on Wheat in Pakistan (1983)

Table 9. Wheat Imports and Exports of Pakistan, 1964 to 1986 (t)

	Imports	Exports	Net
1964	806,566	7,061	853,505
1965	1,590,560	18,901	1,571,659
1966	756,136	8,130	748,006
1967	1,165,209	35,617	1,129,592
1968	1,441,636	456	1,441,180
1969	16,479	108,339	91,866
1970	228,916	107,010	121,951
1971	322,211	11,000	311,211
1972	717,852	20	717,832
1973	1,369,308	2	1,369,306
1974	1,232,949	0	1,232,949
1975	1,344,735	0	1,344,735
1976	1,186,207	0	1,186,207
1977	497,778	261	497,517
1978	1,051,628	2,222	1,049,406
1979	2,236,564	0	2,236,564
1980	604,405	0	604,405
1981	304,850	0	304,850
1982	361,182	5	361,177
1983	396,012	99,081	296,931
1984	290,775	219,475	71,300
1985	982,030	47,707	934,323
1986	1,909,198	0	1,909,198
1987	377,788	0	377,788

Source: FAO Trade Yearbook Data Tapes

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