Chapter 2

The International Wheat Improvement System and Wheat Breeding Research Investments

This chapter outlines the structure of the international wheat breeding system and presents information about current levels of wheat improvement investment in both CIMMYT and NARSs. Public sector research, of which the CIMMYT-NARS system is an extremely significant component, has been particularly important for wheat technology development worldwide, although private sector investment rose rapidly in Europe and other parts of the industrialized world in the last third of the 20th century. Investments in wheat improvement research in developing countries rose rapidly in real terms from the inception of the Green Revolution in the mid-1960s, but became mixed and fragmentary from the mid-1980s. Real resources invested in CIMMYT's wheat research program fell from that time. Some evidence suggests that NARS research investments have also decreased, but data are fragmentary, and in large producers such as China or India this may not have been the case. Our limited data indicate that the number of scientists involved in wheat improvement research in the 1990s increased in China, much of the WANA region, and in Brazil and Argentina.

Evolution of the International Wheat Breeding System

Geographical movement of wheat germplasm is not new. Like other domesticated crops, wheat spread from its ancient zones of origin in Mesopotamia at the dawn of agriculture. Wheat was cultivated in many parts of Eurasia and North Africa by 3000 B.C. and reached China by the second millennium B.C. (Harlan 1987). More recent diffusion of wheat can be described as "colonial" wheat germplasm flows, which began about 1500 A.D. (Smale and McBride 1996).

Modern scientific plant breeding can trace its development to cereal hybridization or planned cross-breeding which began in England in the 1790s and continued there through the work of Sherriff in the mid-19th century. The last decades of the 19th century were marked by greater interest in both cross-breeding and better methods of selection in Europe, North America, and Australia. Wheat improvement began to take the form of crossing locally adapted material with wheat from other areas to improve production characteristics or quality (Lupton 1987).

The rediscovery of Mendel's laws of heredity at the turn of the 20th century led to renewed interest in using genetics to improve crops. New approaches were developed to define the objectives of plant breeding, develop selection methodology, and choose parents for hybridization. Many scientists and statisticians who were involved in developing these methods were motivated by the desire to solve practical problems in plant breeding. Mendelian theory helped to make sense of successes and failures of practical breeding, to suggest new solutions to old problems, and to create new problems to be solved (Paul and Kimmelman 1988; Sprague 1975).

The advent of scientific plant breeding in areas of the world characterized as "developing" probably began in India in the first decade of the 20th century (Jain and Byerlee 1999). Research stations were founded with the aim of wheat improvement in Turkey in the 1920s and the 1930s, and planned crosses were made in Argentina and Brazil in the 1930s. Although some crossing was done in China as early as the 1920s, it was not until the 1950s that planned crossing began to replace selection from landraces as the primary means of wheat improvement. Introduction of foreign germplasm into China also became more prominent in the 1950s (Dalrymple 1986; Smale and McBride 1996; Yang and Smale 1996; He and Rajaram 1997).

In the developing world, the evolution of the modern system of wheat improvement has often been linked to the "Green Revolution" in wheat. The Green Revolution had its origins in the transfer of semidwarf wheat varieties developed by the Rockefeller Foundation research program in Mexico to India and Pakistan. This initial transfer was followed by the establishment of CIMMYT in Mexico in 1966 as successor to the Rockefeller Foundation program. Countries that already had wheat improvement programs reorganized and expanded them, and countries without wheat research programs began to develop them. The pace of interchange of wheat germplasm between NARSs and CIMMYT and among NARSs accelerated. International nursery activity became prominent, and visits of wheat scientists to CIMMYT and other countries also grew rapidly. The development and functioning of the international wheat improvement system is described and analyzed more comprehensively by Dalrymple (1986), Byerlee and Moya (1993), and Maredia and Byerlee (1999). Smale and McBride (1996), Skovmand et al. (1995), and Smale et al. (1996) document the flows of wheat germplasm within the global system.

In industrialized countries, wheat breeding has also remained within the public sector, especially in Australia, Canada, and the United States (U.S.), as well as in the countries of Eastern Europe and in the former Soviet Union. As in developing countries, the public wheat breeding system developed with an emphasis on germplasm exchange among different research institutions (Kronstad 1996). Wheat germplasm flows also continued between industrialized and developing countries. This is in contrast to maize, where the development of hybrid varieties led to the protection of inbred line development, encouraged widespread private sector investment in maize breeding, and discouraged direct germplasm exchanges among distinct breeding programs. In the case of wheat, factors such as plant varietal protection, the role of wheat within the cropping system, and level of wheat yields affected incentives for private companies to invest in wheat breeding. Private sector wheat breeding was practiced in Europe from the early 20th century and accelerated in the mid-1960s. Today 70% or more of European wheat area is planted to private varieties. Private varieties are less common in the U.S., Canada, and Australia, but institutional developments such as research funding through farmer check-offs, or the strengthening of intellectual property rights in plant breeding, continue to influence the organization of wheat breeding in these countries (Heisey, Srinivasan, and Thirtle 2001).

In developing countries, private sector wheat breeding has a long history in the Southern Cone of South America, particularly in Argentina.

Outside of the Southern Cone, the only countries where private sector wheat breeding is important are South Africa and Zimbabwe.

In summary, the global wheat improvement system consists of both national and international public sector wheat improvement programs, as well as private sector firms. Historically, public sector programs have provided the majority of wheat varieties grown, although private sector breeding programs have become increasingly important in Europe and, to a more limited extent, in the U.S.

IARC and NARS Investments in Wheat Genetic Improvement

In this section, we describe CIMMYT's wheat research program and analyze investments made by international agricultural research centers (IARCs) and NARSs in wheat genetic improvement. International wheat improvement research is collaborative and depends on international testing by a network formed by CIMMYT and national research systems worldwide (Maredia and Byerlee 1999). In the WANA region, CIMMYT also collaborates with ICARDA on wheat genetic improvement.

EVOLUTION OF THE CIMMYT WHEAT BREEDING PROGRAM AND BREEDING OBJECTIVES[2]

Following its inception in the 1940s, CIMMYT and its predecessor organization, the Office of Special Studies, an agricultural research initiative by the Rockefeller Foundation and the Government of Mexico, initially focused breeding efforts on the development of semidwarf spring bread wheat varieties suitable for cultivation in irrigated areas. By the late 1960s, CIMMYT's breeding program began to address disease problems found in higher rainfall rainfed areas. In addition to spring bread wheat, by the end of the decade, CIMMYT also established spring durum wheat and triticale breeding programs.

During the 1970s, wheat breeding expanded in a number of directions: a program to inter-cross spring and winter wheat gene pools; a shuttle breeding program between CIMMYT and NARS in Brazil to develop aluminum-tolerant germplasm for acid soil areas; breeding for warmer environments; and greater emphasis on marginal rainfed environments of the WANA region following the establishment of the joint CIMMYT/ ICARDA program in 1979.

During the 1980s, CIMMYT wheat breeders concentrated on incorporating new traits such as resistance to Karnal bunt (*Tilletia indica*) and head scab (*Fusarium* spp.) into material targeted primarily at irrigated and high-rainfall environments. Resistance to barley yellow dwarf virus (BYDV) and to Russian wheat aphids, which were more important in drier areas, was also targeted. The head scab effort, which was based primarily on a shuttle breeding partnership between CIMMYT and China, exemplified many germplasm development projects that featured cooperation between CIMMYT and other research programs. The spring x winter crossing program came to fruition with the release of a number of materials, including the extremely successful "Veery" lines. In 1986, a winter wheat program targeting some 26 million hectares of winter wheat grown primarily in Turkey, Iran, Afghanistan, and China, was established in Turkey. This program also has close ties with Eastern European countries and the newly independent Central Asian countries.

When characterizing wheat-growing environments, it is important to distinguish between the time of planting and growth habit.

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[2] The following discussion of CIMMYT's wheat breeding condenses earlier information found in Byerlee and Moya (1993) and adds additional material to cover the 1990s.

Time of planting information helps in determining stresses that wheat plants are likely to face during the growing season (e.g. drought, heat, frost) and also provides clues about where wheat fits into the larger crop rotation picture. Information about growth habit is arguably more important, especially for plant breeders. Winter habit wheats ("winter wheats" for short) have a vernalization requirement. This means that they will flower only after young seedlings have been exposed to cold temperatures for a number of weeks during the vegetative growth phase. Vernalization delays the onset of booting and flowering until the danger of frost has receded. In cold environments, winter wheats are planted during the fall and harvested the following summer.

Spring habit wheats ("spring wheats" for short) do not have a vernalization requirement and do not need to be exposed to cold temperatures to flower. In high-latitude regions (e.g., Central Asia, Russia, northern China, Canada, northern U.S.), spring wheats are sown in the spring (after the cold period has passed) and harvested during the late summer. By contrast, in the low-latitude regions (< 35 N and S) in which much wheat is grown in the developing world, winters are relatively mild and summers excessively hot, so spring habit wheats are often sown during the fall and harvested the following spring to avoid summer heat stress.

Facultative wheats are intermediate in growth habit between winter wheats and spring wheats. They possess fewer of the dominant genes for vernalization than true spring wheats and require less vernalization. The growing areas for facultative wheats tend to overlap with spring and especially winter wheats.[3]

Throughout the 1980s, much success was achieved in more traditional areas of breeding. During the 1990s, more emphasis was given to abiotic and biotic stresses and better management practices for increasing yields in a sustainable manner. In other words, emphasis was placed on conserving the environment and raising yields at the same time. The CIMMYT Wheat Program provided germplasm to NARSs that was increasingly efficient in its use of nitrogen, phosphorus, and water. Drought tolerance research was increased, and new germplasm with various types of drought tolerance is now available. Other abiotic stresses such as heat and soil toxicities were also emphasized, and the selection criteria for tolerance to these stresses were improved. The 1990s saw the production of germplasm with expanded genotypic diversity and increased efforts in genetic resource management (Smale et al. 2001), which should contribute to maintaining that diversity.

The incorporation of leaf and yellow rust resistance into CIMMYT germplasm was enhanced by greater understanding of the genetic basis of durable types of resistance. Increased efforts were made in the search for and application of molecular markers for selection, especially for disease resistance and quality characteristics. Results with markers for resistance to BYDV have been very promising.

The search for increased yields intensified in the 1990s. Several approaches are being explored including F_1 hybrids, synthetic hexaploids, and architectural changes in the wheat plant. The best prospects for hybrid wheat appear to be in high-yielding environments or environments in which the seeding rate can be greatly reduced. Methods of improving seed set in female plants and greater knowledge of heterotic groupings in wheat could improve the economic feasibility of hybrids by lowering seed costs and increasing hybrid yield advantage, respectively (Jordaan 1996; Lucken 1987). Changes in the architecture of the wheat

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[3] Many countries do not distinguish clearly betwen winter and facultative wheat. For simplicity, throughout this report "winter wheat" denotes winter wheat and facultative wheat, except in cases where the two are specifically disaggregated.

plant based on developing a plant with robust stem, long head, multiple spikelets and florets, large leaf area, and broad leaves, have been achieved. Advances based on this plant type depend on increasing seed set abilities (Rajaram and Borlaug 1997). Architectural changes may in time be coupled with hybrid development, but it is too early to determine which approaches to increased wheat yield potential will result in the highest payoffs.

International cooperation increased during the 1990s, as NARS scientists participated in several formal consultations with CIMMYT to set strategic research priorities. Additionally, regional programs were strengthened in key areas such as Kazakhstan, the Caucasus, and China, where the CIMMYT Wheat Program now has offices. The Kazakhstan office focuses on wheat in the Central Asian Republics. These are traditional wheat producing areas with limited resources for wheat breeding in the post-Soviet era. This effort has resulted in increased research into wheat for higher latitudes. Winter wheat research also received greater emphasis.

The challenge for the future will be to focus on the needs of developing countries and provide germplasm and technology for sustainable wheat production. Funding issues related to support for food production and agricultural research in the new millennium will be as important as the science, as will negotiating an increasingly complex research environment with greater private sector participation. We will return to these issues in later chapters.

DEFINITION OF WHEAT BREEDING ENVIRONMENTS

The mid-1980s witnessed a revision of definitions of environments where CIMMYT targets its wheat germplasm. "Mega-environments" (MEs) were defined as "large, not necessarily contiguous areas having similar requirements for wheat, such as time to maturity, resistance to particular diseases, and tolerance to various abiotic stresses" (Rajaram, van Ginkel, and Fischer 1993; Byerlee and Moya 1993). Cropping systems requirements, consumer preferences, and volume of production may also have contributed to ME definitions (Pingali and Rajaram 1999). Mega-environments are useful for defining breeding objectives because each ME comprises millions of hectares that are relatively homogeneous for wheat production (Dubin and Rajaram 1996).

The most recent ME classifications are described in Table 2.1. The most notable change in the present classification (van Ginkel, Trethowan, and Çukadar 2000) compared with the original classification (Rajaram, van Ginkel, and Fischer 1993; Rajaram and van Ginkel 1996; Pingali and Rajaram 1999; Byerlee and Moya 1993; Maredia and Ward 1999) has been the re-classification of the hot, irrigated, low humidity environments (old ME 5B) into a sub-environment of ME 1.

Table 2.2 indicates the division of wheat areas in developing countries into MEs. The first six columns are based on findings from the present study, other secondary information, and the old CIMMYT wheat ME database. They cover wheat in all developing countries producing over 20,000 tons annually in 1997, including countries that did not respond to our survey. They do not, however, include countries of the former Soviet Union.

Spring habit wheat covers about three-quarters of all wheat area in the developing world; winter wheat types cover the remaining area. Most wheat (92% of total area) is bread wheat. Durum wheat is planted on about 8% of total wheat area. Irrigated spring bread wheat is by far the most extensive wheat growing environment in the developing world.

Byerlee and Moya (1993) estimated the proportion of wheat production coming from different environments. Generally speaking, the proportion of production from a given environment is higher than the proportion of area in irrigated and high rainfall environments (MEs 1, 2, 5, 7, 8, 10, and 11), and the proportion of production is lower than the proportion of area in low rainfall environments (MEs 4A, 4B, 4C, 6, 9, and 12).[4]

The greatest uncertainty regarding the classification of wheat area into MEs lies in the division of area between MEs 1, 5, and 4C in the Indian sub-continent. The estimates here are based on data collected for this study, the old ME database, and estimates of India's irrigated wheat area reported by the Fertilizer Association of India. It is clear that irrigated wheat area in India has expanded greatly over the last half century, but it is not clear whether non-irrigated areas have shrunk to the levels estimated by van Ginkel, Trethowan, and Çukadar (2000), or whether these unirrigated areas should be classified as ME 4C. A second major uncertainty is the degree to which wheat area in China, particularly winter wheat area, is irrigated. During the preparation of this report, there were no direct sources to answer this question, and indirect evidence and expert opinion allow widely varying estimates. At present,

Table 2.1. Classification of mega-environments used by the CIMMYT Wheat Program.

Mega-environment (ME)	Latitude (degrees)	Moisture regime[a]	Temperature regime[a]	Growth habit	Sown[b]	Major breeding objectives[c]	Representative locations / regions	Year breeding began at CIMMYT
SPRING WHEAT								
1 Irrigated, low rainfall	35°N-35°S	Low rainfall irrigated	Temperate	Spring	A	Resistance to lodging; durable resistance to SR, LR, YR; resistance to KB (many locations); resistance to PM in China; tolerance of saline soils (some locations); preferred grain color is white	Gangetic Valley (India); Indus Valley (Pakistan); Nile Valley (Egypt); parts of Zimbabwe; irrigated river valleys in parts of China (e.g. Chengdu); Yaqui Valley (Mexico)	1945[d]
			Hot			In addition to above objectives, heat tolerance	Kano (Nigeria); Wad Medani (Sudan)	
2 High rainfall	35°N-35°S	High rainfall	Temperate	Spring	A, S	Resistance to SR, YR, LR; resitance to ST; resistance to pre-harvest sprouting. In many locations, resistance to SC, BYD, bacteria, PM, and root disease complex. In many locations, tolerance to soil micronutrient imbalances; preferred grain color is mostly red	High rainfall locations in West Asia and North Africa; high rainfall locations in Southern Cone and Andean Highlands, South America; East and Central African highlands; Izmir (Turkey): Toluca (Mexico)	1972
3 High rainfall, acid soil	35°N-35°S	High rainfall	Temperate	Spring	A	As for ME2, plus tolerance to aluminum and manganese toxicity; phosphorus deficiency another major constraint; preferred grain color is mostly red	Passo Fundo, Brazil; some locations in Central Africa and in the Himalayas	1974

Source: Adapted from van Ginkel, Trethowan, and Çukadar (2000) and Byerlee and Moya (1993), who based their descriptions on Rajaram, van Ginkel, and Fischer (1993).

[a] Moisture and temperature regimes refer to conditions during the growing season. For rainfall just before and during the crop cycle, High: ≥ 500 mm.; Low: < 500 mm.

[b] A = autumn; S = spring.

[c] These are factors additional to yield and industrial quality. SR = stem rust; LR = leaf rust; YR = yellow (stripe) rust; KB (Karnal bunt); SC = Scab (*Fusarium* spp.); ST = *Septoria tritici*; PM = powdery mildew; BYD = barley yellow dwarf virus.

[d] Rockefeller Foundation-Government of Mexico wheat improvement program in Mexico, precursor to CIMMYT wheat program.

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[4] Two MEs do not fit this general classification scheme based on relative yields. One is ME 3, where acid soils have historically reduced yields below those in other high rainfall environments. The other is ME 6, where yields are relatively high in northeastern China, the area most represented here, but relatively low in dry, high latitude spring wheat areas in countries of the former Soviet Union (FSU), which are not included in the current study.

Table 2.1. (continued) Classification of mega-environments used by the CIMMYT Wheat Program.

Mega-environment (ME)	Latitude (degrees)	Moisture regime[a]	Temperature regime[a]	Growth habit	Sown[b]	Major breeding objectives[c]	Representative locations / regions	Year breeding began at CIMMYT
4 Low rainfall, drought environments								
4A Winter rain or Mediterranean-type drought (moisture available <400mm)	35°N-35°S	Low rainfall; post-flowering moisture stress	Temperate	Spring	A	Drought tolerance; resistance to YR, LR, SR, root rots, nematodes, and bunts. Heat stress or late frosts may both be problems	Aleppo, Syria; Settat, Morocco; Cape Prov., South Africa	1970
4B Winter drought or Southern Cone-type drought (<400 mm)	35°N-35°S	Low rainfall; pre-flowering moisture stress	Temperate	Spring	A	Drought tolerance; resistance to LR, YR, and SR; resistance to ST and SC. Resistance to pre-harvest sprouting, many locations	Marcos Juárez, Argentina	1970
4C Residual moisture after monsoon rains; Indian subcontinent type drought (<400 mm)	35°N-35°S	Low rainfall; continuous drought under receding moisture	Hot	Spring	A	Resistance to drought; resistance to heat in seedling stage	Dharwar, India	1980
5 Warm area environment (< 1000 masl.)	23°N-23°S	High humidity; irrigated or high rainfall	Hot (mean minimum temperature in coolest month >17°C	Spring	A	Heat tolerance; resistance to *Bipolaris sorokinana, Drechslera tritici-repentis*, LR; tolerance to pre-harvest sprouting	Pusa, Bihar, India; Joydebpur, Bangladesh; Chiangmai, Thailand; Encarnación, Paraguay; Poza Rica, Mexico	1981
6 High latitude environments								
6A High latitude environment[e] (> 400 mm)	>45°N or S	High rainfall	Temperate	Spring	S	Yield potential; industrial quality; Resistance to SC, *Drechslera tritici-repentis*, YR, LR, SR; tolerance to sprouting; Photoperiod sensitivity also a consideration.[e]	Harbin, Heilongjiang, China	1989
6B High latitude environment (< 400 mm)	>45°N or S	Semiarid	Temperate	Spring	S	Drought tolerance; medium-tall stature; photoperiod sensitivity	Astana, Kazakstan	1998
WINTER WHEAT								
7 Favorable, irrigated, moderately cold	>30°N or S	Irrigated	Moderate cold (0°-5° coldest month)	Facultative	A	Resistance to YR, LR, and PM; cold tolerance; rapid grain fill	Zhenzhou, Henan, China	1986
8 High rainfall, moderately cold	>30°N or S	High rainfall	Moderate cold (0°-5° coldest month)	Facultative	A	Resistance to YR, LR, PM, eyespot; cold tolerance	Temuco, Chile; Corvallis, Oregon, U.S.A.	1986
9 Semi-arid, moderately cold	>30°N or S[g]	Low rainfall	Moderate cold (0°-5° coldest month)	Facultative	A	Resistance to YR and bunts; cold tolerance, drought tolerance	Diyarbakir, Turkey; Vernon, Texas, U.S.A.	1986
10 Favorable, irrigated, severely cold	>35°N or S[g]	Irrigated	Severe cold (-10°-0° coldest month)	Winter	A	Resistance to YR, LR, PM; resistance to winterkill	Beijing, China	1986
11 High rainfall, severely cold	>35°N or S	High rainfall	Severe cold (-10°-0° coldest month)	Winter	A	Resistance to LR, YR, PM, eyespot	Odessa, Ukraine; Krasnodar, Russia	1986
12 Semi-arid, severely cold	>35°N or S[g]	Low rainfall	Severe cold (-10°-0° coldest month)	Winter	A	Resistance to bunts; drought tolerance; resistance to winterkill	Ankara, Turkey; Kansas, U.S.A.	1986

Source: Adapted from van Ginkel, Trethowan, and Çukadar (2000) and Byerlee and Moya (1993), who based their descriptions on Rajaram, van Ginkel, and Fischer (1993).

[e] Description refers primarily to this environment as found in northeastern China.

[f] These 18 m. ha. of high latitude spring wheat grown primarily in Kazakhstan and southern Siberia are not considered in the remainder of this report.

[g] A few areas south of these latitudes in mountainous areas of Iran or Afghanistan may be classified in these environments.

Table 2.2. Distribution of wheat area in developing countries by mega-environment, 1997 with a comparison to 1990.

	Area (million ha)			Percentage (%)			Area[a] (million ha) (van Ginkel, Trethowan, Cukadar 2000; Braun et al. 2001)	1990 percentage (Byerlee and Moya 1993)	
ME	**Bread**	**Durum**	**Total**	**Bread**	**Durum**	**Total**	**Bread**	**Bread**	**Durum**
Spring									
1	38.4	0.6	39.0	36.3	0.6	36.9	36	32.3	0.4
2	7.1	2.1	9.2	6.7	2.0	8.7	>8	7.6	2.4
3	1.5	0	1.5	1.4	0	1.4	<2	1.7	0
4A	5.9	4.0	9.9	5.6	3.8	9.4	6	5.5	4.8
4B	3.2	0.1	3.3	3.0	0.1	3.1	3	3.2	0
4C	6.8	0.1	6.9	6.4	0.1	6.5	2 - 3	4.4	1.5
5	3.8	0	3.8	3.6	0	3.6	9	7.1	0
6	4.9	0	4.9	4.6	0	4.6	20[b]	4.9	0
Subtotal spring	71.7	6.8	78.5	67.7	6.5	74.3	85-90	66.8	9.1
Facultative									
7	9.9	0	9.9	9.4	0	9.4	2.8	5.6[c]	0[c]
8	0.2	0	0.2	0.2	0	0.2	1.4		
9	3.4	0	3.4	3.2	0	3.2	5.3	4.5	1.2
Subtotal facultative	13.6	0	13.6	12.8	0	12.8	9.5	10.1	1.4
Winter									
10	3.1	0	3.1	2.9	0	2.9	1.5	6.6[d]	0.2[d]
11	3.6	0.1	3.7	3.4	0.1	3.5	-		
12	5.7	1.1	6.8	5.4	1.0	6.4	6.9	6.0	1.2
Subtotal winter	12.4	1.2	13.6	11.7	1.1	12.9	8.4	12.6	1.4
Subtotal Facultative / Winter	26.0	1.2	27.2	24.6	1.1	25.7	17.9[e]	22.7	1.4
Total	**97.7**	**8.0**	**105.7**	**92.3**	**7.7**	**100.0**		**89.5**	**10.5**

[a] Source: van Ginkel, Trethowan, and Cukadar (2000); H.-J.Braun et al.;.(2001).

[b] Includes countries in the former Soviet Union (FSU).

[c] Includes ME's 7 and 8.

[d] Includes ME's 10 and 11.

[e] Includes only the facultative and winter wheat areas in WANA, and Central Asian and Caucasus Republics.

geographic information systems (GIS) techniques are being applied to refine the definition of MEs using various criteria, particularly irrigation, precipitation, temperature, soil acidity, and elevation (White et al. 2001). A better understanding of the economic importance of wheat production in different MEs will result if mapping based on physical characteristics can be combined with relatively high quality data on actual areas planted and amounts of wheat produced. Future classifications may also be modified as breeding objectives or technical factors change.[5]

Wheat Improvement Investment in CIMMYT

From its inception, CIMMYT's primary research focus has been on genetic improvement of wheat and maize. CIMMYT's entire budget could be considered devoted to genetic improvement of these two crops, although certain CIMMYT research activities, such as farming systems and natural resources research, and some economic analysis, may not appear to be directly related to crop genetic improvement.

In the following analysis, we use three approaches to measure investments in wheat genetic

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[5] For example, as basic constraints caused by soil acidity have been overcome, it might be possible to merge ME 3 into ME 2.

improvement research at CIMMYT. In two of the approaches, we assume that all Wheat Program staff, including representatives of disciplines such as pathology, agronomy, physiology, and plant breeding, are involved in genetic improvement. In the first of the two approaches, we assume that CIMMYT's entire budget can be charged to crop genetic improvement. Here, we allocate the total budget—including money spent on other programs[6] and administration—between wheat and maize according to the proportion that the Wheat Program budget comprises of the total budgets of the two crop programs. The second assumption is that the total CIMMYT budget is allocated to wheat genetic improvement according to the proportion of Wheat Program senior staff relative to all CIMMYT senior staff, including staff in programs other than the Maize Program, as well as administration. The set of figures from the first approach may be an overestimation of true investments in wheat genetic resource improvement; the figures from the second approach may be an underestimation. The third approach is similar but not identical to that of Byerlee and Moya (1993). In this approach, we assume that 65% of the Wheat Program budget is devoted to wheat improvement, along with a 26% overhead.[7]

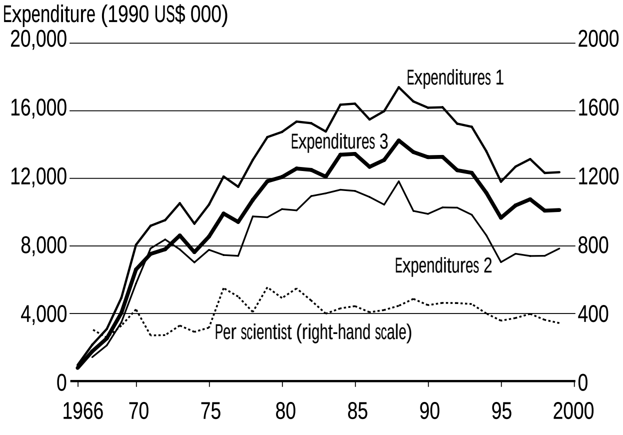

Figure 2.1. CIMMYT wheat research expenditures and expenditures per researcher, 1966-99

Total investments in wheat genetic improvement (in 1990 US dollars) at CIMMYT are presented in Figure 2.1. In addition, Figure 2.1 indicates cost per scientist as calculated from the first (high) assumption. Using the first assumption, real CIMMYT investment in wheat genetic improvement rose steadily until the late 1980s, after which it fell significantly. By the second measure, real investment began to fall slightly earlier, from the mid-1980s. The difference is the result of the second assumption's basis in staff numbers—numbers of non-crop program staff relative to crop program staff have risen since the mid-1980s. Using the third method, CIMMYT's investment in wheat improvement lies between the first two sets of assumptions. The estimated decline in real CIMMYT investment in wheat improvement may have been tempered in recent years, but by all three measures, this decline was substantial from the late 1980s through the 1990s.

By all assumptions, real CIMMYT investment in wheat genetic improvement in recent years is now roughly back at the 1970s level. By the high assumption, CIMMYT today invests about US$ 12 million annually in wheat genetic improvement; by the low assumption, the investment is about US$ 7-8 million per year; and by the intermediate assumption, it is about US$ 10 million per year.

Numbers of CIMMYT Wheat Program staff are shown in Figure 2.2. These can be combined with the first set of assumptions in Figure 2.1 to calculate expenditure per scientist.[8] The number of Wheat Program scientists peaked in

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[6] Currently there are five research programs at CIMMYT- Wheat, Maize, Economics, Applied Biotechnology, and Natural Resources.

[7] These proportions are identical to those used by Byerlee and Moya. However, we begin with actual Wheat Program budgets; Byerlee and Moya multiply 65% of the full time equivalent (FTE) scientists by estimated cost per scientist.

the mid-1980s and declined slightly thereafter. Real expenditure per scientist has fluctuated but also began to decline from about 1980.

Allocating ICARDA expenditures to wheat genetic improvement is more difficult, as ICARDA does not have a wheat breeding program but does allocate some resources to joint CIMMYT/ ICARDA efforts. Based on ICARDA reports of staffing and research programs, as well as estimates of joint CIMMYT/ICARDA investments in 1990 (Byerlee and Moya 1993), we estimate that in the 1990s, ICARDA may have invested up to US$ 1 million (1990 dollars) annually in wheat improvement research.

Wheat Improvement Investment in NARSs

Measures of NARS research investments in wheat improvement in developing countries can be constructed either by directly measuring research expenditure or by focusing on another input measure: numbers of scientists involved in wheat improvement. In the latter, monetary expenditures are sometimes estimated by multiplying numbers of scientists by assumed cost per scientist.[9] In practice, most of the estimates presented below are based on numbers of scientists in wheat improvement, since this information is more easy to obtain than total wheat improvement research expenditures.

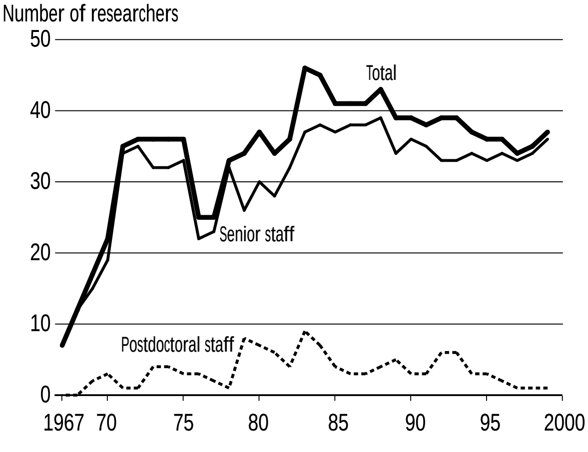

Figure 2.2. CIMMYT Wheat Program staff numbers, 1967-99

Analysis based on the actual number of scientists involved in wheat improvement research must still be treated with considerable caution, however, given the inherent constraints of an impersonal questionnaire and the difficulty of enumerating scientists outside of NARS who conduct research related to wheat improvement (e.g., researchers in universities). These factors could lead to an underestimate. On the other hand, both early 1990s surveys (Bohn and Byerlee 1993; Bohn, Byerlee, and Maredia 1999; Byerlee and Moya 1993) and 1997 surveys (the present one) asked respondents to identify the number of full-time equivalent scientists involved in wheat breeding, even when they represented disciplines other than plant breeding. In some instances, this could lead to an overestimate of the effort devoted to wheat improvement research, as opposed to, for example, wheat crop management.[10]

In terms of the number of scientists per million tons of wheat production, wheat research intensity appears to be slightly greater since the Bohn and Byerlee study (1993): 6.2 scientists per million tons across the developing world in 1997 compared to 5.3 scientists per million tons in 1992–93 (Figure

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[8] The second measure of investment is based on scientist numbers and therefore could not be used to calculate expenditures per scientist. The third measure is also based on the Wheat Program budget and would not yield information on expenditures per wheat improvement scientist much different than expenditures per Wheat Program scientist based on the first set of assumptions.

[9] Cost per scientist may be taken from some other data source, such as ISNAR's study of NARSs agricultural research investment in the mid-1980s (Pardey, Roseboom, and Anderson 1991).

[10] In a few cases information received on questionnaires was considered unreliable, for example large reported numbers of wheat improvement scientists in countries that produce very little wheat. In a few cases, we adjusted estimates based on the experience of international wheat scientists familiar with the wheat improvement program in the country in question.

2.3). This difference is caused largely by a greater number of wheat improvement scientists reported for China in 1997; when China is excluded, the 1992–93 and 1997 figures are nearly identical. Furthermore, research conducted by the International Food Policy Research Institute (IFPRI) and the International Service for National Agricultural Research (ISNAR) suggests that financial support for agricultural research in many NARSs has fallen in recent years. This trend has been masked at the aggregate level by continued support for research in strong NARSs such as China and India. Wheat improvement by NARSs may be polarizing, with large countries continuing their support, while funding in many smaller country NARS is declining in real terms. Hard evidence, however, is limited. We return to this question below.

Survey data confirm one empirical regularity in the number of wheat improvement scientists: research intensity measured by scientists per million tons of wheat production tends to fall with increasing wheat production (Figure 2.4). Because of the inverse relationship between production level and research intensity in the developing world, small wheat producing countries tend to have high wheat improvement research intensities. This pattern was observed in the early 1990s (Bohn and Byerlee 1993; Bohn, Byerlee, and Maredia 1999).[11]

Byerlee and Traxler (1995) estimated purchasing power parity (PPP) expenditures, in 1990 US dollars, by NARSs on spring bread wheat genetic improvement. Their estimates did not include China and were based on comparing numbers of scientists working on spring bread wheat genetic improvement to numbers of agricultural scientists in general, and then applying this percentage to PPP expenditures on all agricultural research. The latter data were taken from Pardey and Roseboom (1989). We extended these estimates to all wheat outside of China by using the ratio of "all wheat releases / spring bread wheat releases" for different periods to adjust investment figures upward.[12] For China, we applied the same methods used by Byerlee and Traxler to research data reported in Fan and Pardey (1992).

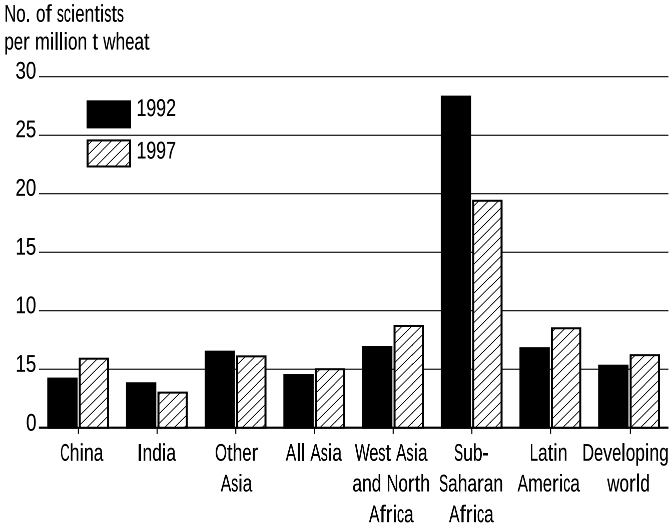

Figure 2.3. Wheat improvement scientists per million tons of wheat production, developing world, 1992 and 1997.

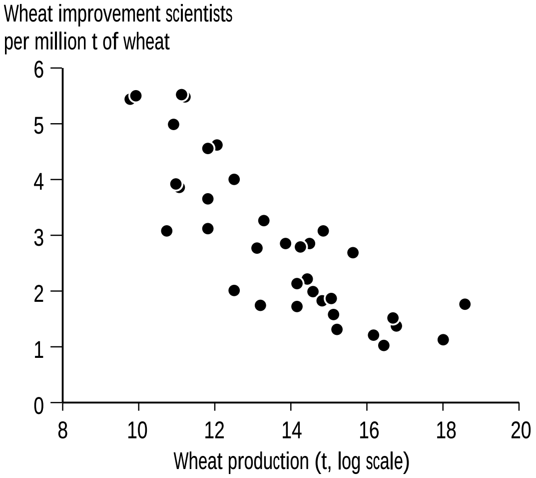

Figure 2.4. Wheat improvement scientists per million tons of wheat production.

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[11] Maredia and Byerlee (1999) consider the important issue of research efficiency, particularly for small programs.

[12] This measure was considered preferable to others, for example "total improved wheat area / total improved spring bread wheat area," because it could be applied in more time-specific fashion. Furthermore, we felt that the measure we used would be less likely to result in upward biases, particularly in the WANA region.

By these assumptions, real investments in NARS wheat genetic improvement research grew steadily from the mid-1960s to about 1990 (Table 2.3). In 1990, NARSs invested about US$ 100 million in genetic improvement research.[13] It is difficult to measure NARS investments in wheat genetic improvement past 1990. Most publicly available data on NARS agricultural research investments end in the late 1980s or early 1990s. The consensus is that worldwide, in both developing and industrialized countries, public investment in agricultural research stagnated or grew slowly during the 1990s. Certainly projections of 1980s trends in Latin America and sub-Saharan Africa support this view. Projections of 1980s trends in China (Fan and Pardey 1992) and India (Evenson, Pray, and Rosegrant 1999) suggest some continued growth in NARS investments.

It is hard to tell whether the apparent increases in NARS investments in wheat genetic improvement in the 1990s, based on numbers of wheat improvement scientists, were reflective of actual increases in real dollar investment, declining research support per scientist, or a combination of the two. Anecdotal evidence suggests that in some research programs, particularly in smaller wheat-producing countries, declining support per scientist combined with relatively stagnant wheat improvement budgets might have been the rule.[14] At the aggregate level, however, this might have been overcome by continued strong investments in wheat genetic improvement by large producers, particularly China and India. These contentions are largely speculative, however, with little hard data to support them. If wheat genetic improvement research budgets had increased over the 1990s consistent with late 1980s trends in aggregate research budgets, increased investments in the developing world would imply that total investments today exceed US$ 140 million (1990 dollars). To the extent that these increases are real, they would have for the most part bypassed Latin America and sub-Saharan Africa. At present, therefore, we estimate that NARS expenditures in wheat genetic improvement fall somewhere between US$ 100 and US$ 150 million (1990 dollars).

Table 2.3. Wheat genetic improvement research expenditures by NARSs, 1990 PPP US$[a].

	1965	1970	1975	1980	1985	1990
World	29.9	41.1	56.2	74.1	86.9	97.5
Asia	12.0	15.8	22.4	32.4	40.1	45.9
China	6.6	7.5	10.0	14.7	20.0	22.9
India	4.2	7.0	10.1	13.6	14.7	16.0
Other Asia	1.1	1.3	2.3	4.1	5.4	7.1
Latin America	5.4	8.8	12.4	16.2	16.3	16.6
Sub-Saharan Africa[b]	1.7	2.5	3.8	4.3	3.4	3.7
WANA	10.8	14.1	17.6	21.1	27.1	31.2

Source: Authors' calculations based on data in Byerlee and Traxler (1995); Bohn, Byerlee, and Maredia (1999); Fan and Pardey (1992); Evenson, Pray, and Rosegrant (1999); and CIMMYT wheat impacts database.

Note: [a] For countries excluding China, wheat improvement research expenditures were calculated from data provided by Byerlee and Traxler (1995) for spring bread wheat by adjusting by the proportion "total releases/spring bread wheat releases" for the relevant periods. For China, the same methods used by Byerlee and Traxler were applied to research expenditure data reported by Fan and Pardey (1992) and data on numbers of wheat genetic improvement researchers from the CIMMYT wheat impacts database.

[b] Excludes South Africa.

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[13] Recall that CIMMYT invested about US$ 16 million annually (high estimate) in wheat genetic improvement during the same period.

[14] Even in cases where the level of investment per wheat improvement scientist may have remained steady throughout the 1990s, in many programs a high percentage of this investment (80% or 90% or higher) has always gone to salaries, with little left over for operational budgets.