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Understanding Global Trends in the Use of Wheat Diversity and International Flows of Wheat Genetic Resources

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Abstract: This document describes wheat's origins and the flows of germplasm between various regions of the world. It summarizes some of the tools biological and social scientists use to measure genetic diversity. It examines patterns of bread wheat diversity in farmers' fields and evidence of genetic variation from breeding programs. Findings suggest that the often-invoked dichotomy between the gene-poor North and the gene-rich South has little validity for wheat. Findings also suggest that yield stability, resistance to rusts, pedigree complexity, and the number of modern cultivars in farmers' fields have all increased since the early years of the Green Revolution. Also included is a description of how economists approach the valuation of genetic diversity. Key policy issues for future research are identified. The report concludes with a brief overview of the world wheat situation in 1995/96, followed by selected statistics on production, consumption, and trade for all regions of the world.

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Foreword

The key to CIMMYT's success in producing improved wheat varieties for a hungry world has been our unique ability to bring together genetic materials from all over the globe and combine them in creative ways. In the near future, genetic resources will become increasingly valuable as advances in science, especially biotechnology, permit greater access to genetic secrets now just beyond our reach.

In this issue of the *Facts and Trends* series, we report on CIMMYT's ongoing study of wheat diversity and international flows of genetic resources. Part 1 of this document expands on the analysis in our *World Wheat Facts and Trends Supplement 1995;* the work is part of a joint project between CIMMYT's Economics and Wheat Programs. As is customary in this series, Part 2 provides a brief overview of the world wheat situation in 1995/96, and Part 3 provides selected statistics on production, consumption, and trade for all regions of the world.

In the tradition of our other *Facts and Trends* studies, this document examines some deceptively simple questions whose answers often turn out to be remarkably complex: Who owns the earth's genetic resources? What do we mean by *diversity?* How do we measure and value it? How has scientific plant breeding affected diversity in farmers' fields?

Aside from being able to determine "how much" diversity can be found in farmers' fields, researchers and policy-makers need to know where that diversity came from and how genetic resources have been used in wheat improvement programs. The ancestry of any wheat variety reflects a millennia of natural evolution and breeding by farmers and eventually researchers. A single cultivar can represent the lineages of wheats from several continents. But how can we determine whether the system of national and international wheat improvement research has actually enhanced the "useful" genetic diversity in wheat? And if it has, can it continue to do so, or are sources of diversity disappearing?

Our *1995/96 World Wheat Facts and Trends* addresses these kinds of questions. It represents an important addition to the intense debate over the use of wheat genetic resources by national and international breeding programs. And it is an important step in CIMMYT's ongoing effort to clarify how international agricultural research has affected wheat genetic diversity in the past and how it can enhance that diversity in the future.

Timothy G. Reeves
Director General

Part 1

Understanding Global Trends in the Use of Wheat Diversity and International Flows of Wheat Genetic Resources

Melinda Smale and Tim McBride

Introduction

Scientific *hubris* has long been a subject of public concern: Prometheus steals fire from the gods and pays for it with unspeakable torment; the physicist explores the atom and imperils all mankind. In the biological sciences, such misgivings have a special relevance. Indeed, the word *hybrid* derives from *hubris* (Thomas 1979) and thus echoes the fear that by directing life's genetic machinery scientists are assuming a god-like prerogative, unleashing forces whose full effects they can neither fathom nor control.

Such concerns must not be idly dismissed by a plant-breeding institution like CIMMYT. Public acclaim that our work has saved lives, increased food production, and protected natural resources is often accompanied by a corresponding fear that we have bestowed a kind of Midas wish: that the golden bounty of wheat and maize will prove somehow fatally flawed, that our much-heralded triumphs contain—hidden within them—the germ of their own undoing.

These fears often focus on the subject of genetic diversity. Since the leaf blight epidemic which swept the U.S. maize crop in 1970 (National Research Council 1972), public attention has been directed to the role of genetic diversity in reducing crop vulnerability to disease. There is also a general concern that the loss of complexity in natural and agricultural systems may compromise our ability to cope with as yet unforeseen challenges to long-term food security.

At present, however, the debate about the relationship between scientific agriculture and genetic diversity has generated more questions than answers. Between easy pronouncements that diversity is valuable and the simple fact that not all diversity can (or should) be preserved lie the more difficult questions: How do we measure and value diversity? Is genetic diversity in farmers' fields actually declining? What impact has scientific plant breeding had on diversity in farmers' fields? What potential does plant breeding have for expanding genetic diversity?

Equally important are questions concerning the availabiltiy of genetic resources to plant breeders and farmers: Who owns the earth's genetic resources? To what extent have industrialized nations benefited disproportionately from plant genetic resources freely appropriated from developing countries? What are the implications of restricting the free flow of germplasm? Would such restrictions serve the interests of developing countries?

CIMMYT's ongoing study of wheat genetic diversity seeks to answer some of these questions. A joint initiative of the Wheat and Economics Programs, the study's initial objectives are:

- To develop a deeper understanding of *genetic diversity* within a crop species by identifying, comparing, and integrating the indicators social and biological scientists use to measure it;
- To characterize global patterns of genetic variation among the wheats now grown in the developing world;
- To clarify how genetic resources have been used in scientific plant breeding; and
- To help establish a foundation upon which economic methods and tools can be used to value various aspects of genetic diversity.

In every instance, our work is informed by a central conviction: economic analyses of wheat genetic diversity must be based on biological science. By integrating economic and biological approaches, we hope to clarify how agricultural research can safeguard and enhance the wheat genetic diversity that is potentially valuable to present and future generations.

This report documents the current status of our efforts.

- **Section II** provides a general framework for our discussion by clarifying wheat's origins and the flow of germplasm between various regions of the world. Our data suggest that the often-invoked dichotomy between the gene-poor North and the gene-rich South has little validity for wheat.
- **Section III** describes some of the tools biological and social scientists use to measure genetic diversity. We conclude that scientists still face considerable challenges in understanding the practical implications of their work and in integrating their disciplinary perspectives.
- **Section IV** is divided into three parts: the first examines patterns of wheat diversity in farmers' fields; the second examines evidence of genetic variation from breeding programs; the third reviews the ways in which wide crosses and biotechnology can expand the classical boundaries of wheat's genetic diversity by introducing genes from distant species or even genes wholly synthesized in the laboratory. Throughout this section, our focus is on bread wheats, which, in the developing world, far exceed all other wheats in terms of cultivated area. Our findings suggest that yield stability, resistance to rusts, pedigree complexity, and the number of modern cultivars in farmers' fields have all increased since the early years of the Green Revolution.
- **Section V** describes how economists approach the valuation of wheat genetic diversity and identifies some key economic policy issues for future research.
- **Section VI** presents conclusions.

Wheat Origins and Germplasm Flows

It is often asserted that, for at least two centuries, industrial nations have benefited disproportionately from crop improvement programs that have had free access to genetic resources from developing countries (see Kloppenburg and Kleinman 1988). According to some proponents of this view, the "privatization" of advanced germplasm through the enactment of plant breeders' rights in industrialized countries has produced a particularly inequitable result: seed industries in developed countries are able to sell advanced products to the very nations that contributed—free of charge—the genetic resources upon which those products are based. Concern over these apparent inequities has led to varietal protection proposals as a means of controlling the use by industrialized nations of genetic resources from developing countries.

The availability of genetic resources to scientists and farmers and the effects of varietal protection on germplasm use are critical public policy issues. The formulation of those policies should be based on a realistic assessment of a crop's unique germplasm history. As we show in the following subsections, the geographical origins of wheat are diffuse, the dispersal of cultivated forms throughout Asia and the Mediterranean region having occurred thousands of years ago. Contrary to the popular dichotomy (i.e., gene-poor North, gene-rich South), landraces from *all* the major wheat-producing regions have contributed germplasm to the varieties now being grown by farmers in the developing world.

Wheat's ancestors

An awareness of wheat's ancestry is important for understanding both the range of genetic diversity in its primary and secondary gene pools and the potential for incorporating useful genes or gene complexes (such as those that confer disease resistance or stress tolerance) into cultivars. (See Appendix A for a glossary of technical terms.)

Cultivated bread and durum wheats descend from hybridized wild grasses. Durum wheat *(Triticum turgidum),* is a hybrid that occurred spontaneously between an as yet unidentified wild grass and einkorn, a primitive diploid wheat.[1] Bread wheat *(T. aestivum),* a hexaploid, is the product of a later spontaneous hybridization between a

[1] *Triticum searsii* is believed to be the closest relative to the wild grass. Diploids (such as the wild grasses and the primitive wheat that donated the genomes for durum and bread wheats) have 7 pairs of chromosomes; tetraploids have 14 pairs; hexaploids have 21 pairs.

tetraploid wheat and *T. tauschii* (also *Aegilops squarrosa* or "goat grass"), which is still found in the wheat fields of Asia Minor and, perhaps, China (Figure 1). Scientists speculate that events leading to the formation of today's wheats may have occurred many times in nature, rather than as a single hybridization event.

Bread wheat is the most widely grown wheat species and one of the few crops for which no wild forms have been identified—although its primary gene pool contains species (e.g., einkorn, emmer) that have wild forms and that continue to share a natural gene flow with wild grasses (Harlan 1992). If, as many suppose, bread wheat has been cultivated since its hybridization, then it has long been relatively isolated from other species and may have a much lower potential for genetic variation than its wild progenitors and other relatives. On the other hand, its early geographic dispersal may have contributed to its wide adaptability. According to some scientists, landraces maintained in collections offer only limited possibilities for diversifying the gene pool of domesticated bread wheat (Jaaska 1993). By some standards, durums, emmers, and other species and genera have contributed at least as much to bread wheat breeding programs as have bread wheat landraces (see Sharma and Gill 1983). Reductions in the area grown to bread wheat landraces probably began early in this century in many major production areas (see Box 1).

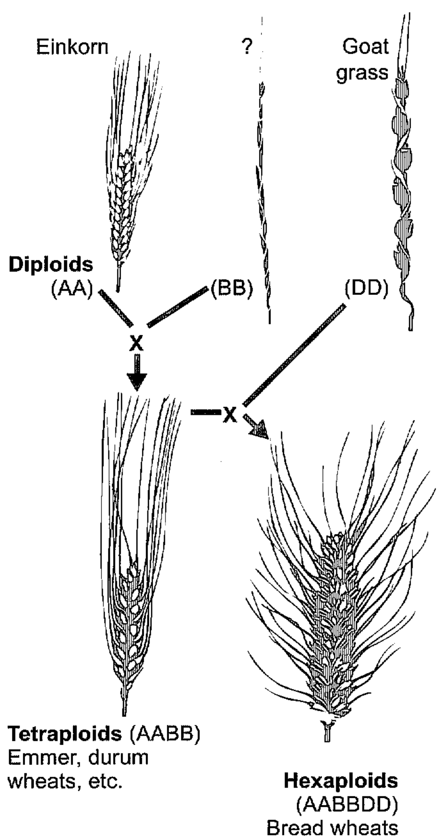

Figure 1. Origin of cultivated wheat types.
Source: Hancock (1994).

Wild germplasm is a valuable resource for improving bread wheat productivity and durability (Cox, Murphy, and Goodman 1988; Mujeeb-Kazi and Hettel 1995). As human and animal populations expand, however, the marginal lands on which these wild relatives thrive may need protection (see Box 2). Wide crosses and other biotechnological innovations have the potential for breaking the crossing barriers encountered in conventional breeding. So too do transformation techniques that use genes extracted from other crops and organisms.

Geographical centers of origin and centers of diversity

A pioneer in the classification of crop plants, the Russian scientist N. I. Vavilov defined geographical "centers of diversity" for major crops based on patterns of observable variation in collections made from each species (1926, 1951). Vavilov's central idea was that the place of origin for a cultivated plant species is the area where it exhibits the greatest variation. The underlying assumption is that selective forces in the environment remain relatively constant throughout a species' evolutionary history.

Vavilov recognized that his original hypothesis was a simplification. As scientists have now shown, selective forces are not constant, and as a consequence, within-species variation builds up at different paces in different places. Topography and geographical isolation play a role in how rapidly plant populations diverge genetically from one another. In addition, variation patterns are unique to the history and distribution of each crop and its wild progenitors (Harlan 1992). Some crops were domesticated several times, for example, others only once. Some spread early and developed secondary centers; others spread recently and can be traced to their origins by historical data.

Early in this century, Vavilov and his colleagues found that the number of bread wheats in Europe and Siberia was already rather restricted. Anatolia, Syria, Palestine, and Transcaucasia contained other forms and types of wheat (Zohary 1970). Vavilov also defined several other centers of variation, including the Ethiopian plateau and the Mediterranean basin for durum wheats and Afghanistan for bread wheats.

Scientists generally conclude that the diploid grass progenitors of durum and bread wheats originated in the Fertile Crescent. But Harlan (1992) describes wheat as "diffuse," and Zohary (1970) refers to its origins as "confused." New arrays of locally adapted cultivars evolved as wheat dispersed over vast geographic areas. Bread wheat is a relative latecomer among cereals, and its domination in cultivated area (replacing emmer and other wheat forms) in Europe and northern Africa did not occur until historical times (Harlan 1987).

An historical profile of germplasm flows

An important early period in the history of wheat germplasm, the Neolithic Dispersal (roughly 6000-3000 B.C.) was associated with the development of a stable food-producing economy in the Near East (Harlan 1987). This "unprecedented evolutionary expansion" resulted in a broad ecological differentiation as wheats adapted to different latitudes, altitudes, soil moisture regimes, and cultural practices (Bennett 1970). Traces of wheat in archaeological sites suggest that it spread into southern Europe between 5000-6000 B.C., into Egypt by 4500 B.C. (and probably earlier), the Netherlands by 4000 B.C., England and Scandinavia by 3000 B.C., the Indus cultures by at least 3000 B.C. (and evidence from Pakistan and Baluchistan suggests much earlier), and China by at least the second millennium (Harlan 1987). After 3000 B.C., wheat populations continued to evolve and spread, in concert with changing human settlements and cultivation practices; however, the crop probably remained confined to the Afro-Eurasian landmass until about 1500 A.D.

Box 1. A Broader View of Genetic Narrowing

According to a popular misperception, the principal cause of genetic narrowing in wheat has been the adoption of semidwarf varieties produced by Japanese, U.S., and Mexican-based scientists. In the broadest sense, of course, such narrowing began over 9000 years ago with the domestication of einkorn and emmer. As with any cultivated plant, the human selection pressures that accompanied domestication were inherently narrowing: rather than trying to preserve the widest possible range of plant types, farmers selected for plants that produced more seed and for grain that threshed easily but shattered less.

Porceddu et al. (1988) argue that, for wheat, at least two major stages of genetic narrowing have occurred in modern times. The first took place in the 19th century, when scientific plant breeders responded to the demand for new plant types that would meet the needs of emerging farm systems based on livestock production, organic manures, and the intensive use of land and labor. Changes in cultivation methods favored those genotypes which diverted large amounts of photosynthates to the ear and grain. The second stage identified by Porceddu et al. occurred in the twentieth century, when genes were introduced to produce major changes in plant type. Use of the dwarfing genes *Rht*1 and *Rht*2, for example, conferred a positive genotype-by-environment interaction in which yield increases proved greater given a certain combination of soil moisture, soil fertility, and weed control.

Not all researchers agree, however, about what constitutes genetic narrowing or precisely when such narrowing has occurred. In contrast to Porceddu et al., for instance, Hawkes (1983) cites the introduction of *Rht*1 and *Rht*2 genes into Western breeding lines (through the crossing of the Japanese line Norin 10) as an example of how diversity has been *broadened* by scientific plant breeders. Norin 10 carried the dwarfing genes from the landrace Daruma, believed to be of Korean origin (Dalrymple 1986).

As this example suggests, today's breakthrough in achieving genetic diversity is tomorrow's potential source of narrowing precisely because such breakthroughs often produce wheat cultivars that many farmers adopt. The 1B/1R translocation from rye widened the gene pool of bread wheats and provided resistance to certain stresses, but it also contributed to the widespread use of Veery and its descendants in farmers' fields (Villareal et al. 1991).

Interestingly, however, the percentage of area planted to the dominant cultivar has declined in many industrialized countries since the early years of this century and in many developing countries since the early Green Revolution period. (See Section III for more details on the relationship between modern plant breeding and *spatial diversity*).

Box 2. *Ex situ*, *In situ*, and Farmer-managed Conservation*

Within a center of diversity, a crop can be fairly uniform over large areas yet show enormous variation in small pockets or "microcenters of diversity" (Harlan 1992). Forty years ago, says Harlan, such microcenters of wheat diversity could still be found in Turkish Thrace, Transcaucasia, Iran, and Afghanistan—in areas dominated now by modern cultivars. How best to conserve genetic resources in remaining microcenters is an urgent global concern.

There are three basic approaches to genetic conservation: *ex situ, in situ,* and farmer-managed. The International Plant Genetics Resources Institute (IPGRI) defines *ex situ* as "out of place; not in the original or natural environment" and *in situ* as "in place; where naturally occurring" (1991). *In situ* conservation enables scientists to observe the ongoing evolution of wild or domesticated forms as they interact with pests and pathogens. For domesticated species or subspecies, *in situ* conservation requires the management by farmers of a diverse set of crop populations in the systems where the crops have evolved (Bellon et al. 1996). Such management involves complex socioeconomic and scientific issues, most of which have not yet been rigorously investigated.

The general case for *ex situ* conservation is as follows. Scientific plant breeding has improved farmers' varieties and local landraces by incorporating useful variation from diverse genetic sources. Inevitably, farmers adopt the better cultivars and discard the others. *Ex situ* strategies conserve plant seeds and propagating parts in genetic resource collections, thus preventing the unintentional loss of species, subspecies, or wild relatives due to wars or natural and human selection processes. Landraces are better stored *ex situ,* proponents argue, where useful genes may be identified and bred into new varieties or where new genetic bases may be assembled and breeding populations developed. According to this view, the adaptive genetic complexes found in landraces are not necessary for continued scientific advances.

Other arguments encourage the maintenance of diversity in the field or the wild, in addition to the gene bank. Proponents point out that the replacement of landraces with modern varieties is not an inevitable process (Brush 1992b; Brush et al. 1992); farmers often continue to grow landraces even after adopting modern varieties on part of their land. Further, useful qualities in landraces and wild forms may still be evolving or emerging *in situ* and may not otherwise be available to plant breeders. *In situ* conservation allows adaptive, evolutionary processes to continue and natural prebreeding to occur (Jana 1993). Moreover, for farmers "left out" of the development process, farmer-managed efforts may provide at least some economic benefits, while also protecting genetic resources. The research by Meng et al. (1995 and ongoing) is a first step toward identifying feasible policy incentives that support the management of genetic diversity by Turkish farmers. Through projects that enable farmers to better manage their own genetic resources, the work of plant breeders and the needs of farmers in marginal agroecosystems may be harmonized in ways that serve both science and local communities.

A growing consensus holds that *ex situ* and *in situ* strategies should be complementary, thus offsetting the limitations of the individual strategies. *Ex situ* conservation, for example, is geared toward a fairly small number of known plants, "fixes" the genetic material of a plant at the time of extraction, and can conserve only a sample of the total genetic diversity present in a wild species. Similarly, *in situ* conservation results in detailed knowledge only of specific sites where a species or subspecies occurs, and the risk of extinction due to some natural or man-made process is likely to be greater. For security reasons, maintaining small subsamples of selected wild populations in an *ex situ* gene bank can complement *in situ* efforts. Should the wild population disappear from natural sites, it could be reintroduced from the gene bank.

* Much of the material in this section is drawn from Dempsey (1996).

Migrating farmers and governments seeking trade opportunities also spurred germplasm exchange (Figure 2). By 1529, Spanish settlers had planted wheat in Mexico (Heiser 1990). The first recorded planting of wheat in Brazil also occurred in the 1500s (Bastos-Lagos, n.d.). By 1790, wheat was being planted in Australia. Mennonites migrating into the Crimea and, in 1873, from the Crimea into Kansas carried the landrace ancestor of the hard winter wheats of North America, called "Turkey Red" for the Turkish farmers who provided the seed; Turkish farmers also taught the Mennonites how to grow winter wheats.[2]

Transmitted as food in cargo holds and seed in settlers' sacks, wheat probably spread to almost all of the current production areas during the colonial period. Secondary flows occurred within colonial empires and commercial spheres—for example, from Cape Town in South Africa to India and Australia; between South and North America; and among North Africa, East Africa, and other territories. No note is made in Figure 2 of migrations originating in or directed over the broad expanse of West Asia, Eurasia, and China, but we imagine that important germplasm transmissions also occurred in these regions.

At the close of the nineteenth century, scientific breeding programs began to develop throughout the wheat-producing world. Figure 3 shows some of the major landraces used by such programs, including those that have contributed important genes or gene complexes to today's bread wheats and those with the highest estimated genetic contributions, when calculated using Mendelian principles. The approximate period in which landraces were first used by scientific plant breeders, and their known origin, are indicated as well.

Contrary to popular notions that depict certain regions as mere appropriators of genetic resources, our findings suggest that farmers from *all* of today's major wheat-producing zones have made important germplasm contributions. Landraces that were first used by plant breeders before 1920 and that still figure heavily in the pedigrees of today's bread wheats include Sheriff's Squarehead, Zeeuwse Witte, Turkey, Blount's Lambrigg, Purple Straw, and Fife. Sherriff's Squarehead, one of the earliest products of modern plant breeding, originated in Great Britain in the mid- to late 1800s; along with its descendants, Squarehead became a cornerstone of the early French, Belgian, German, Dutch, Swedish,

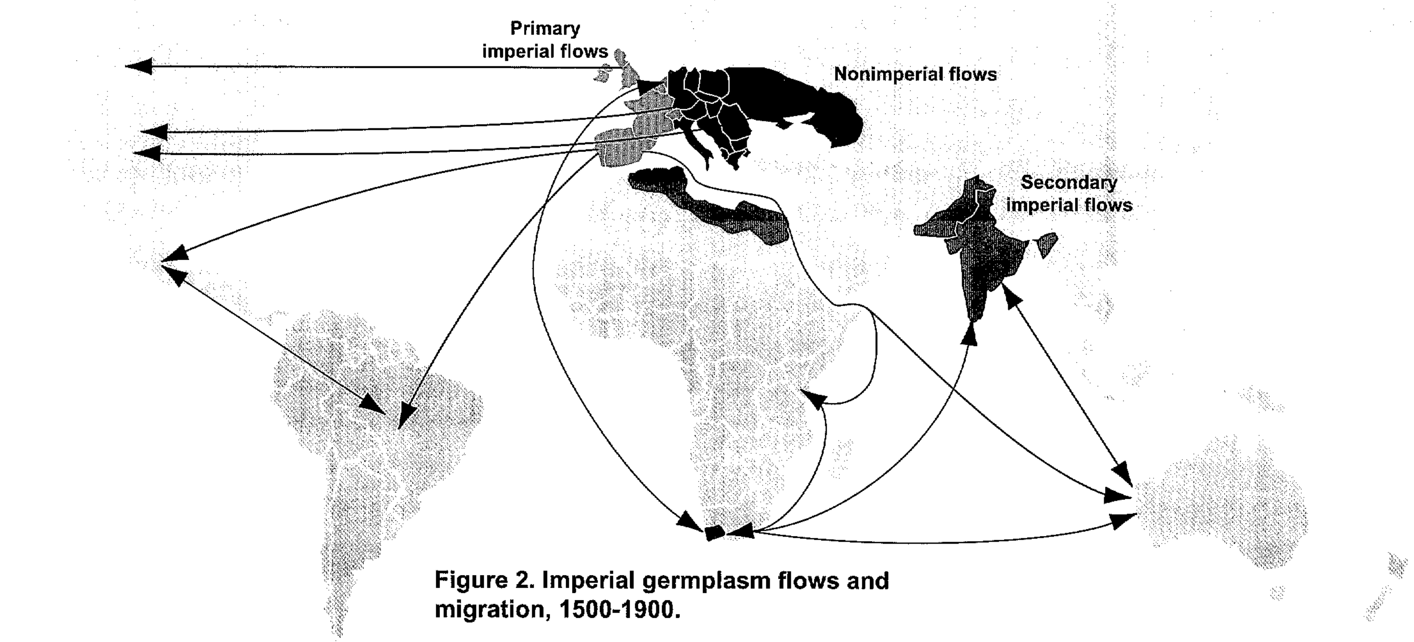

Figure 2. Imperial germplasm flows and migration, 1500-1900.

[2] There is some disagreement about whether the Mennonites were first to grow hard red winter wheat in Kansas; in any case, they do seem to have played an important role in popularizing that wheat (Schlabach 1988). The name *Turkey Red* probably refers to a number of landrace selections.

and (indirectly) Italian breeding programs (Lupton 1987). Zeeuwse Witte, a Dutch landrace, was crossed with Squarehead to produce Wilhelmina. In the Italian breeding program initiated during the 1930s, Strampelli crossed Wilhelmina with an early-maturing Italian landrace, Rieti, and top-crossed the F_1 (i.e., the first filial generation) with Akagomughi, a Japanese dwarf variety. Two progeny of this cross, Ardito and Mentana, became the major progenitors of bread wheats grown throughout the Mediterranean, South America, the former Soviet Union, and China (Lupton 1987; Dalrymple 1986; Yang and Smale 1996).

Evidence abounds of wide-ranging germplasm exchange. Blount's Lambrigg and Purple Straw, for example, were used in Australian breeding work beginning with Farrer. The former is named for the U.S. farmer A.E. Blount from whom Farrer obtained it (Macindoe and Brown 1968); the latter is believed to have originated in the U.K. Similarly, Fife is believed to have originated in the Polish region of Galicia, but selections from it are the building blocks of the North American spring wheats, the Australian wheats, and the bread wheats grown today in the developing world. Hard Red Calcutta, a commercial class of wheat exported from the city for which it is named (Pal 1966), is the other major parent of the North American spring wheats and the single most frequent female cytoplasm donor for the bread wheats grown in the developing world (Nightingale 1996).

Major sources of disease resistance and other important traits introduced into breeding lines from 1900 to 1920 include the tetraploid wheat Iumillo, Yaroslav emmer, Red Egyptian, Indian G, and Etawah. Yaroslav emmer is another key cytoplasm donor for the bread wheats grown in the developing world (Nightingale 1996). Indian G and Etawah figure heavily in the pedigrees of the Australian lines. Steinwedel, used for disease resistance by Australian breeders, is named for the German farmer who discovered it in his Australian fields; it is believed to have reached that country via South Africa (Macindoe and Brown 1968). Red Egyptian is of unknown African origin, usually attributed to Ethiopia or the Republic of South Africa, although its name suggests that Egypt is the source.

Alfredo Chaves and Polyssu—Brazilian landraces first crossed by Beckman in 1935—are among the most frequent female cytoplasm donors for the bread wheats now grown in the developing world (Nightingale 1996). One of the selections from that cross, Fronteira, is the probable source of an important gene complex for durable leaf rust resistance (Singh and Rajaram 1992;

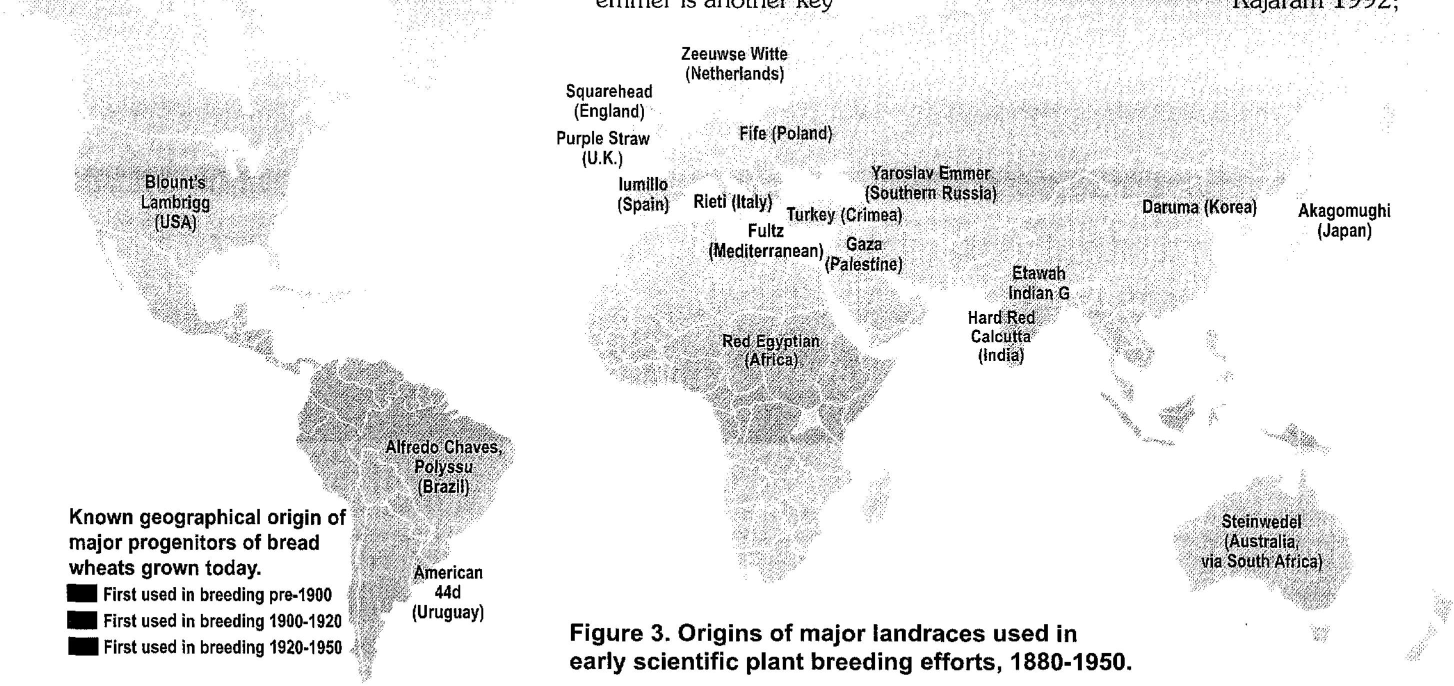

Figure 3. Origins of major landraces used in early scientific plant breeding efforts, 1880-1950.

Box 3. Vulnerability to Disease

Visible uniformity in cultivar characteristics is not necessarily associated with *genetic vulnerability*. Crops can be relatively uniform in many respects and remain invulnerable. Diversity can be hidden, revealing itself only when the environment changes. Uniformity can also be hidden, as when apparently diverse varieties prove identical in the gene or genes that create the conditions for susceptibility (see BOA/NRC 1993; NRC 1972).

It is important to recognize three basic facts concerning the genetic basis of disease resistance. First, resistance is not an absolute quality: it ranges from partial to near total.[1] Second, because pathogen populations constantly evolve in complex interaction with host plants, resistance may be of short, unpredictable duration. Genetic variation in the pathogen is of great importance: a host plant may be nearly immune to some forms of a pathogen, but completely susceptible to others. Wheat rusts can be particularly problematic in this regard because they readily develop new races. Third, resistance genes may respond differently under various environmental conditions.

"Effective" resistance in a genotype is based on one or several genes of known importance from among the genome's many unidentified genes. In diseases such as wheat rusts, scientists have long recognized that developing *monogenic resistance* (also known as race-specific or qualitative resistance) contributes to a "boom-bust" cycle because the pathogen is able to mutate rapidly and form new strains.

Breeding for this type of resistance is still practiced by some because it is relatively cheap and the presence of the resistance gene can be verified easily in the seedling as well as in the adult plant. In certain environments and for certain diseases, such a strategy may be effective. In the long-term, however, this type of breeding can lead to an ongoing, expensive search for new single-gene sources of resistance, often referred to pejoratively as "gene hunting."

Most plant breeders and pathologists now seek more *durable resistance* to wheat rusts based on multiple genes, each of which has a minor effect. To that end, researchers accumulate genes from diverse sources and genes controlling various resistance mechanisms within single cultivars. Breeding for this type of resistance tends to produce more long-lasting solutions. The basic reason for this is fairly simple: pathogen mutations are random events; thus, the greater the number of genes that confer resistance, the greater the number of mutations that must occur to break that resistance.[2]

Genetic resistance is often likened to a kind of lock designed to keep out disease. But those who fail to distinguish single-gene resistance from polygenic resistance also fail to appreciate the way in which the locks have improved. By developing polygenic resistances, wheat breeders are, in effect, adding numbers to the combination required to open the lock—additions which increase significantly the likelihood that any random series of numbers (or mutations) will be able to overcome the resistance.

In the 1970s, with growing interest in agricultural systems that mimic natural ecosystems, "alternative" genetic strategies using multiline varieties and varietal mixtures became increasingly popular. An attraction of the former is that the multiple lines differ in specific resistance genes. Similarly, varietal mixtures consist of seed with differing resistance genes from previously released cultivars.

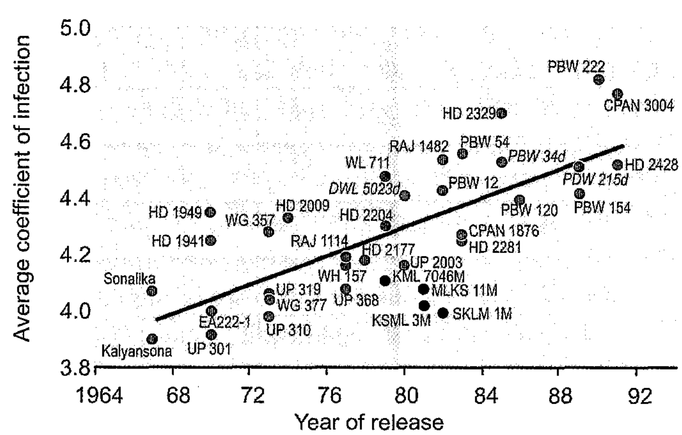

Figure A. Yield trend in wheat varieties (green dots) and multilines (red dots) released for India's northwestern and northern plains zones, 1967-1991 (crops were grown under irrigated conditions and sown in a timely fashion). Source: K.B.L. Jain (personal communication).

1 As evidence of this topic's complexity, consider that plant pathologists have used over 30 terms to characterize resistance (Thurston 1971).

2 Breeders typically work from advanced lines, and most such lines are relatively uniform with respect to single, known resistance genes.

The primary constraints to the development and diffusion of multilines and varietal mixtures have been economic. Uniform phenotypes are a prerequisite for mechanized agriculture, and uniform grain quality is important to industrial processors of bread wheats. Multilines take a long time to develop—with the result that they yield as much as the lines from which they are derived but less than other available varieties (Figure A). Consequently, they have not proven very profitable for seed companies or very attractive to commercial farmers. The principal advantages are a more natural system in which host plants are not genetically identical and in which the pathogen population can be stabilized at intermediate levels and numbers (Roelfs et al. 1992).

Although a wheat variety's resistance to rust is genetically determined, the risk of an epidemic is determined by the extent to which susceptible genotypes are contiguously cultivated. To avoid epidemiological problems, plant breeders and pathologists primarily recommend changing cultivar portfolios in the hope of maximizing spatial and temporal diversity.

Public policy exerts a strong influence on disease development and control. Indeed, the successful implementation of many scientific advances depends on decisions by governmental or public institutions and the allocation of public resources to disease control (see NRC 1972; for an example, see Dubin and Torres 1981). "Curative" strategies are also essentially matters of public policy. Disease reconnaissance and monitoring are important for enabling rapid responses to outbreaks. How best to control the spread of a disease (chemically or otherwise) is increasingly a source of policy debate.

Kohli 1986; see Box 3 for more on *durable resistance).* Leaf rust is endemic in the Southern Cone of South America (Samborski 1985).

Although South American wheats were originally introduced from Europe, no known past or present European cultivars appear similarly resistant to leaf rust. Americano 44d, a Uruguayan landrace of unknown origin (called Universal 2 in Argentina), was used by Klein in breeding early Argentinian lines and is now considered another important source of durable resistance to leaf rust (van Ginkel and Rajaram 1993).

Key landraces in breeding work that preceded the release of semidwarf wheats include Gaza, carried to Australia from Palestine by a soldier after World War II (Hanson et al. 1982); Fultz, also called "Mediterranean"; and Daruma, which carries the major dwarfing genes *Rht*1 and *Rht*2 and which originated in Japan or Korea (Dalrymple 1986).[3] Daruma was one of the recommended wheat varieties in the Tokyo and Kangaw prefectures around 1900; it was first used by Japanese breeders in crosses with selections from Fultz (imported from the U.S. by the Japanese government in 1887) in the early 1900s. Norin 10 derives from this breeding work. Released in Japan during the 1930s, Norin 10 was the line through which *Rht*1 and *Rht*2 were bred into the Green Revolution wheats during the 1950s and 1960s.

Several landraces not mentioned here (such as Criewener) have been the sources of important traits for the semidwarf and Veery wheats produced since the 1960s. Particularly significant is the breeding of Petkus rye into the winter wheat parentage of the Veery lines via Kavkaz (from the former Soviet Union), an example of an important natural wide cross that occurred spontaneously in a farmer's field. The cross occurred early in this century and is now found in the ancestry of the lines that dominate wheat area in the developing world.

The period from 1950 to the present is characterized by the prominence of international nurseries and an increase in national exchanges among developing countries. Flows of genetic resources are in one sense more centralized now, as the financial resources and capacity to maintain diverse sources of germplasm are concentrated in a few large banks and nurseries. Yet current flows are, if anything, even more complex than in previous periods. Indeed, as national programs have become stronger, transfers among the breeding programs of the non-industrialized world have become more prevalent (Byerlee and Moya 1993). Modern transport allows seed to be air-freighted in boxes.

[3] The influence of dwarf wheats from Japan began much earlier than the Green Revolution. Short Japanese varieties were introduced into France in the 1860s and were used for experimental breeding work from 1930 to 1955, but do not appear to be parents of significant commercial varieties. Akagomughi, mentioned above, was provided by an Italian flower seed producer to Strampelli, whose goal was to breed varieties that were early maturing (to "escape" rust losses) and short statured (to resist lodging) (Dalrymple 1986).

Computer technology enables the pedigrees and selection history of any breeding line to be transmitted to scientific breeders throughout the world (see Skovmand et al. 1995; Fox and Skovmand, in press).

Landraces by source and destination

Table 1 shows the percentage distribution, by region of origin, of all distinct landraces in the pedigrees of bread wheats grown in developing countries.[4] Each landrace is counted only the first time it appears in a pedigree. The economic contribution of landraces to yield, disease resistance, or other traits is not expressed in these calculations. When recurrent use or landrace frequency in the genealogies is considered, the relative importance of the industrialized world increases. Appendix B provides a list of the countries included in the regions discussed below.

The bread wheats now grown in the developing world contain more than 140 different landraces in their pedigrees. Only South Asia and the Southern Cone of South America have contributed the greatest number of landraces to the pedigrees of bread wheats now grown in their own region. For each of the other developing-country regions, self-contributions are exceeded by contributions from the region made up of Poland, Germany, and the territories of the former Soviet Union. The second largest regional contributor is the Southern Cone of South America.

On average, regions of the developing world contributed 47% of the landraces grown in the developing world; industrialized nations contributed 45%. The remaining average of 8% are of unknown origin. West Asia appears to have contributed a relatively small number of landraces to the pedigrees of bread wheats now grown in the developing world. Recall, however, that in wheat evolution forms and races spread very early from West Asia to secondary centers of diversity. Pedigrees track the use of germplasm only from the beginning of scientific plant breeding.

Sub-Saharan Africa's apparent importance may reflect the fact that little is known about the origin of several Kenyan breeding lines. The first scientific wheat breeder in Kenya, G.W. Evans, used Rieti (Italy), Red Fife (Poland), and varieties from Egypt and Australia. After being posted by Kenya's colonial government in 1920, G.I.L. Burton developed a number of lines that Norman Borlaug would use extensively in Mexico during 1960s. Burton's records were destroyed in a fire (Dalrymple 1986), so all materials derived from the Kenyan lines have been classified as being from sub-

Table 1. Origin and destination of landraces in pedigrees of bread wheats grown in the developing world in 1990

	Region of destination in the developing world						
Region of origin	**Sub-Saharan Africa**	**North Africa**	**West Asia**	**South Asia**	**Mexico/ Guatemala**	**Andean Region**	**Southern Cone of S.A.**
	Percentage distribution of numbers of landraces in pedigrees						
Sub-Saharan Africa	12	9	7	9	10	12	7
North Africa	2	4	2	3	2	1	1
West Asia	2	1	7	2	1	1	1
South Asia	10	8	7	21	6	10	6
Mexico/Guatemala	4	3	7	6	9	7	5
Andean Region	0	0	0	0	1	1	1
Southern Cone of South America	14	16	8	11	16	17	31
China	1	1	1	1	1	1	1
Developing World [a]	*45*	*42*	*39*	*53*	*46*	*50*	*53*
North America	8	6	9	4	9	9	10
Northern Europe	10	8	5	6	9	8	6
Southern Europe	7	10	15	8	8	9	8
Poland, Germany, F.S.U.	15	21	16	18	21	19	14
Japan and Korea	1	3	2	2	2	2	2
Austrailia	1	0	2	0	1	0	1
Industrialized World	42	48	49	38	50	47	41
Unknown	13	10	12	9	4	3	6
All	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: Calculated from CIMMYT Wheat Impacts Survey and Wheat Pedigree Management System; Macindoe and Brown (1968); Zeven and Zeven-Hissink (1976); Dalrymple (1986); Lupton (1987).

[a] All countries in the *developing* category are low or middle income. All countries in the *industrialized* category, with the exception of the former Soviet Union (F.S.U.) and Poland are high income.

[4] In the strictest sense, the term *landrace* implies that no further information is known about the pedigree of the progenitor. Because information about the source of early progenitors is often incomplete, the data do contain measurement errors. Where possible, we have adjusted the information by consulting various databases and other records for the history of the major progenitors found in the pedigrees. Many of the major progenitors used to generate the data reported in Table 1 have been described above.

Saharan Africa even though they probably originated in Europe and North Africa.

Similarly, the apparent contributions of landraces from the Southern Cone of South America must be understood in the context of the little we know about cultivars that "migrated" long ago to Brazil and Argentina with European settlers. In Argentina, E. Klein began scientific plant breeding about 1920. The pedigrees of his early releases contain more than 50 varieties of distinct origin. These include selections from Argentinian and Uruguayan populations. Also included are North American cultivars (such as Marquis; Kanred, a selection from Crimean hard red wheat; and Blackhull, a selection from the variety Turkey); Italian cultivars (such as Ardito and Mentana—both descended from Rieti, Akagomughi, Zeeuwse Witte, and Squarehead); and cultivars from France, Russia, Brazil, Germany, and Australia.

Brazil also has a long history of scientific plant breeding. One of the earliest and best known releases is Frontana, a cross of Fronteira (whose importance in rust resistance is noted above) and Mentana. Fronteira is a cross of Alfredo Chaves and Polyssu, both known as selections from the local wheats of the Rio Grande de Sul (Kohli 1986).

East Asia contributed only a few landraces (Akagomughi, Daruma, and one or two others reported to be of Chinese origin). But these were used frequently, their Mendelian contribution is great, and their economic importance is clearly even greater. Similarly, Fife, Turkey, and Yaroslav emmer largely account for the importance of Eastern Europe and the former Soviet Union as a landrace contributor. Hard Red Calcutta, Indian G, and Etawah are the main contributions from South Asia.

The evidence in Table 1 and Figures 2 and 3 is fairly conclusive: germplasm flows for bread wheats have long been international and multi-directional. We need only examine wheat pedigrees to learn that all regions are "indebted" to varieties from other regions. Indeed, in almost all cases, the largest contributor of landraces to a given region is not the region itself. For bread wheats, neither the distinction "North-South" nor "developing-developed" is useful for characterizing germplasm origins or flows, especially since, with political changes, national boundaries also change. Finally, the term "landrace" is often a measure of our own ignorance because the progenitor may have been the result of a farmer's selection, a scientist's cross, or a commercial seed shipment.

How scientific plant breeding incorporates landraces

Preserving landrace populations in their original forms does not necessarily enable us to recapture their usefulness. Landrace populations evolve with human populations. Further, conserving landraces either in gene banks or on-farm does not ensure that plant breeders will use them directly in their crossing programs. One reason for this reluctance is that breeders "want the genes and not the linkages" (Harlan 1992, p. 155). To breed "in" desirable traits while breeding "out" undesirable ones usually takes repeated backcrossing, after which traits still may not be stable in the variety.

Wheat pedigrees necessarily become longer as plant breeders continue to make new selections and cross lines with existing materials. In most cases, however, plant breeders do not know the genealogies of the new materials they borrow or obtain from other nations. Typically, the new materials brought into a wheat breeder's program are advanced lines with long pedigrees that contain numerous landraces. Many of these advanced lines have pedigrees similar to the breeders' older materials. Some have fairly distinct pedigrees. Only a few are landraces that have never before been used in the genetic background of any of the breeders' materials. The more international the breeding program, of course, the more likely it is that new materials will include new landraces or advanced lines that contain in their genealogical background ancestors that have not been used previously or that do not occur in the genetic background of older materials.

Segments of the pedigrees for several leading cultivars now grown in the developing world are reproduced in Appendix C, which illustrates the different ways breeders incorporate new materials, as well as the sheer length and breadth of the pedigrees. A number of sources were used to label each landrace or farmer's selection with a probable or known country of origin;

also, each scientific cross or line is labelled with the country in which it is believed to have been produced and the approximate date.

Appendix Figure C1 shows major segments of the pedigree for Sonalika, the bread wheat cultivar planted across the largest area in the world in 1990 (primarily in the Asian subcontinent). Both wide and long, the pedigree reveals that:

- Farmers in 17 countries contributed landraces or selections.
- Breeders in 14 countries contributed lines.
- Landraces and lines originated on six continents and in most of the major wheat-producing nations of the world.

Veery's pedigree (Appendix Figure C2) is also very large. The segment depicted shows two "wide crosses." The Kavkas grandparent carries the IB/IR translocation[5] through a wide cross with Petkus rye—a cross that occurred naturally in a farmer's field. One of Veery's ancestors is Bezostaya (from the former Soviet Union), which is among the few products of early scientific plant breeding that has been called a "wide" cross due to the breath of its ancestry (Lupton 1988). Through both Bezostaya and Mexipak (cross II8156, not expanded here; see Smale and contributors 1996), familiar European, North American, and South American landraces recur. Mexipak's pedigree includes major European landraces (Squarehead, Fife, Rieti, and Zeeuwse Witte through Mentana), Kenyan lines of unknown origin, East Asian landraces (Akagomughi and Daruma), landraces of the Southern Cone (such as Barleta and Pelon), and various other landraces.

For Veery and Sonalika, and for most modern wheats, new landraces tend to be incorporated through crossing lines with their own distinctly different pedigrees. For example, crosses and selections from Gabo in the Mexipak pedigree bring in the genetic background containing Steinwedel, Blount's Lambrigg, and Gaza. The Kenyan lines introduce unknown genetic backgrounds and landraces such as Red Egyptian. The well-known Norin 10-Brevor cross introduces Daruma. Strampelli's Mentana cross contributes Akagomughi. In Veery, the cross of Buho with Kavkas carries a number of lines and landraces from Germany and the former Soviet Union.

The way landraces are introduced in the pedigree of Gerek 79 (a winter wheat that has facultative characteristics) is an exception among the major wheats grown in the developing world. Gerek 79's pedigree (Appendix Figure C3) includes direct and recent introductions of Turkish landraces. One of Gerek 79's parents is a selection from a local landrace. One of Gerek 79's grandparents is a selection from a mixture of crosses between Mentana and other Turkish landraces.

On the other hand, Gerek 79's pedigree also appears relatively simple compared to Veery's or Sonalika's. Through Mayo 48, Gerek 79 carries pedigrees of lines that are common to many advanced lines now grown in both the developed and developing world. Unlike most of today's popular wheats, however, Gerek 79 does not contain the *Rht*1 or *Rht*2 genes and is not of semidwarf stature.

Measuring Genetic Diversity

Unless we can measure genetic diversity, we cannot track its path or ascribe an economic value to it. In applied genetics, *genetic diversity* is a statistical concept referring to the variance at individual gene loci (among alleles of a gene), among several loci or gene combinations, between individual plants within plant populations, or between populations. In principle, each level or type of variance can be estimated from measurements taken on a sample of plants drawn from a plant population. The relationship between population geneticists' precise definitions of variation and what can be observed in farmers' fields, however, is not so simple. In wheat, this is true for at least two reasons.

5 Refers to the translocation of the short arm of chromosome 1R of rye and the long arm of chromosome 1B of wheat.

First, a plant's genotype, or the constitution of its genes, is distinct from its phenotype, or physical appearance. The environment in which a plant grows influences the expression of its genes. Such influences include everything from soil, moisture, and light conditions to the physical proximity of plants. Environmental differences can cause two identical genotypes to appear different. Conversely, two genotypes may appear similar in an environment that inhibits the expression of their genetic differences.

Second, many economically important, observable traits are controlled by more than one gene. Examples of such traits include yield, grain quality, and the polygenic forms of disease resistance (see Box 3). This fact complicates the analysis of genetic variation. It implies, for example, that similar phenotypes can be produced by different gene combinations. Often, large differences in the expression of economically important traits are associated with relatively small differences in genotype.

Further, the range of variation that we can estimate from a sample we draw today is much more restricted than the *potential* range of variation. Potential variation is determined by the total number of gene combinations that *could* occur in the primary, secondary, and tertiary gene pools. That number is clearly unknown. Molecular biologists can expand the potential for genetic recombination—and hence the breadth of the gene pool—by introducing genes from distant species or genes wholly synthesized in the laboratory.

Biological and social scientists approach the study of genetic diversity from different perspectives; consequently, their tools measure different dimensions of diversity. In some cases they use similar terminology to denote different phenomena, as in the case of *yield stability* (Box 4). In general, the relationship among indicators is difficult to establish empirically. For example, techniques from molecular biology are the key to measuring diversity among genes, but the empirical relationship between molecular and other indicators (e.g., morphological or parentage) may be weak (see Cox et al. 1985; Sorrells et al. 1993).

Crop breeding perspectives

Wheat breeding involves the continual reassembly of genes and gene combinations in an attempt to alter, by selection, the average expression of a wide range of economically important traits. Today's scientific plant breeders work not only with visible variation in plant characteristics through conventional genetic analysis, but also increasingly with parent-offspring studies, pedigree analysis, and information provided by molecular biologists. There are many indicators, or "windows," on genetic diversity; these can be measured in gene banks, at laboratories, in on-station trials, and in farmers' fields. Some of these indicators are shown in Table 2.

At the molecular level, genetic diversity can be detected with biochemical and molecular markers. Biochemical markers include seed storage proteins and isozymes—proteins with an enzymatic function (also used in genetic fingerprinting). Isozyme techniques are comparatively inexpensive but powerful

Table 2. Measuring genetic diversity in crop plants

What is being measured?	Measurement tool
1. Diversity in single genes	Biochemical analysis of variation in alleles for a single gene
	Classical Mendelian analysis
2. Polygenic diversity	Multivariate analysis of morphological variation in traits whose expression is determined by more than one gene
3. Latent diversity of genome	Genealogical analysis
	Analysis of cytoplasm donors
	Molecular (DNA) analysis and probes
4. Pedigree complexity	Genealogical characteristics
5. Performance-based complexity	Analysis of genotypic variance and genotype-by-environment interactions
	Analysis of yield variance at farm, district, national, or regional level
6. *Ex situ* diversity	Analysis of numbers of accessions within and among species
	Morphological analysis of accessions
7. Spatial diversity	Number of cultivars by percentage of area
	Percentage distribution of area by cultivar
8. Temporal diversity	Average age of cultivars
	Rate of cultivar replacement

methods of measuring allele frequencies for specific genes, but because there are few isozyme systems per species (not more than 30), there are relatively few markers. Molecular markers are more expensive to use, but thousands of them are now known, thus enabling the study of a much larger number of the genes that code for plant expression, as well as other non-coding segments of the chromosome.[6]

Molecular geneticists have techniques to classify lines, populations, and landraces; to establish genetic linkages with traits of agronomic and economic interest; and to detect the effect of genetic variation on those traits. Once genes and alleles related to the expression of a trait are identified, the allele frequencies in a segregating population can be described by a standard set of summary statistics, and the apportionment of genetic variation within and between populations, races, or cultivars can be summarized and compared by multivariate analysis.

Box 4. Clarifying Yield Stability: Implications for Policy-Makers

In many developing countries, the consumption of staple foods depends on a small number of staple crops. A fairly stable national supply for these crops is generally believed to be beneficial. Large annual changes in the national production of staple foods can lead to unexpected imports. These place a burden on road and distribution systems and must often must be purchased under disadvantageous world market conditions. How stability of crop output affects the income of individual farmers depends on the composition of their farm and non-farm activities and on their ability to market their resources and products.

Unfortunately, social and biological scientists often use the phrase *yield stability* to denote different phenomena. As a consequence, the impact of plant breeding on national yields relative to other determinants is not easily understood.

When plant breeders test the lines they develop, they look for individual genotypes whose yields are stable over a broad range of environments. The most common method of assessing the yield stability of a genotype is to relate (through statistical regression) its mean yield by test site to the mean yields for *all* genotypes by site. A regression slope of 1 implies that a genotype performs similarly across sites.

By analyzing data from scientific trials, plant breeders are able to determine what part of the total yield variation is attributable to differences among genotypes, to differences in how genotypes interact with the environment (i.e., locations or years), or to differences among environments. Often, the largest part of the total yield variation is due to differences among environments—although the extent to which new varieties contribute to changes in yield variability differs greatly among regions (Arnold and Austin 1989).

Yield variation across regions is clearly influenced by social and economic factors that are beyond the purview of biological scientists. Economists typically use the ratio of the standard deviation to the mean as a measure of crop yield stability. They also use time-series estimates of crop yield data—adjusted to take out the effects of a rising mean over time—for given intervals. In this calculation, all wheat cultivars are grouped, and yields are aggregated at the district, regional, or global level.

Statistical analysis reveals that year-to-year variation in national yields primarily reflects changes in weather and the use of crop management inputs rather than varietal change (see Anderson and Hazell 1989; Singh and Byerlee 1990). The spread of irrigation has reduced the influence of weather conditions, but input use is very much influenced by pricing policy and supply.

For social scientists and policy-makers concerned about the stability of aggregate crop output, the most important determinants to consider are thus price policies, input supply, and crop management practices. Understanding the meaning of yield stability across disciplines remains a challenging task. (See, for example, Clevleand 1996.)

[6] Despite its great power, the molecular study of plant genetic diversity is in its infancy, and few detailed investigations of gene variations in wheat have been conducted. Molecular biology has shed light on the actions of specific genes and portions of genomes, but scientists still know little about the interactions of identifiable genes and other DNA sequences. DNA analysis is perhaps best classified as a means of measuring latent diversity in that it is most powerful when combined with conventional plant breeding methods, in testing for the presence or absence of traits that have economic value, or in seeking new ways to incorporate useful diversity from other species.

Classical or Mendelian genetic analysis can be used to evaluate variation in single known genes (qualitative traits), such as those conferring certain types of disease resistance. Forms of multivariate analysis can be used to analyze variation in traits whose expression is governed by one or more gene loci. Pairwise coefficients of parentage can be calculated from pedigree information and used as indicators of genetic diversity (Cox et al. 1986). Souza et. al. (1994) have described the coefficient of parentage as an indicator of *latent genetic diversity.*[7]

In both experiment-station and on-farm trials, crop scientists use statistical methods to measure the yield stability of lines and to attribute observable variation to one of three sources: genotype, genotype-by-environment interactions, or environment. Scientists use univariate and multivariate statistics to analyze the variation in *ex situ* accessions by source, type of accession, or morphological characteristics. Trials can also be designed to analyze the performance of cultivars represented in collections. Genetic distance measures can be calculated with molecular, morphological, or genealogical data (see Dudley 1994).

Social science perspectives

Compared to plant breeders and molecular geneticists, social scientists measure genetic diversity with rough and imprecise tools. That roughness reflects, in part, a difference in focus. Social scientists are concerned less with variation as measured at the molecular level than variation as it is recognized by farmers and valued by various social interest groups. In the more detailed case studies of diversity in farmers' fields, human ecologists and anthropologists have attempted to understand and relate farmers' knowledge systems and taxonomic classifications to those recognized by biological scientists (e.g., Bellon 1990; Brush et al. 1992; Sperling et al. 1994; Dennis 1987; Richards 1985). Less detailed studies have used farmer surveys to elicit information about the number of cultivars and area planted by trait, crop use, and source of seed. Research by Meng et al. (1995) in Turkey is a unique example which combines molecular, varietal, and household survey data (see Box 2).

At the other extreme from this field-based work are those studies based on secondary sources and published data. On the basis of broad distinctions such as cultivar names or classifications such as "modern" and "traditional," cultivar numbers or the percentage distribution of crop area by cultivar type are used as indicators of *spatial diversity.*[8] Changes in these counts or area distributions provide measures of "diversity in time" (Duvick 1984). Other measures of *temporal diversity,* such as the average and weighted (by area) age of cultivars, have been proposed, used, and reviewed by Brennan and Byerlee (1991) and Brennan and Fox (1995). Genealogical characteristics have been used by Gollin and Evenson (1990); these include numbers and origin of landraces, and numbers of breeding generations since the first cross (referred to as *pedigree complexity).*

For economists, performance-based measures of diversity include analyses of crop yield stability over geographical areas and analyses of variance in net economic returns (Box 4). The primary purpose of such analyses has been to identify the factors that affect farm- and national-level risks, not genetic diversity.

Integrating diversity indicators

To understand how the diversity found in farmers' fields can be managed or enhanced to serve productivity or conservation objectives (or both), researchers still face the challenge of integrating measures that are meaningful for conducting biological research with those that are meaningful for designing economic policies. One major obstacle has been that the classification of cultivars, varieties, and traits found in aggregated data or derived from socioeconomic surveys is not easily related to biological classifications unless the work is designed with an interdisciplinary approach.

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[7] The coefficient of parentage (COP) (Malecot 1948) estimates the probability that a random allele taken from a random locus in one cultivar is identical, by descent, to a random allele taken from the same locus in another cultivar. Values range from 0 to 1, higher values indicating higher relatedness. St. Martin (1982) adapted the COP to the analysis of inbred crops and Cox (et al. 1986) developed assumptions to account for the effect of re-selection. The coefficient of diversity = 1 – the coefficient of parentage.

[8] Other measures of spatial diversity, such as the Herfindahl and dynamic Herfindahl indexes used by Pardey et al. (1996), are also based on area shares or percent area in cultivars.

Another difficulty is that variation at gene loci provide the most explicit measure of genetic variation, but farmers choose cultivars, not DNA sequences. Farmers' choices are based on readily observable plant characteristics. These choices are constrained by a number of social and economic factors, such as seed price and availability. Links need to be established between methodologies for understanding and predicting the effect of policy variables on farmers' cultivar choices with methodologies designed to understand genetic variation in plant populations.

In deciding which are the appropriate indicators to use in a particular context, researchers may wish to distinguish between managing genetic resources for strict conservation purposes and managing them to enhance productivity by improving yield stability and reducing losses due to disease. These two objectives are interrelated (and may conflict) when the issue is how to develop incentives for conserving crop diversity among farmers who grow both traditional and modern cultivars (see Box 2).

Genetic Variation Among Major Bread Wheats in the Developing World

This section is divided into three parts: we begin by examining evidence of genetic variation in farmers' fields, follow that with a similar examination of evidence from breeding programs, and conclude by noting the ways in which wide crosses and biotechnology can expand the gene pool of cultivated wheats. Throughout, our focus is on bread wheats grown in the developing world as of 1990—although we also include points of comparison with industrialized countries (see also Box 5).[9]

Throughout this section, we use the term *modern* to denote both tall and semidwarf varieties that are products of a plant breeding program. We use the term *traditional* to refer to those varieties which are the products of farmer selection. We base much of our analysis on the number of distinct crosses rather than the number of cultivars, since several varieties can result from the same cross and any one of these varieties can be released and grown under different cultivar names. The latter happens, for example, when national programs re-release (and rename) a line or variety obtained from an international research institution or another national program.[10] Information on data sources appears in Appendix B.

Evidence from farmers' fields

Bread wheats dominate the wheat area of South Asia, eastern and southern Africa, the Southern Cone of South America, and Mexico/Guatemala. Less than 20% of the developing world's total bread wheat area is still sown to traditional cultivars. Most of the area in traditional bread wheats is in West Asia (i.e., Afghanistan, Iran, and Turkey).

Spatial diversity

In 1990, South Asia and the Southern Cone were the developing-world regions with the greatest absolute number of modern bread wheat cultivars and crosses planted in farmers' fields (Table 3). Our findings indicate that regions with the largest bread wheat area (South Asia, the Southern Cone of Latin America, and West Asia) are the least diverse as measured by the number of distinct crosses grown per million hectares.

Table 3 shows the percentage of area planted to the top five unique crosses for each developing country region. The area share of the top five crosses ranges from 43% in the Southern Cone to 71% for Mexico/Guatemala and the Andean Region. West Asia has a relatively high level of spatial diversity, which may in part reflect the importance of traditional bread wheats grown in that region.

[9] The People's Republic of China is the largest national producer of wheat in the developing world, but the CIMMYT Wheat Impacts Survey contains data on cultivars grown in only one of its regions. CIMMYT is currently working to improve the coverage and quality of data on wheat releases and pedigree information in China (see Box 5).

[10] The most precise level of detail for identifying a unique product of a breeding program—a variety—is given by a combination of cross and selection information. In the tables, and for calculating coefficients of parentage, selections from one cross have been treated as the same cross. This slightly overstates the similarity of parentage and probably understates the diversity.

Box 5. Wheat Genetic Diversity in the People's Republic of China*

Chinese farmers have been growing bread wheats for thousands of years. The government of China also pursued an isolationist policy for more than two decades after the establishment of the People's Republic in 1949. Given these two facts, one might expect national landraces to dominate the ancestral pool of China's modern wheat cultivars. Preliminary analysis suggests that this expectation is wrong.

Chinese landraces served as key ancestors in the nation's early phases of modern plant breeding, and there may now be a resurgence of interest in their special characteristics. But foreign parents (particularly several Italian and U.S. lines) have figured prominently in the pedigrees of major cultivars grown over the past few decades. The key Italian lines are descendants of the famous cross made by Strampelli in about 1930 (see Section I). Italian cultivars and their derivatives were once planted directly to large portions of China's wheat area.

Through the Italian lines, and later through the Mexican lines, the ancestry of China's modern wheats is inextricably linked to the ancestry of the major cultivars now grown in other parts of the developing world. Through the U.S. and Mexican lines, China's wheats are also linked to those of North America, and, through them, to the Crimea, even though many of the lines introduced more recently and directly from the former Soviet Union have not adapted well to China's growing conditions.

Ironically, the ancestry of China's modern wheats traces to Europe and back to East Asia. As noted elsewhere, the dwarfing genes in China's dwarf and semidwarf varieties originated with Akagomughi and Daruma (both from East Asia). Chinese breeders introduced Daruma's genes more recently and directly than Akagomughi's through crosses with Suweon 86 of Korea. Although evidence is inconclusive, there may be other, indigenous Chinese sources of dwarfing genes.

Recent political reforms have had important implications for wheat breeders. Germplasm exchange has become more routine, and the use of Chinese germplasm by other national and international breeding programs, as well as the use by Chinese breeders of new sources of foreign germplasm, has likely expanded.

Political and economic reforms have also had an important impact on farmers. Prior to the late 1970s, cultivar diffusion was to a large extent planned through a government hierarchy and administered through collectives. With decentralization and the devolution of decision-making from the national government to the provinces, counties, and individual farmers, the spatial pattern of cultivars grown in China has gradually changed. Previously, numerous landraces were planted locally, along with *a few dominant modern wheats*, many of which were *introduced* rather than nationally bred. Presently, few landraces are planted locally, and *a larger number of modern wheats*—most of which are *nationally bred*—are each planted in small areas.

This pattern is similar to that found in India and the U.S., although all the wheats in the U.S. were initially introduced by migrating farmers, and in many parts of India, a few modern cultivars still dominate vast areas (see *World Wheat Facts and Trends Supplement 1995,* Part 1). In particular the percentage of area planted to the top five cultivars in China's major wheat-producing zone (Henan) is considerably lower than that of the Punjabs of India and Pakistan.

* Drawn from Yang and Smale (1996).

Although the share of wheat area planted to leading cultivars may appear high, it is probably lower today than in earlier decades of this century when new products from plant breeding programs dominated the wheat fields of Europe, India, Australia, and North America. Wilhelmina, released in 1901, dominated Dutch wheat acreage for 30 years and was also used in plant breeding in other countries. In Australia, Federation (1901) was the most popular variety from 1910 to at least 1925 (Macindoe and Brown 1968). The variety Gentil Rosso, derived from an Italian landrace, was cultivated over a large part of northern and central Italy, where it represented over 60% of the wheat crop in the early 1920s (de Cillis 1927).

Since the early years of this century, however, the percentage of wheat area planted to the dominant cultivar has declined in Italy (durum wheat), as well as in France, the U.K., the Netherlands, Hungary, and Yugoslavia (winter wheats) (Figure 4; see Lupton 1992 for more data). Bagnara et al. (1996) report that the number of varieties grown in Italy is higher now than it was several decades ago, with many of these varieties suited to their own agroecological niche. The pattern of concentration in area is less clear, and the study period too brief, for Sweden, Norway, Czechoslovakia, Poland, Spain, and Germany. In none of these countries, however, does the percentage distribution among leading cultivars appear more concentrated over time (Lupton 1992).

Downward trends are found in the U.S. since the 1920s and in the Indian Punjab since the early Green Revolution, although the concentration of area in leading cultivars remains high in the Indian Punjab (see *CIMMYT World Wheat Facts and Trends Supplement 1995,* Part 1, and Smale and contributors 1996). Estimates suggest that a tall bred cultivar called C591 covered most of the irrigated area and some of the rainfed area in the Indian Punjab during the late 1950s.

Since the beginning of the Green Revolution, the concentration of planted area among leading bread wheats in the developing world has also changed. The number of cultivars released in developing countries from the Veery cross is at least twice that of the cultivars derived from the II8156 (Mexipak) cross, but the area planted to all of them in 1990 was only about one-fifth the area once sown to II8156 alone (Byerlee and Moya 1993).

The European experience suggests that the early phases of commercialization in agriculture played a large role in reducing crop diversity in farmers' fields. Varieties bred by Henri Lévèques de Vilmorin and his son Philippe, for example, dominated French wheat breeding for the first half of the 20th century. Protective legislation further restricted the number of varieties French seed merchants could sell to farmers (Lupton 1987). Agricultural mechanization, such as more complex and precise seeding and harvesting machinery, requires more uniform phenotypes to work properly. Larger areas grown to uniform phenotypes are linked to economies of scale in machinery use (i.e., the per-unit cost of

Table 3. Indicators of spatial diversity among bread wheats grown in the developing world in 1990

	Sub-Saharan Africa	North Africa	West Asia	South Asia	Mexico/ Guatemala	Andean Region	Southern Cone	Developing world
Number of modern cultivars	39	28	51	64	42	27	64	310
Number of crosses from which cultivars are selected	30	23	47	51	36	25	54	234
Area in modern cultivars (million hectares)	0.7	1.8	8.4	29.2	0.9	0.2	8.8	49.8
Modern cultivars as % of area in bread wheats	86	83	53	93	94	87	93	82
Crosses/million hectares of modern cultivars	45	13	5	2	41	145	6	5
Top five crosses as % of area in modern cultivars	64	62	48	59	71	71	43	36.4

Source: Calculated from CIMMYT Wheat Pedigree Management System and data from CIMMYT Wheat Impacts Survey, summarized in Byerlee and Moya (1993).
Note: Regional numbers of cultivars and crosses do not total developing world because the same cultivar or cross may be grown in more than one region. The *developing world* category excludes China (see Box 4).

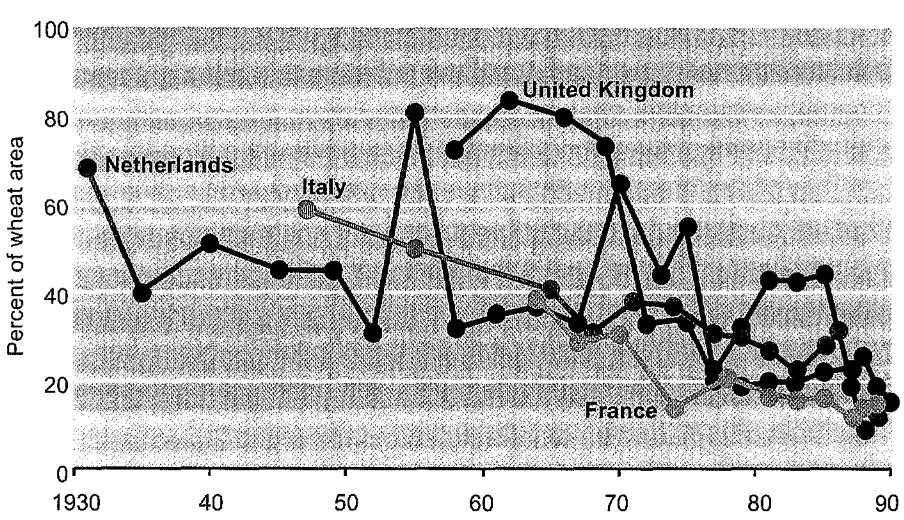

Figure 4. Area in dominant wheat cultivar, Europe, 1930-1990.
Calculated from Lupton (1992).

machinery declines as area on which it is used increases). Industrial processing also demands uniform grain quality. Today, the breadth of materials available to farmers and breeders in both developed and developing countries is clearly influenced by seed industry development and the impact of government regulations on public- and private-sector breeding efforts.

Temporal diversity

The average age of crosses in farmers' fields, weighted by area planted, is a measure of temporal diversity (the lower the age, the higher the temporal diversity). On a broad scale, such diversity ranges from about 8 years for Mexico/Guatemala to about 15 years for North Africa (Table 4). The rapid change implicit in the lower figure reflects, in part, the need to keep pace with variations in rust fungi.

Brennan and Byerlee (1991) have estimated the weighted average age of cultivars for a number of wheat-producing zones over several decades. Among zones they studied, the Yaqui Valley of Mexico had the highest temporal diversity, with a weighted average age of only 3.1 years. The Punjab of Pakistan proved the least temporally diverse, with a weighted average age of about 11 years. Wheat-producing zones in Brazil, Argentina, the U.S., Australia, New Zealand, and the Netherlands averaged from 7 to 10 years. By contrast, Canada showed a relatively low level of temporal diversity for an industrialized wheat producer: over the past 20 years, the average age has ranged from about 10 to 13 (see Thomas 1995).

Table 4. Temporal diversity among bread wheats grown in the developing world in 1990

Region	Weighted average age of crosses
Sub-Saharan Africa	11.3
West Asia	10.6
North Africa	14.7
South Asia	12.8
Southern Cone	9.2
Andean Region	13.7
Mexico/Guatemala	8.0

Source: Calculated from CIMMYT Wheat Pedigree Management System and data from CIMMYT Wheat Impacts Survey, summarized in Byerlee and Moya (1993).
Note: Weights are percent area planted to cultivars derived from the same cross. China is excluded.

The weighted average age of crosses has implications for resistance to both known and unknown pathogens. Using data from a number of countries, Kilpatrick (1975) estimated that, as an overall average, monogenic resistance to leaf and stripe rust lasts only five to six years. According to that estimate, all developing-world regions—and most countries within those regions—had weighted average ages below the desired range in 1990. Rust resistance is environment-specific, however, and the socially optimal period for cultivar replacement is a function of many economic (Heisey and Brennan 1991) and biological factors, among which pathogen resistance is only one. Higher turnover rates are associated with more favorable production environments because the conditions conducive to high productivity are also conducive to disease development. Varietal turnover is important for modern agriculture and in some ways substitutes for spatial diversity (Apple 1977).

Diversity indicators based on genealogical characteristics: Latent diversity

As calculated from the coefficients of diversity (see footnote 7, above), the latent diversity of the top ten cultivars planted in the developing world in 1990 appears fairly high, although the average coefficient of diversity varies by geographical region (Table 5). Among regions of the developing world, the average coefficients of diversity are significantly higher among the top ten cultivars grown in West Asia and the Southern Cone of South America than in South Asia or in Mexico/Guatemala.

As a point of comparison, Table 5 also presents the same indicators for three of the four major bread wheat producers of the industrialized world. In Australia, average and weighted coefficients are almost equal, which implies that the crosses are distributed more or less equally as a percentage of national area. Each Australian state has a different set of leading cultivars, and the environment is more varied than in the U.S. or Canada. The lowest diversity among pairs of cultivars is near zero in Canada, and the highest is lower than for the other industrialized producers and the developing regions.[11] The top ten cultivars grown in Canada are statistically less diverse than the top ten cultivars of the other developing or industrialized regions considered.

[11] France, the fourth major producer in the industrialized world, is not represented, although some well-known aspects of its wheat-breeding and patenting history suggest that latent genetic diversity may be fairly low in that nation.

An estimate of "genealogical distance" suggested by the work of Weitzman (1992)[12] is also shown in Table 5. As compared to a simple average of the coefficients of diversity for each group of ten cultivars, this indicator represents the sum of the distances of each cultivar from all other cultivars in the set based on the pairwise coefficient of diversity as a measure of distance. Once again, Canada's leading spring wheats appear markedly less diverse than those of the other major industrialized wheat producers or the developing regions. Mexican wheats, grown in a small and relatively homogeneous production environment, also appear considerably less diverse—a result that tends to be obscured by simply averaging the coefficients of diversity. The top ten bread wheats of West Asia continue to appear relatively diverse compared to other developing country regions.

As these data indicate, variables that affect area distribution among cultivars can influence both temporal and latent diversity in farmers' fields. For all developing country regions, weighting by planted area reduces the coefficient of diversity, but not by a large magnitude. For Canada, weighting by percentage of area halves an already low average coefficient of diversity.

The difference between the weighted and unweighted measures of diversity crudely reflects the impact of seed distribution systems and other factors related to varietal adoption. Farmers will choose to grow the variety that is most attractive to them (in terms of profits or other measures of economic value), but their choices are often limited by locally available seed types. It may be important to remember that wheat science has little influence over the complex of socioeconomic factors that affect farmers' choices of varieties and the rate of varietal replacement in farmers' fields.

Table 5. Latent diversity of the top ten bread wheat crosses grown in regions of the developing world and in selected industrialized nations in 1990

Region/Country	Average coefficient of diversity	Average coefficient of diversity weighted by cultivated area	Minimum pair-wise coefficient of diversity	Maximum pair-wise coefficient of diversity	Genealogical distance
Developing world	0.78	0.70	0.43	0.98	8.18
Sub-Saharan Africa	0.79	0.77	0.28	0.99	8.29
North Africa	0.79	0.73	0.57	1.00	7.88
West Asia	0.84 [a]	0.80	0.67	0.99	8.11
South Asia	0.72 [b]	0.63	0.35	0.96	7.70
Mexico/Guatemala	0.69 [b]	0.63	0.57	0.88	5.80
Andean Region	0.80	0.72	0.41	0.99	7.89
Southern Cone	0.82 [a]	0.80	0.69	1.00	7.78
Industrialized producers					
Canada (spring wheats)	0.48 [e]	0.22	0.01	0.80	4.71
Australia (spring wheats)	0.74 [b]	0.72	0.30	0.98	8.63
U.S. (hard red spring wheats)	0.84 [a]	0.79	0.53	1.00	8.71

Source: Calculated from CIMMYT Wheat Pedigree Management System and data from CIMMYT Wheat Impacts Survey, summarized in Byerlee and Moya (1993).

Notes: Coefficient of diversity = 1 – coefficient of parentage. Genetic distance is measured as the total length of the dendogram constructed from Ward's cluster analysis of coefficients of diversity (see Weitzman 1992). Average coefficients of diversity with different letters are statistically different, using a nonparametric test. China has been excluded.

Diversity indicators based on genealogical characteristics: Pedigree complexity

Table 6 describes the developing world's top ten wheat crosses for 1990 in terms of pedigree complexity. Sonalika, Veery, II8156, and Bluebird have all been released by various names in various countries. South Asia has the largest wheat area and the most wheat producers. Seven of the top ten crosses were first released in India and Pakistan, and most of the area planted to these crosses is found in those nations. Klein Chamaco (an Argentinean cross), Gerek 79 (a Turkish cross), and Veery (released first in Mexico and Pakistan and subsequently in other countries) are also among the top crosses.

Together, the ten crosses covered about half the wheat area in the developing world in 1990. Sonalika alone, one of the oldest crosses, covered more than 10% of the area, all (or almost all) in the Asian subcontinent. The weighted (by area planted) average age of the top ten crosses, raised significantly by Sonalika and II8156, is 13 years. Since

[12] The sum of the branch lengths of the dendrogram constructed from Ward's cluster analysis of pairwise, ultrametric distances. Here, the pairwise distance measures are coefficients of diversity. Any pairwise distance measure that satisfies ultrametric properties can be used as the basis of analysis. A distance has ultrametric properties if $d(i,j) \geq 0$; $d(i,i) = 0$; and $d(i,j) = d(j,i)$—where d represents distance, and i and j represent points or individuals.

1990, however, the area planted to Sonalika has decreased substantially.

The breeding effort required to produce these leading crosses is evident in the large number of landraces, generations, and crosses in each pedigree. Sonalika and II8156—the oldest and probably the most popular over time—have among the shortest and narrowest pedigrees (in number of generations and number of crosses/generation), but less redundancy in use of crosses (i.e., a higher proportion of crosses are used only once in the pedigree).

The top ten crosses grown in the developing world in 1990 contain an average of 44 landraces, 19 generations, and 1192 parental combinations in their pedigrees, of which about 20% were used only once. By comparison, for all the different crosses grown in the developing world in 1990, the average number of distinct landraces per pedigree is 36. By region, in that year, the lowest average number of distinct landraces per pedigree is found in West Asia (21) and the highest in Mexico/Guatemala (49). Overall, the evidence suggests that, for 1990, the bread wheats that were the most "successful" in the fields of developing country farmers' also possess some of the most complex pedigrees, both in terms of investment by farmers (landraces) and investment by scientific breeders (generations and parental combinations).

Yield stability

Yield stability across developing regions is compared in Table 7. For every region, variation in wheat yields was greater in the decade preceding 1965 (i.e., the early phase of the Green Revolution) than in the most recent decade. In regions in which the largest proportion of wheat area is planted to modern wheats—South Asia, Mexico/Guatemala, and the Southern Cone of South American—variation in wheat yields has declined since 1965. In West Asia and North Africa, where modern wheats cover a smaller proportion of area, yield stability has not worsened over the past four decades. Only in the Andean Region and sub-Saharan Africa, both of which have small wheat areas, does yield variation appear to have increased since 1965. In both of these regions, however, the overall level of variation is quite low.

Table 7. Yield stability of all wheats grown from 1955 to 1994 in regions of the developing world

	Sub-Saharan Africa	North Africa	West Asia	South Asia	Mexico/ Guatemala	Andean Region	Southern Cone of S.A.
	Coefficient of yield variation adjusted for trend (%)						
1955-1964	10.8	13.4	8.7	6.5	12.3	9.8	12.9
1965-1974	4.3	10.3	8.0	9.1	7.9	2.4	8.1
1975-1984	7.1	12.1	4.0	3.0	5.6	5.6	12.2
1985-1994	8.8	11.0	7.5	4.0	5.5	4.8	5.0

Source: Constructed from FAO yield data using Cuddy-Della Valle Index (Cuddy and Della Valle 1978).
Note: China is excluded.

Table 6. Characteristics and pedigree details for the top ten bread wheats grown in the developing world, 1990 [a]

Year of cross	Initial release	Area planted (million ha)	% area in developing world	Number of generations in pedigree	Total no. of PCs [b] in pedigree (a)	No. of different PCs in pedigree (b)	% different of all PCs in pedigree (b/a)	No. of different landraces in pedigree	Country of initial release
Sonalika [c]	1966	6.28	12.61	17	420	90	21	39	India
HD 2329	1985	4.07	8.16	22	1946	153	8	58	India
Veery [c]	1977	3.36	6.75	23	3169	128	4	49	Mexico
HD 2285	1983	2.83	5.67	23	3295	187	6	59	India
WH 147	1977	1.59	3.19	17	295	85	29	48	India
II8156 [c]	1965	1.55	3.12	14	117	58	50	37	Pakistan
Gerek 79	1979	1.44	2.89	11	56	31	55	20	Turkey
Klein Chamaco	1978	1.14	2.28	21	1299	141	11	47	Argentina
Bluebird [c]	1969	1.11	2.23	18	668	91	14	42	Mexico
Lok 1	1981	1.09	2.18	18	650	104	16	39	India

Source: Calculated from CIMMYT Wheat Pedigree Management System and data from CIMMYT Wheat Impacts Survey, summarized in Byerlee and Moya (1993).
[a] China is excluded from the developing country category.
[b] Parental combinations.
[c] Selections from this cross have been released in various countries under different names.

Since the 1950s, then, the balance of general evidence from farmers' fields suggests that wheat yields have become more stable even as mean yields have increased. This holds true for the world, for the major wheat-producing countries of the developing world, and for India (see Anderson and Hazell 1989; Singh and Byerlee 1990). As explained in Box 4, however, year-to-year variation in crop yields is associated more with input supplies, pricing policies, and variations in growing environment than with genotype or plant stature.

Evidence from breeding programs

Diversity indicators based on genealogical characteristics: Latent diversity

The International Spring Wheat Yield Nursery (ISWYN) contains some of the most advanced materials available to developing country breeding programs, including some CIMMYT and many non-CIMMYT entries. From these lines, national programs can select materials suitable for release to farmers, subject to approval by national varietal release committees. ISWYN entries thus represent the potential for diversity among future varietal releases in developing countries. Over the past 30 years, latent diversity in ISWYN materials, as measured by the average coefficient of diversity among entries (see footnote 7, above), appears to have decreased slightly within a range that suggests a fairly high level of diversity (Figure 5). The downward trend is statistically significant, though small in magnitude.[13]

Diversity indicators based on genealogical characteristics: Pedigree complexity

In a sample of pedigrees of over 800 wheats released in developing countries since the early 1960s, the average number of different landraces per pedigree has increased over time. The upward trend observable since the 1970s suggests an average of one new landrace per pedigree, per year (see *CIMMYT World Wheat Facts and Trends Supplement 1995*). Table 8 further demonstrates that among the more widely grown CIMMYT bread wheats released since 1950, the number of *distinct* parental combinations and *different* landraces occurring in the pedigrees have both increased.

These are important findings. The nature of plant breeding is to build on past successes, and as a result, the number of generations, the total

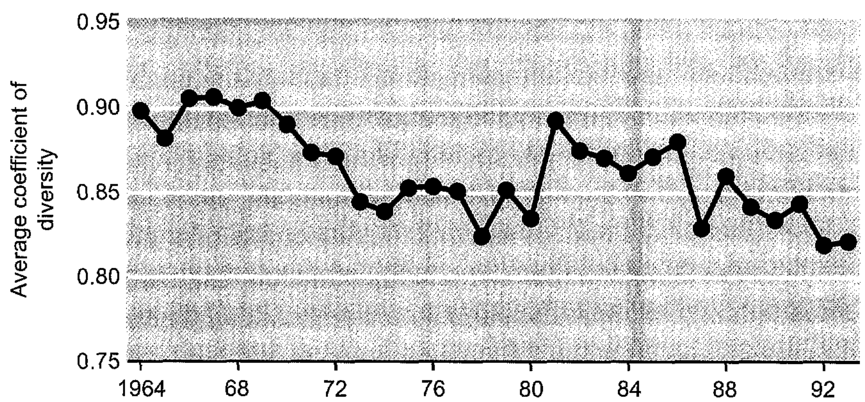

Figure 5. Latent diversity of ISWYN bread wheat entries, 1964-1993.
Source: International Spring Wheat Yield Nursery Annual Reports; Nightingale (1996); updated by Efrén del Toro.

Table 8. Pedigree complexity of widely grown CIMMYT bread wheats, 1950-1992

Cultivar	Year of release	Maximum number of generations in pedigree	Number of different parental combinations in pedigree	Number of different landraces in pedigree
Yaqui 50	1950	8	20	12
Penjamo	1962	13	40	26
Sonora	1964	15	55	31
Inia	1966	17	71	34
Tobari	1966	16	61	35
II8156	1966	14	57	35
Bluebird	1971	18	92	39
Tanori F 71	1971	18	84	36
Jupateco F	1973	19	96	40
Pavon F	1976	20	124	45
Nacozari F	1976	21	105	45
Ciano T	1979	21	160	62
Veery (Seri M8)	1982	23	127	47

Source: Calculated from CIMMYT Wheat Pedigree Management System and data from CIMMYT Wheat Impacts Survey, summarized in Byerlee and Moya (1993).

[13] Calculated with a Cox-Stuart one-tailed test; however, missing genealogies in the later years were excluded from analysis, so measurement errors may affect results.

number of parental combinations, and the frequency with which landraces occur in pedigrees can be expected to increase over time. In the early part of this century, for example, wheat breeders in many regions of the world used a few landraces from the former Soviet Union, Europe, and India extensively (see above). When advanced materials were later exchanged among breeding programs, the frequency with which many of these landraces occurred in the pedigrees of wheat releases increased, but not necessarily the number of *different* landraces.

As explained in Section I (above), however, only in a few cases today (e.g., Gerek 79) are landraces the recent and direct parents. New landraces are generally incorporated into the pedigree of modern wheats through the crossing of advanced materials with different genetic backgrounds. Box 6 summarizes the results of a recent survey investigating how wheat breeders in developing and developed countries use landraces, wild relatives, and various types of advanced materials in their crossing blocks and breeding programs.

Yield stability

Recent releases exhibit greater yield stability than did the early semidwarf varieties of the Green Revolution. CIMMYT's best advanced line in 1989, for example, yielded more than Yaqui 50 (1950) and Nainari (1960) across a range of moisture regimes, nitrogen levels, and weed conditions (Figure 6). Econometric analysis of trial data provides evidence that since the 1950s, successive CIMMYT wheat releases have shown either increasing yield stability, higher mean yields, or both (Traxler et al. 1995). Moreover, compared to tall varieties, leading varieties based on CIMMYT germplasm have required smaller and smaller amounts of land and nitrogen to meet the same level of wheat output (Figure 7); this is true over successive decades since the initial release of semidwarf wheats. In other words, leading varieties based on CIMMYT germplasm can make land available for alternative uses and reduce the chances for overuse of nitrogen.

Vulnerability to wheat rusts

Wheat rusts are not modern diseases. The Romans sacrificed red dogs to the god of grain in the hopes that he would prefer meat to wheat and thus keep the red rust at bay (Large 1962).[14] Historically, rusts have been the most serious wheat disease. Plant breeding programs were initiated, in large part, as an attempt to control them (see examples in Lupton 1987; Macindoe and Brown 1968; Howard and Howard 1909).

In the Asian subcontinent, the first stem rust epidemic was recorded in 1786 (Nagarajan and Joshi 1975), and concern for the magnitude of rust

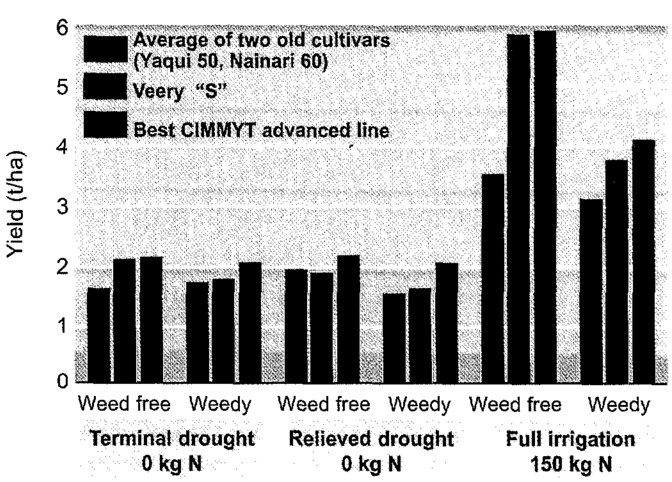

Figure 6. Input efficiency of old and new CIMMYT varieties under differing production conditions.
Source: Pfeiffer and Braun (1989).

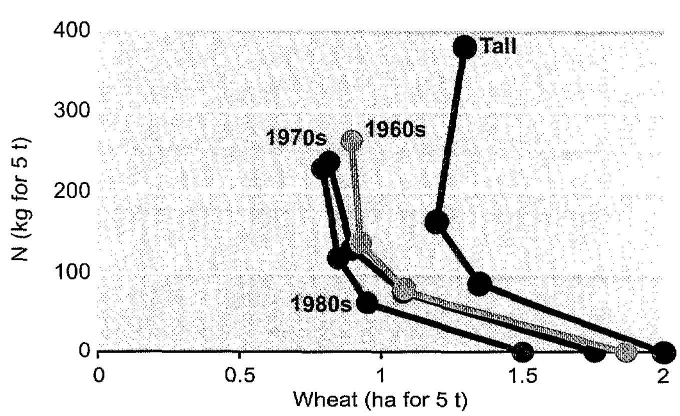

Figure 7. Kg of N required to grow 5 t of wheat. From right: *Tall*, two tall cultivars of 1950 and 1960; *1960s*, three semidwarfs of 1962-66; *1970s*, three semidwarfs of 1971-79; and *1980s*, two semidwarfs of 1981 and 1985.
Source: Calculated by Waggoner (1994) from data in Ortiz-Monasterio et al. (1996).

[14] In 700 B.C., the Romans reportedly created the god Robigus to protect them from the red rust of wheat (NRC 1972).

losses was expressed in government documents from 1839, well before the birth of scientific plant breeding programs. According to such records, Indian landraces— planted to millions of contiguous hectares—were notably susceptible to rust (Howard and Howard 1909; Nagarajan and Joshi 1985). One attraction of the semidwarf cultivars released in the 1960s was that they were less vulnerable to rust than the older, taller, later-maturing cultivars (Pal 1966; ICAR 1978). CIMMYT breeders worked for 20 years to develop semidwarf wheat varieties resistant to the major rust diseases (Byerlee 1994). From 1978 to 1981, in 50 locations in over 30 countries, CIMMYT tested traditional and modern

Box 6. Wheat Breeders' Perspectives on Genetic Diversity and Germplasm Use: Findings from CIMMYT's World Wheat Facts and Trends Survey, 1995.*

In a recent survey, wheat breeders working in national wheat research programs around the world expressed concern that lack of available genetic diversity may limit future scientific advances. Those surveyed enter advanced lines and released cultivars more often than other types of germplasm in their crossing blocks (Table A), but they use wild relatives and landraces in the pursuit of specific breeding objectives, such as disease resistance or drought tolerance. CIMMYT germplasm is used at least as often in breeding for disease resistance as for yield (Table B). The crossing blocks in developing countries contain larger sections of landrace materials and lines from CIMMYT International Nurseries, and as a result, may be more genetically diverse in terms of types and geographical origin of parent materials than those used in high-income countries or the former Soviet Union (F.S.U.) and Eastern Europe (Table A).

All of the wheat breeders surveyed in high-income countries stated that their country uses some form of varietal protection, as compared with only half of those in developing countries. Responses suggest that the establishment of global regimes for varietal protection would reduce the exchange of useful materials *among* developing nations as well as *between* developing and industrialized nations. Particularly affected would be the exchange among developing nations of nationally bred, advanced lines. The use of foreign landraces would probably decline too, directly through reduced exchange of available materials and indirectly since advanced lines borrowed from other countries often contain landraces from those countries in their genetic background.

Table A. Type of parent materials in wheat breeders' crossing blocks, 1994

Parent material	[illegible]		
	Developing countries	High-income countries	F.S.U. and Eastern Europe
Wild relatives	1	1	<0.5
Landraces of local origin	6	2	2
Landraces of foreign origin	2	5	4
Own advanced lines	35	46	50
Advanced lines from other countries	10	12	14
Released cultivars	16	18	24
CIMMYT International Nurseries	25	10	4
Others	5	6	2
Total	100	100	100

Table B. Type of parent materials used in crosses, by breeding goal, for developing countries, 1994

Parent material	Percent of crosses, by goal				
	Yield	Biotic resistance	Abiotic resistance	Quality	All
Wild relatives and landraces	5	15	22	21	14
Own and borrowed advanced materials	69	55	51	55	60
CIMMYT International Nurseries	23	27	22	20	23
Others	3	3	5	4	3
Total	100	100	100	100	100

* Of the 115 wheat breeders who responded, about one-third work in high-income countries and slightly under two-thirds work in developing countries. The remaining respondents work in the former Soviet Union or Eastern Europe. CIMMYT received a response from 68% of its questionnaires, which were either mailed or delivered personally. Countries are classified as *high-income* or *developing* according to the World Bank (1994). For more detail see Rejesus, van Ginkel, and Smale (1996).

spring wheats for stem, leaf, and stripe rust resistance. Figure 8 depicts the average coefficient of infection—an index ranging from 0 (disease free) to 100 (maximum infection)—for each cultivar type or category in 1980. Similar comparisons were found in the other study years. For leaf and stem rust, the semidwarf wheats were clearly superior to both traditional and modern (tall) varieties. Data on stripe rust indicate that semidwarfs were, on average, less susceptible than farmers' selections, but slightly more susceptible than modern (tall) varieties (Rajaram et al. 1988).

Of the six screening nurseries that CIMMYT annually distributes to cooperators in wheat-growing countries around the world, the one with the longest history is the International Bread Wheat Screening Nursery (IBWSN), initiated in 1967. The nursery contains 200-400 new, elite advanced lines from CIMMYT's Bread Wheat Breeding Program. Data on leaf rust resistance in the IBWSN since 1967 is shown in Figure 9 (updated from van Ginkel and Rajaram 1993); similar trends are found for stem and stripe rust. As measured by average coefficients of infection, advanced lines have in general proven increasingly resistant to stem, leaf, and stripe rust.

Today, most of CIMMYT's bread wheat germplasm contains what are currently understood as the sources of durable resistance to stem and leaf rust. CIMMYT's strategy for breeding host-plant resistance to wheat rusts is to accumulate genes from diverse sources and genes controlling various resistance mechanisms within individual cultivars (see Box 3). As befits such a strategy, the geographic origins of those sources are correspondingly broad; they include the Southern Cone of South America, the Andean region of South America, Mexico/Guatemala, North America, the eastern highlands of Africa, North Africa, the Iberian Peninsula, the Middle East, the Nile Valley, Europe, Australia and New Zealand.

Table 9 reveals the complexity of breeding for durable, polygenic resistance to the wheat rusts. As shown by the column describing resistance at the seedling stage, none of the single, named genes still confers resistance. Where resistance endures, it is partial and is conferred by more than one gene, each of which has a minor additive effect; unknown genes in the cultivar's background also appear to contribute to the resistance. The currently understood source of durable resistance is the combination of the gene *Lr*34 and other genes of minor effect.

Comparing types of resistance for several cultivars illustrates how little is known about its genetic basis. In Table 9, for example, WH147, Sonalika, Lok1, and WL711 all carry the known leaf rust resistance gene *Lr*13. All of them are also susceptible at the seedling and adult plant stages. HUW234 also carries *Lr*13, but is still moderately resistant—perhaps because of unknown, background sources. Similarly, although all of the known resistance genes in Pavon 76 have been overcome, the cultivar continues to

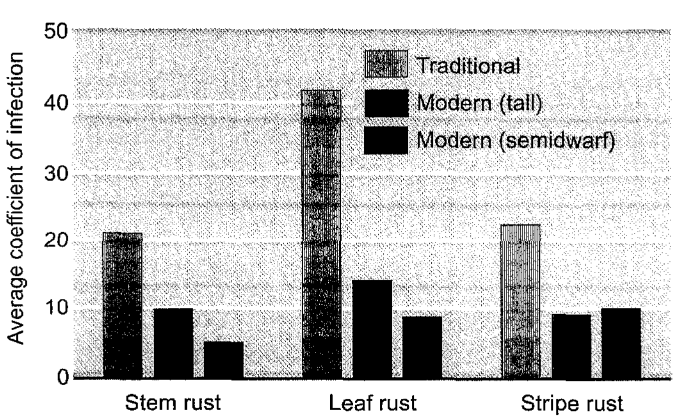

Figure 8. Rust resistance by wheat type, 50 locations in 30 countries, 1980.
Source: Rajaram et al. (1988).

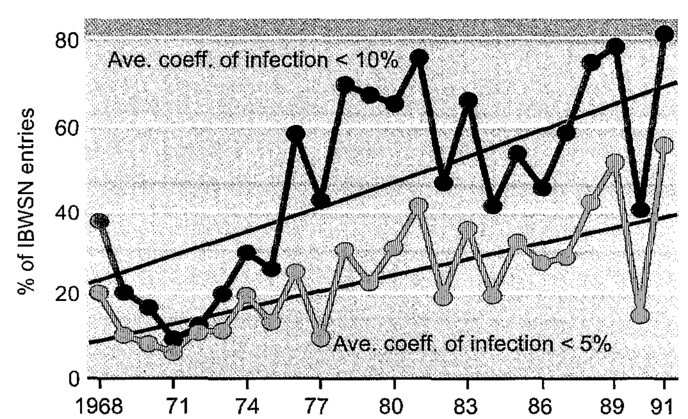

Figure 9. Resistance of advanced lines to leaf rust.
Source: Updated from van Ginkel and Rajaram (1993).

carry moderate resistance when planted on extensive areas in Pakistan due primarily to partial resistance based on minor genes. Incorporation of new single genes has not solved the resistance problem, even when they are alien resistance genes such as *Lr*26 (present in the 1B/1R translocation) and *Lr*19 (from Agropyron). In each case, new pathotypes have evolved shortly after the release of the cultivar.

Wide crosses and biotechnology

Over the past 15 years, CIMMYT wheat breeders have been conducting wide-cross experiments with the *Triticum* and *Aegilops* grass species (see Mujeeb-Kazi and Hettel 1995). The principal aim of that work is to enrich the gene pool of cultivated bread wheats by tapping the vast genetic resources available in the plant's wild relatives. These sources of variability have generally proven inaccessible to conventional breeders because of the difficulty of producing fertile progeny.

Of the approximately 325 perennial and annual grasses within the Triticeae tribe, relatively few have been hybridized with wheat. Recent successful hybridizations among wheat species now provide a potential stock of new germplasm. CIMMYT is adding to this stock a growing number of synthetic bread wheats, which are being developed through crosses between durum wheat and a number of diploid grass species and through other hybrid combinations produced by crossing wheat with various perennial species from the Triticeae tribe. In 1996, CIMMYT initiated its first international nursery for elite materials from the wide-cross program.

One prerequisite for the continued success of wide-cross breeding programs is the capacity for long-term investment with delayed payoff periods. Another is international collaboration among specialists and institutions. Both prerequisites are more easily met by international than national institutions.

Molecular biologists have an important role to play in broadening and enhancing the genetic diversity that plant breeders can then make available to farmers. By developing a detailed understanding of the wheat genome, they will help trace useful chromosome segments with greater accuracy. Already, such information has facilitated the wide-cross work described above. Molecular markers can now be used to test for the presence of alleles conferring resistance to disease. DNA "fingerprinting" can be used to increase the efficiency of germplasm banks by verifying that their accessions do not contain duplicates. Isozyme analyses can be used to measure the extent of gene flows between introductions and local populations. Such measurements have implications for the design of conservation projects. Other techniques, such as genetic transformation, may radically expand the genetic bases of crop plants.[15]

Table 9. Named genes for leaf rust resistance and current adult plant resistances of some cultivars grown in South Asia

Cultivar	Named Lr gene(s)	Current resistance	
		Seedling	Adult plant
Sonalika	*Lr*13	S	S
HD2329	*Lr*10, *Lr*13	S	MR-MS
HD2285	*Lr*13, *Lr*23	S	MS
PAK 81	*Lr*23, *Lr*26	S	MR-MS
WH147	*Lr*13	S	S
MEXIPAK	Unknown	S	MS
LOK1	*Lr*13	S	S
UP262	*Lr*13, *Lr*23	S	MR
WL711	*Lr*13	S	S
HUW234	*Lr*13	S	MR-MS
LYALLPUR73	*Lr*1, *Lr*13, *Lr*34 [b]	S	MR
C306	*Lr*34	S	MR
KANCHAN	*Lr*13, *Lr*23	S	MR-MS
PAVON 76	*Lr*1, *Lr*10, *Lr*13	S	MR
PARI 73	*Lr*1, *Lr*13	S	S
HD2009	*Lr*10, *Lr*13, *Lr*34	S	MR

Source: R. Singh, updated from Singh and Rajaram (1991) and Singh (1993).
Note: Based on the prevailing pathotypes during the 1994-95 growing season. All cultivars were R or MR at the time of release. R (resistant) indicates that the cultivar possesses good resistance; MR (moderately resistant) indicates adequate resistance; MR-MS (moderately resistant to moderately susceptible) indicates that although resistance is usually adequate, in some years it could be inadequate; MS (moderately susceptible) indicates inadequate resistance; and S indicates susceptibility to disease.
[b] *LR* 34 is an adult plant resistance gene which confers MR-MS response.

[15] For more detail on CIMMYT's activities in wheat genetic resources, international nurseries, prebreeding techniques, and molecular genetics, see Skovmand et al. (1995). See Box 2 for an overview of various conservation strategies.

Valuing Genetic Resources and Diversity

Economic analyses of biodiversity issues generally focus on endangered species. Economists have developed tools for valuing such species and for evaluating various protection strategies. These tools—some of which can also be applied to the study of diversity within domestic species—have often been criticized on *ethical grounds* (i.e., humans have no right to decide the fate of a species or subspecies) (Ehrenfeld 1981, 1988) and on *methodological grounds* (i.e., the tools are ineffective at predicting future needs in complex biological systems).

With respect to crop plants (as opposed to their wild relatives), the first of these criticisms seems much attenuated. Crop species, after all, are not in danger of extinction. Particular varieties are largely human constructs, selected and shaped to meet changing human needs. Preserving these constructs is not the moral equivalent of preserving a wild species—any more than maintaining a standard sheepdog color is the equivalent of saving wolves from extinction.

Individual cultures may wish to preserve selected varieties for a range of non-monetary reasons. Such preservation, however, is not the moral obligation of these cultures. They are free to transform or abandon particular varieties to suit their own changing needs. Given that not all genetic configurations can be preserved, economic methods may prove useful in establishing pragmatic selection criteria based on local and global needs and desires. Unless cultures are coerced into accepting varieties they do not want, it is not obvious how the selection of one such configuration could be morally or ethically superior to the selection of another.

With respect to the criticism that economics is poorly equipped to value biological diversity for practical ends, particularly with respect to future values in an open, dynamic system, one might ask this question: does the difficulty of such assessments and the rudimentary nature of the current tools mean that economists should abandon the field? The blunt fact is that farmers, policy-makers, and biological scientists are going to make decisions that affect genetic diversity based on acknowledged or unacknowledged assumptions of value. The relevant question is not whether economists are in a position to make perfect valuations, but whether economists can help these other groups make decisions based on a more accurate view of their likely consequences.

Valuing genetic resources is a challenging task that will require input from a variety of disciplines. At present, physical scientists cannot state with any certainty how much variation will be needed to ensure the most fundamental goals (e.g., long-term food security). Nor have social scientists always been adequately vigilant about examining the underlying assumptions of their various disciplines.

Valuing diversity

Valuing diversity poses difficult economic problems. Although questions of species existence are inherently moral judgments, economics operates within a utilitarian framework: its focus is human society and how to choose the best means of achieving a predetermined social goal (Randall 1986). In such a paradigm, diversity counts to the extent that people want it: humans assign value to diversity; other species become a means for satisfying human goals. Economists thus tend to approach diversity issues with what Ehrenfeld calls "the arrogance of humanism" (1981).

Even if we accept a utilitarian ethical framework, a number of difficulties remain. First, exploiting resources (commercially or otherwise) involves a trade-off between accruing benefits today and paying for resource scarcity tomorrow. But how the future is valued relative to the present differs among individuals, between individuals and society as a whole, between societies at different levels of income, and (most likely) between types of resources.

Second, uncertainty about the long-term consequences of current decisions obscures our view of how we should best use resources over time. Attitudes toward risk and uncertainty are also subjective. The passing of time brings information about the consequences of present actions, so there is a premium on the value of actions that preserve flexibility or substitutes—as in the case of a gene or gene complex that has been considered useless but whose value may increase when farming conditions change (see Brown and Goldstein 1984). The risk, of course, is that those who make conservation decisions today may undervalue such flexibility.

Third, genetic resources are public goods. Commercial markets thus "fail" to allocate them among their alternative users according to their full social value. By definition, it is costly to exclude individuals from using such resources, and more than one individual can consume them simultaneously. Either property rights need to be established to make genetic resources private and therefore exclusive and tradable, or other incentives need to be established so that those who use them value them fully.

But property rights are no panacea. Legal frameworks "fail" when their object is unidentifiable. And as we have shown, many aspects of genetic diversity are not easily (or are only partly) observable. Moreover, the essential genetic resource is not the gene, but the gene in combination with the genome (see below). Further, even if we could agree on what constitutes a genetic resource and identify it easily, the history of seed industries in industrialized countries demonstrates clearly that there are well-known incentives for interest groups or powerful lobbies to control property rights. Such control may not increase access to genetic resources by poorer nations or poorer farmers (Brush 1992a).[16]

The general framework for total valuation of resources

How can we value goods which are only partially traded in markets or not at all? The total valuation framework used by resource economists is based on a utilitarian notion of value and includes three components: current use value, expected future use value, and existence value (Randall 1988).

Use value (current or future) derives not only from direct commercial value through trading the good or service on the market, but from its use as an input in another production process; also included are non-commercial uses or aesthetic satisfactions—either personally or vicariously experienced. Expected future use values take into account the risk that the good or service may no longer be available when some future demand arises and that conversion of a resource into use today eliminates the possibility of preserving it and using it in different ways in the future.[17]
Existence value (Krutilla 1967) for a resource, also referred to as non-use value, is the satisfaction some individuals may derive simply from knowing that it exists, independently of how and when it is used.

Both the validity and relevance of certain valuation categories have been debated, but most typologies can be expressed as variations of the above. Some researchers have argued that the economic approach is incomplete because it fails to properly incorporate cultural values, folk knowledge systems, and the complex motivations people have in using certain natural resources (Brown 1994). In general, economists' typologies of total value do not include the philosophical notion of intrinsic value—that something has a value in and of itself (Mitchell and Carson 1989).

A valuation framework for wheat genetic resources and diversity

A simple but useful modification of the general framework proposed by resource economists is to identify which types of values derived from the use of a resource accrue locally and which accrue globally (Turner et al. 1993). Tables 10 and 11 apply the resulting valuation framework to the case of genetic resources and genetic diversity in wheat. Wheat genetic *resources* are differentiated from wheat genetic *diversity* in order to highlight more specifically the potential role of plant breeders and germplasm banks.

[16] Pray and Knudson (1994) have estimated the impact of intellectual property rights on genetic diversity in U.S. wheat. Using the weighted average coefficient of parentage as an indicator, they concluded that the passage of the Plant Variety Protection Act has not decreased genetic diversity in wheat.

[17] There is considerable debate in the economics literature over these concepts and the definitions of *option price, option value,* and *quasi-option value* (e.g., Arrow and Fisher 1974; Fisher and Hanemann 1986; Weisbrod 1964).

Wheat genetic resources

The basic unit of genetic resources is "a gene within the genome."[18] This definition encompasses each of the existing known and unknown combinations of genetic sequences that affect wheat biology, as well as potential sequences resulting from natural and scientific recombination and mutation.

The economic benefit of wheat genetic resources tends to be measured exclusively by the market value of primary and secondary wheat products and by-products (i.e., the prices of grain, wheat straw, bread, pasta, and biscuits) (Table 10). These values accrue to the farmers who produce the primary products, to the marketing and distributional chain for the secondary products, and to the world at large through trade.[19]

Table 10. Typology for valuing wheat genetic resources

Type of benefit	Accruing at local level	Accruing at global level
Direct Use Value		
Marketable primary and secondary products deriving from the plant, such as grain, straw, flour, bread, and pasta	x	x
Non-marketable products which have value to the household or community, such as aesthetic value, ritual value, folk medicinal value	x	
Indirect Use Value		
Positive effects on the output of other crops, on the species life of wild wheat relatives, or on domesticated wheats	x	x
Biotechnological research that results in transfer of wheat genetic resources to other species	x	x
Non-Use Value		
Existence of a domesticated wheat population, breeding line, cultivar or wild relative	x	x

Table 11. Typology for valuing wheat genetic diversity

Type of benefit	Accruing at local level	Accruing at global level
Direct Use Value		
Host plant resistance to biotic and abiotic stress	x	x
Yield potential	x	x
Yield stability	x	x
Aesthetic, ritual, or other culture-based value derived from morphological variation	x	
Indirect Use Value		
Positive ecosystem effects of diversity	x	x
Biotechnological research that uses wheat genetic variation in work with other species	x	x
Non-Use Value		
Existence of observable or potential (unobservable) genetic variation	x	x

A number of other benefits are associated with crop plants such as wheat, including aesthetic value, ritual value, and medicinal value. Such benefits are defined exclusively by the culture in which the crops are grown; similarly, benefits accrue only to members of that culture in areas where the crops are produced. Although these are direct use benefits, their value is hard to measure because they do not carry a market price and must be imputed or estimated through other means.

Wheat genetic resources may also produce indirect use benefits in the form of support to other members of the local and global ecosystem in cultivated or wild environments. For example, in the Netherlands, wheat is grown in rotation to break nematode development in the potato crop. Wheat also provides good ground cover in the form of straw, which protects the soil from erosion and provides nests for birds.

[18] D. Hoisington, personal communication. Often, we think of the most basic unit of genetic resources as a gene (a DNA sequence) because modern scientific technologies can manipulate genes, moving them from one plant to another. But this mechanistic definition ignores the more fundamental fact that the expression of any single gene is determined by many other genes, and that even noncoding sequences may play an important (if not fully understood) role in gene expression and inheritance.

[19] In the first study of its kind, Gollin and Evenson (1990) assessed part of the direct use value of genetic resources through yield impacts (for improved rice in India), measuring genetic resources in clusters of variables that describe their characteristics. A similar study has recently been conducted by Hartell for wheat in the Punjab of Pakistan (1996). Application of characteristics models (Barkley and Porter 1996; Melton, Colette, and Willham 1994) is a promising avenue of research.

Non-use benefits derive purely from the knowledge that a particular population, line, cultivar, or wild relative can be found locally or globally. For genetic resources in cultivated wheats, the existence value is likely to be far outweighed (at the margin) by use value, since there is little chance that the wheat species will become extinct, and the possibilities for genetic recombinations are still immense. By comparison, the existence value of some wild relatives and the genetic sequences believed to be contained in some remaining durum and bread wheat landraces found only in isolated localities is probably greater relative to their use value, because such resources are becoming increasingly scarce.

Wheat genetic diversity

This refers to the variation, or potential for variation, among all gene sequences, known and unknown, that control the biology of wheat. The direct use value of such diversity can be measured, in part, by its role in increasing host plant resistance to insects, disease, and abiotic stresses. Such increases, in turn, contribute to the major goals of wheat breeding: higher and more stable yields. Changes in crop losses due to stress, yield levels, and yield variation can be measured and valued with market prices.[20]

As expressed in morphological variation, genetic diversity confers some of the aesthetic, ritual, and culture-based values that are not usually prized in commercial markets (Table 11). In wheat, genetic diversity also provides potential benefits to other species, both in natural habitats where wild relatives grow and through biotechnological research. The existence value associated with genetic diversity has been widely expressed by various advocacy groups.

To farm households, the direct use benefits from commercial trade often outweigh the other categories of benefits, which is one reason why such households adopt high-yielding, resistant, stable varieties that are commercially attractive and morphologically uniform. On the other hand, many farmers continue to grow a range of cultivar types, maintaining variation in their own fields or at the community level (for Andean potatoes, see Brush 1992b and Brush et al. 1992; for a conceptual framework, see Bellon 1996). When the population sizes for some of these landraces become so small that genetic erosion or "genetic death" (critically low gene frequencies) is foreseeable, the existence value increases; nonetheless, farmers may not be able to sacrifice the opportunity to grow more commercially valuable crops in order to maintain diversity. And farmers cannot observe gene frequencies.

Both of the above frameworks depict value in current terms only. When we project to the future, these values are calculated based on what we know about attitudes toward risk over time and among individuals in a society. To have meaning in a policy decision, the net economic value (benefits less costs) of an activity designed to conserve or enhance diversity must also be related to the net economic value from the nearest alternative competing activity. Below, we illustrate one component of the cost of increasing diversity in farmers' fields.

An illustration of the costs of diversity[21]

Farmers in the Punjab of Pakistan tend to grow higher-yielding wheat cultivars, whether or not they are known to be susceptible to rust. When many farmers grow cultivars with similar resistance genes, the chances of a breakdown in resistance increase. One way to reduce the chances of a rust epidemic is by encouraging greater spatial diversity of cultivars in farmers' fields. We can calculate the cost of pursuing this strategy by comparing the wheat output associated with the distribution of wheat area and varieties that attain a targeted level of diversity to that associated with the distribution of wheat area and varieties that farmers actually plant.

Table 12 shows the resulting cost stream for the Punjab of Pakistan, from 1978 to 1990. The targeted level of diversity is defined as the area allocation that maximizes the average coefficient of diversity, weighted by the percentage of areas planted to cultivars. Costs are calculated using procurement prices converted to constant 1990 U.S. dollars.

[20] Hartell (1996) addresses yield stability effects of genetic diversity indicators in the Punjab of Pakistan. Widawsky (1996) has also analyzed the relationship of varietal diversity to the stability of rice yields among townships in China, using a diversity measure based on coefficients of parentage.

[21] Drawn from Heisey et al. (1996).

The data illustrate that in all but a few years, and particularly in later years, losses in wheat output are associated with pursuing a strategy to increase spatial diversity. The costs shown are partial; they do not include the costs of designing and implementing the policies that would have achieved the recommended portfolio. The unsolved economic problem is whether discounted social gains from preventing large future losses due to disease would be greater than the discounted stream of losses in wheat output and the costs of policy implementation.

Outstanding issues in economic policy

Wheat is not an endangered species—although certain wheat forms, gene complexes, and genes may be at risk. Analyzing the costs and benefits of conserving wheat forms in unthreatened reserves is a relatively straightforward matter of comparing alternative land uses—although estimating the value of the wheat forms to be preserved still poses a problem. Analyzing the costs and the impacts on productivity of tapping additional genetic resources and diversity (or of employing new technologies that reduce the costs of doing so) also seems a relatively well-defined economic issue—assuming enough is known about how to measure, specify, and evaluate the relationships we identify. The more difficult problem appears to occur at the interface of the conservation and productivity objectives: how is it possible to retain key gene complexes or traits where modern and traditional cultivars coexist and where the economic constraints farmers face (e.g., labor, prices, markets) rather than the pace of scientific achievements are the major determinants of farm-level diversity.

A substantial amount of economic research must be conducted before major policy interventions can be proposed and assessed. The detailed research on factors affecting diversity in the Punjab of Pakistan found in Heisey et. al (1990) is one example of the type of work that is needed for a broader range of production environments and socioeconomic conditions.

Nonetheless, the current dearth of such research should not discourage us from continuing to implement certain low-cost policies whose immediate benefits may be great in terms of avoiding heavier future costs (e.g., continued monitoring, collection, and protection of threatened wheat varieties and forms). Outstanding economic policy issues include, but are by no means limited to, the following:

- Policy factors that affect the rate of cultivar release and the speed of varietal turnover.
- Policy factors that affect the spatial distribution of varieties in farmers' fields (e.g., factors that determine the organization of seed industries and the availability of wheat seed from different varieties).
- The relative costs of various policy interventions to enhance varietal diversity in time and space.
- The comparative impact in farmers' fields of research investments in prebreeding, conventional breeding, and *ex situ* and *in situ* conservation (for national and international programs).
- The costs of, incentives for, and appropriate design of programs aimed to encourage farmer conservation of genetic diversity.
- The effect of intellectual property rights on the diversity of germplasm available for prebreeding and basic breeding activities by national and international programs.

Table 12. Costs of diversity in the Punjab of Pakistan

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
							1000 US$, 1990						
Costs of diversity [a]	5,357	-5,021	-615	12,928	14,204	20,217	13,297	21,536	35,518	57,881	71,361	71,965	78,846

[a] Defined as the value of wheat output losses associated with shifting from the cultivars and cultivar areas that farmers plant to those that maximize spatial diversity. *Spatial diversity* is defined as the weighted average coefficient of diversity (see footnote 7, above).

Summary and Conclusions

An historical sketch of wheat germplasm flows suggests that "to give is to receive." Wheat cultivars moved with human populations from the Near East to Asia, Europe, Africa, North America, and South America. In turn, these cultivars have often been modified by farmers and scientists in ways beneficial to the regions that originally donated the germplasm.

In general, however, landraces and wheat forms that have evolved for specific locations, times, and purposes need considerable reworking in order to be useful to the commercial agriculture of today and tomorrow. Risky, time-consuming, and expensive, such reworking is best undertaken by research organizations with the breadth of activities and funds to accomplish it. Research results also depend on a continual scientific exchange of basic materials, knowledge, and techniques among plant breeders. Restricting the exchange of basic materials (as compared to finished lines) may impede research discoveries and the dissemination of global benefits.

The findings assembled here demonstrate that, over the past 40 years, yields and yield stability have increased—both in experimental lines and in farmers' fields. Much remains to be done in fighting rusts and other diseases, but current research strategies are much improved from the boom-or-bust, race-specific approach of early plant breeding programs. Researchers now work to build durable, polygenic forms of resistance based on the accumulation of genes from diverse sources. However, scientists must still learn how best to combine conventional plant breeding with new molecular and cytogenetic techniques in order to tap new dimensions in genetic diversity.

Our findings here and in the *World Wheat Facts and Trends Supplement 1995* indicate that, for the past several decades, the number of modern cultivars being grown in the major wheat-producing areas has increased and that the percentage of area planted to individual cultivars has decreased. At least some of the factors that influence spatial and temporal diversity in farmers' fields are familiar to social scientists working with plant-breeding institutions. These include factors that affect the structure and performance of seed distribution systems, the rate of cultivar release and replacement, and the diffusion patterns of new cultivars. Much remains to be learned about monitoring the conditions in farmers' fields in ways that incorporate meaningful indicators of diversity. In addition, researchers must work to formulate policy recommendations based on a careful analysis of economic trade-offs.

As cultivars bred by professional plant breeders have come to dominate bread wheat area, ancient patterns of variation have been replaced by modern patterns. In describing the genealogical complexity of modern wheats, we have tried to underscore the effort that has gone into their development and the goals that have informed that effort. But what emerges most clearly from our investigation is how easy it is to devise "indicators" without truly understanding the larger implications of what we are defining and measuring.

That lack of understanding often results in strident polarization. On one extreme are those who argue that humans are destructive intruders with no right to assign value to diversity; at the opposite extreme are those who argue that diversity is valuable only when it can be counted in trade figures or industry profits. Between these views lies what Strachan Donnelley calls, in another context, "the troubled middle" (1990). Charting that terrain is the difficult imperative that lies before us.

In large part, the purpose of this paper has been to move the debate into this uncomfortable region. We have tried to suggest that, insofar as is possible, analyses of diversity issues must be based on empirical fact. Knowing that decisions of one sort or another will be made and that the ramifications of these decisions are both difficult to foresee and profoundly significant for the well-being of future generations, we have also tried to suggest that diversity issues are best approached with what Don Duvick calls "the humility of humanism" (personal communication). Such an approach must avoid the dangerous *hubris* of overestimating our powers of foresight and analysis without succumbing to the equally dangerous tendency of abandoning them.

Finding the most effective ways to involve international agricultural research institutions in the protection and enhancement of wheat genetic diversity remains a daunting task. It is no less important for being daunting, however, and it is clearly a task that such institutions are, at least in part, well-suited to undertake.

Part 2

The Current World Wheat Situation

Paul W. Heisey, Pedro Aquino, Victor Hernández, and Elizabeth Rice

Production

World wheat production in 1995 was estimated at 541 million metric tons, up 2.6% from 1994 levels, but still well below the record harvest of 1990 or the harvests of 1992 and 1993. In 1995, wheat production continued to expand in South Asia. In China, production rose 3% from the previous year. In Australia, production recovered dramatically from the 1994 drought.

In developing countries, the 1995 wheat harvest was the second highest on record, marginally below the 1993 total. Over the past five years, developing countries have produced 45% and more of the world's wheat, compared with about 30% in the 1950s and 1960s. In contrast, wheat production in the transitional economies of the former Soviet Union fell sharply in 1994 and 1995 to levels not seen since the late 1960s (with the exception of a bad harvest in 1975). Wheat output in Eastern Europe was actually above average in 1994 and 1995, but not enough to offset the large reduction in the former Soviet Union. Though wheat production in high-income countries grew steadily from the 1950s through the mid-1980s, the share of wheat output produced in high-income countries has fallen slowly over time, from about 45% in the early 1950s to about 35% recently. For the past decade and more, changes in policies such as land idling requirements and export subsidies have played a particularly strong role in determining wheat production in many high-income countries (Figure 1).

Area fluctuations in high-income wheat producers still influence world wheat output, and there may be potential in the future to restore some area to wheat production in the transitional economies, where it has declined over the last 30 years. But for the world as a whole, expansion of wheat area has not been a major source of greater wheat output for many years. In developing countries, wheat area expansion was lower in the last decade than at any time since the late 1950s and early 1960s (Figure 2). Yield increases remain the major component of increased wheat production in both developing and high-income countries, but in both groups, rates of yield increase from 1986 to 1995 (1.8 and 1.5% per annum, respectively) were lower than in the previous two decades. Wheat yields in developing countries have been higher than wheat yields in the transitional economies for most years since the early 1980s and are now nearly 80% of the average yields for all high-income countries. In the transitional economies, yields as well as areas have declined over the past 20 years.

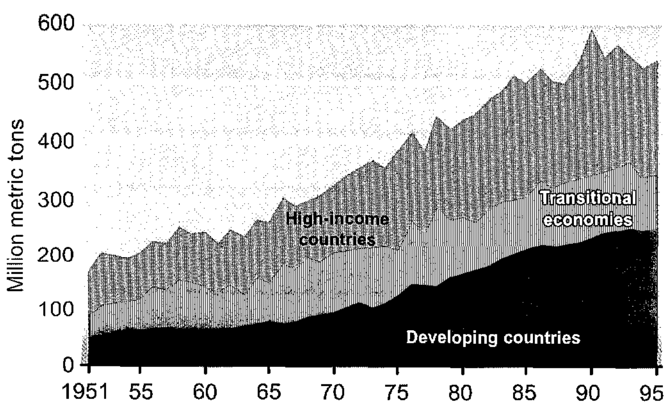

Figure 1. World wheat production, 1951-1995.
Source: FAO Agrostat data files.

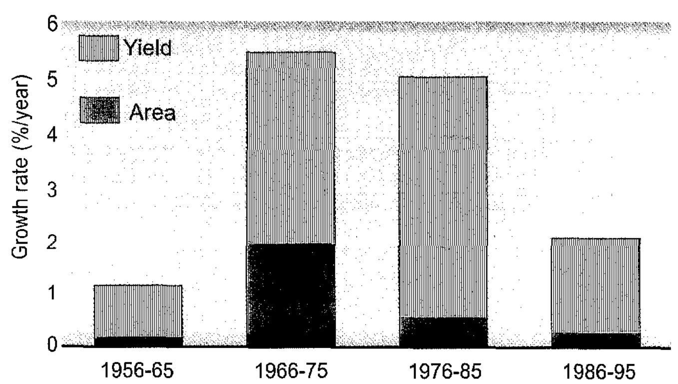

Figure 2. Sources of growth in wheat production in developing countries.
Source: Calculated from FAO Agrostat data files.

Trade

Published sources present varying estimates of the volume of international wheat trade. These differences stem from at least three causes. First is the issue of which transactions constitute international trade. All countries are included in the basic Food and Agricultural Organization (FAO) data series that we use for our historical data on wheat trade. On the other hand, in its periodical publications such as *Food Outlook*, the FAO excludes from consideration trade within the European Union (EU) and within the Commonwealth of Independent States (CIS) of the former Soviet Union. The International Grains Council (IGC) also excludes from consideration EU and CIS inter-trade. The United States Department of Agriculture (USDA) excludes EU inter-trade but includes trade within the CIS in periodical reports such as *Grain: World Markets and Trade*. Second, different sources may use differing time units, such as marketing years, international years, or calendar years for reporting trade figures. Third, basic data obtained by the various institutions estimating world wheat trade may vary.

Based on an "all country" convention, the total volume of wheat traded internationally in 1995 was approximately 108 million metric tons, little changed from the 1994 total and lower than the amounts traded from 1991 through 1993. If EU and CIS intertrade is excluded, international wheat trade in most recent years has been about 93 or 94 million metric tons.

Despite the rapid increase in wheat production in the developing world over the past 30 years, developing countries now account for two-thirds of all wheat imports based on the "all country" convention, up from less than half in 1961. China, the world's largest wheat producer, is also the world's largest wheat importer. Since 1980, Chinese net imports have averaged over 10 million metric tons annually, or (very roughly) 10% of annual requirements. Another large importer in East Asia is South Korea, where per capita wheat consumption is relatively high and where there is almost no local production. A number of countries in North Africa, West Asia, and South Asia produce wheat but also have very high per capita wheat consumption. Among the developing world's largest importers in recent years, these countries include Egypt, Algeria, Iran, Morocco, Pakistan, and Yemen. Other large developing country importers include Brazil (which produces wheat) and Indonesia and the Philippines, (which do not).

From the early 1970s through its breakup, the Soviet Union was, in many years, the world's largest wheat importer. In the first few years of the post-Soviet era, imports into that region remained high. They fell sharply, however, in 1993 and to even lower levels in 1994 and 1995. Since 1994, the transitional economies, including Eastern Europe, have accounted for only about 5% of total world wheat imports. Depending on production conditions, Kazakhstan has been a net exporter in some recent years, shipping as much as 5 million metric tons or more to other CIS countries.

From the early 1960s through the late 1980s, wheat imports by high-income countries remained roughly constant at about 20 million metric tons per year. In high-income countries, wheat imports appear to have increased somewhat in the first half of the 1990s. At the beginning of the 1960s, the largest net wheat importers among high-income countries were the United Kingdom, Germany, and Japan.[1] Wheat imports in Japan rose steadily until the mid-1970s and have remained relatively constant ever since, although Japan is still the leading wheat importer among high-income countries. As a result of expanding wheat production, the United Kingdom and Germany have become net exporters, the United Kingdom in the early 1980s and Germany in the late 1980s. Wheat imports into Italy have risen since the mid-1970s, and today Italy is the second largest net importer among high-income countries. Italy's imports appear to come, for the most part, from other EU trading partners.

Between 1961-1965 and 1991-1995, the major shift in the pattern of wheat exports has been the rise in the share of those exports from the EU, at the expense of the other traditional exporters: the U.S., Canada, Australia,

[1] In 1961, Japan would probably have been classified as an "upper middle income" country.

and Argentina—but particularly the U.S.[2] Nonetheless, the U.S. has remained the world's leading wheat exporter, with a market share of over one-third in the 1994/95 and 1995/96 marketing seasons. Wheat exports from the U.S. remained high in 1995/96 despite lower U.S. production in 1995, as a result of high world prices and the nation's desire to retain a reputation as a reliable exporter. On the other hand, the EU's share of exports to the rest of the world, which had been above 20% in the late 1980s and early 1990s, fell to 17% in 1994/95 and further to 14% in 1995/96. Internal use of EU wheat has risen in the past several years as Common Agricultural Policy (CAP) reform has lowered support prices. Canada's share of the export market has held steady at just over 20%. Australia's share fell in 1994/95 and rose in 1995/96; Argentina's followed the reverse pattern. In both cases these fluctuations in wheat exports reflected fluctuations in wheat production in these countries.

Wheat utilization[3]

World wheat consumption from 1990 through 1995 has fluctuated in a fairly narrow band between 547 and 556 million metric tons, with the exception of 1993, when consumption was estimated at 566 million metric tons. The FAO estimates wheat consumption was 547 million metric tons in 1994. IGC and USDA estimates place 1995 consumption variously between 547 and 552 million metric tons.

Wheat consumption worldwide has grown rapidly in the past 35 years. Rapid growth in both production and imports by developing countries has meant that consumption growth has been particularly fast in these countries (Table 1). Over much of this period, the rate of growth in wheat consumption in developing countries has been slightly higher than the rate of growth in maize utilization and over half again as high as the rate of growth in rice consumption. Growing populations, rising incomes, and lower prices have all played a role in increasing consumption of wheat in the developing world. Wheat consumption in developing countries has grown at a considerably higher rate than the population of those countries, suggesting the importance of income and price factors. The growth of wheat consumption in developing countries appears to have decelerated somewhat in the 1980s and 1990s (Table 1).

In many high-income countries, food wheat markets are mature, with changes in consumption taking place slowly over time, driven by population growth and slowly changing dietary preferences. In these countries, shorter-term and more rapid shifts in total utilization are often associated with shifts in feed use, which in turn are driven by changes in the ratio of the price of wheat to the price of coarse grains that are more commonly used as feed. This phenomenon appears to be a major reason for higher total consumption in high-income countries in the last few years, particularly in some European Union nations.

In the transitional economies, especially in the states of the former Soviet Union, wheat production has declined over the past 20 years, and imports

Table 1. Growth in world utilization of wheat, 1961-1994

	Growth in utilization (% per annum)			
Period	Developing countries	Transitional economies	High-income countries	World
1961-1970	4.9	5.5	2.0	4.2
1971-1980	5.1	2.5	0.4	3.1
1981-1990	3.1	1.5	1.4	2.3
1991-1994	1.3	-7.0	3.2	-0.1
1961-1994	4.4	1.6	1.4	2.8
Growth in per capita utilization, 1961-1994	2.2	0.8	0.6	1.0

Source: Calculated from FAO Agrostat data.

2 In this paragraph, we are deliberately excluding inter-European Union wheat trade from consideration. Trade among the European Union countries also appears to have expanded over the past 30 years, both as a result of increased production and expansion of membership.

3 Wheat utilization or consumption is defined to include food, feed, seed, and processed uses, as well as waste.

have collapsed in the 1990s. Wheat stocks have been drawn down in these countries, but consumption has been down dramatically since 1993 for the entire region (see Table 1). In fact, consumption fell most dramatically between 1991 and 1992 in Eastern Europe and is now increasing slowly there; the more recent sharp declines in wheat use in the transitional economies is attributable solely to the countries of the former Soviet Union. Use of wheat as livestock feed was a prominent feature of consumption in most of the transitional economies; sharp reductions in feed use have nearly always been the major component of sharp reductions in total use.

Stocks and prices

World wheat production in 1994 was considerably below consumption levels, partially due to reduced production in North America, China, and Turkey, as well as to drought in Australia and some countries in North Africa. As noted above, production in 1995 recovered somewhat, but not to the levels of the early 1990s, while consumption held steady. As a result, world wheat stocks were drawn down in 1994 and again in 1995. In 1994, the ratio of closing stocks to consumption was at the lowest level since 1972, and in 1995 that record was broken, bringing the stocks-to-use ratio to the lowest level in the postwar period (Figure 3).

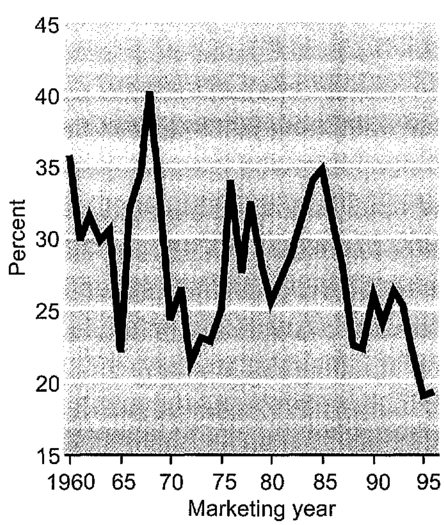

Figure 3. Ratio of world wheat closing stocks to consumption.
Source: USDA.

Figure 3 shows that the overall trend for the wheat stocks-to-use ratio over time has been negative for at least 35 years. This suggests that, over time, greater efficiencies in the marketing channel may have reduced the need for larger stockholdings. Nonetheless, the FAO considers the current levels of world grain stocks in general (stocks of other cereals have also fallen markedly) as being below the minimum levels necessary to cope with an emergency.

Concomitant with the tight world wheat market, nominal export prices for U.S. No. 2 hard red winter wheat, f.o.b. Gulf ports (the world reference standard), reached an all-time high over the 1995/96 marketing season. The highest prices were recorded in May 1996; since then they have fallen back somewhat. The real export price of wheat, however, remains below the levels of the 1960s, 1970s, and early 1980s (Figure 4). Nonetheless, in 1995/96, the real price moved above the trend line for the last 35 years, reaching its highest level since 1988/89.

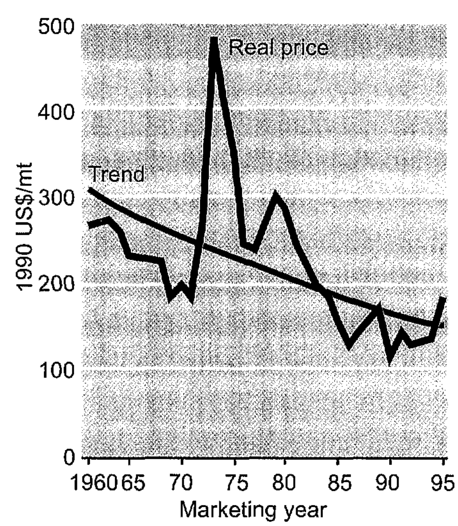

Figure 4. Real wheat export price, U.S. no. 2 hard red winter wheat, Gulf ports.
Source: Prices, International Grains Council; deflator, International Monetary Fund.

As this publication has noted in the past, the reference world export price frequently overstates the actual prices at which wheat is traded on world markets because of the export promotion policies of some major exporters. However, because of tight world wheat supplies and increasing prices, the EU ended its export subsidies in 1995. When domestic prices remained high, the EU even introduced an export tax. Furthermore, in 1995 the EU Common Agricultural Policy mandatory area set-aside was reduced from 15 to 12%. The last U.S. wheat sale under the Export Enhancement Program was made to Egypt in July 1995.[4]

[4] Egypt continued to purchase U.S. wheat on commercial terms.

The short-term outlook

High prices have induced acreage expansion in many countries, including many traditional importers. World wheat production for 1996 is now forecast variously at between 563 and 580 million metric tons, up 4 to 7% over 1995. The latter forecast would imply the second largest world harvest on record. Wheat output is expected to increase particularly in China (which may harvest a record crop), the European Union, Argentina, North Africa, Russia, and Kazakhstan. Production is also forecast to increase over 1995 in Australia and in the U.S. The increase in total U.S. wheat production may only be about 3%, because drought affected the output in some of the southern Great Plains states that produce hard red winter wheat. This was one of the factors behind the increase in world wheat prices in early 1996. Production for 1996 is also expected to be good in Turkey and Pakistan. The Indian harvest is forecast to be reduced slightly from 1995, but is still predicted to be the second highest on record. Wheat output in 1996 in Eastern Europe and the Ukraine will be reduced from 1995 levels.

As the 1996 wheat harvest began, prices fell. In August 1996,the export price for U.S. No. 2 hard red winter wheat averaged US$ 192 per ton in current dollars, over 25% below the May record. World imports for 1996/97 are now expected to be some 4 million metric tons below 1995/96, in large part because of reduced imports forecast for China. Consumption is also expected to be up, and world closing stocks are predicted to rise modestly, by about 3 million tons, which will leave the stocks-to-use ratio still low in historical terms (Figure 3).

The fall in the world wheat price in mid-1996 led the EU to approve a small subsidy in August 1996 for the sale of 20,000 tons of wheat to the African, Caribbean, and Pacific countries. This export restitution was the first EU export subsidy in 15 months.

Wheat in the longer run

Models of the world food economy which attempt to predict future world supply and demand relationships often contain forecasts concerning the wheat sub-sector. They differ in complexity (e.g., degree to which they are based on simple trend extrapolation, the degree to which they take into account supply and demand considerations, and their assumptions regarding trade). Most of the models share certain unstated but implicit assumptions. For example, the assumption that wheat yields will continue to rise along historical trends may imply that research investments in wheat technology will continue at current levels; or that research investments will fall but become more efficient; or, at the extreme, that investments in research will have no effect on wheat productivity.

The International Food Policy Research Institute (IFPRI) has examined some of these assumptions in their *2020 Vision for Food, Agriculture, and the Environment.* Rosegrant, Agcaoili-Sombilla, and Perez (1995) construct a set of 35 country or regional models that determine supply, demand, and prices for 17 agricultural commodities, including wheat. They develop five alternative scenarios. Here, we examine the results for wheat in two scenarios. The "baseline scenario" uses the authors' "best assessments" of future directions for population and income growth, urbanization, technological change and productivity growth in food production, prices, and the responses of supply and demand to prices. In particular, the authors assume that rates of public investment in agricultural research and infrastructure will remain at the reduced levels prevailing in the late 1980s and early 1990s and that income growth rates in developing countries will remain high, although varying by region. In the "low-investment/slow-growth scenario," the authors assume that international and national agricultural research investments will be cut even farther, by an annual total of about US$ 1.5 billion; that non-agricultural income growth will be reduced by 25%, thus lowering the demand for agricultural commodities; and that investment in health, education, and sanitation will be reduced by 20% by 2020.

In the baseline scenario, world wheat production would grow to 841 million metric tons by 2020, up over 50%

from current levels. Production in developing countries would grow at a rate of 2.2% annually, down somewhat from historical trends. Wheat output in developing countries would reach 432 million metric tons by 2020, a 70% increase over current developing country wheat production, and over half the world total in 2020. Developing countries would continue to import 122 million metric tons of wheat—primarily into Asia and West Asia/North Africa—and wheat consumption by the developing world would be nearly two-thirds of the world total. The international price of wheat is forecast at US$ 132 per metric ton in 1990 dollars, slightly under the trend price prevailing in recent years, but 50% higher than the price would be in 2020 were the price trend of the past 30 years to persist for the next 30 years (Table 2).

In the low-investment/slow-growth scenario, IFPRI estimates that world wheat production in 2020 would be 793 million metric tons, 6% under the total in the baseline scenario. Production in developing countries is predicted to grow at the lower rate of 1.7% annually, and would only be 378 million tons, 13% lower than in the baseline scenario. In the low-investment/slow-growth scenario, wheat production in high-income and transitional economies would be slightly *higher* than predicted in the baseline scenario, as farmers in these countries would respond to higher world prices by producing more wheat. Despite higher prices, developing countries would import 139 million metric tons of wheat, 14% more than in the baseline forecast. Most of these added imports would go into Asia, where incomes will be high enough to finance wheat purchases, despite lower income growth for developing countries in general. The international price of wheat is forecast at US$ 166 per metric ton in 1990 dollars, 25% over the price in the baseline scenario.

Table 2. Projected wheat data in 2020, baseline and low investment/slow growth scenarios

	Baseline scenario	Low investment/slow growth scenario
Growth rates in wheat production	(% per annum)	
Asia	2.0	1.5
Latin America/Caribbean	1.9	1.6
Sub-Saharan Africa	3.3	2.9
West Asia/North Africa	2.7	2.3
All developing countries	2.2	1.7
High-income/transitional	1.0	1.0
World	1.5	1.3
Total wheat production in 2020	(million metric tons)	
Asia	286.7	250.0
Latin America/Caribbean	39.3	35.3
Sub-Saharan Africa	4.5	4.0
West Asia/North Africa	101.2	88.4
All developing countries	431.7	377.7
High-income/transitional	409.0	415.5
World	840.7	793.2
Developing countries' share of world wheat production	(%)	
	51.4	47.6
Developing countries' share of world wheat consumption	(%)	
	65.9	65.2
Total wheat imports in 2020 by developing countries	(million metric tons)	
Asia	64.5	80.5
Latin America/Caribbean	3.6	4.3
Sub-Saharan Africa	12.5	11.6
West Asia/North Africa	41.6	42.7
All developing countries	122.1	139.1
Price of wheat	(1990 US$/metric ton)	
	132	166

Source: Rosegrant, Agcaoili-Sombilla, and Perez (1995).

In the low-investment/slow-growth scenario, developing nations would suffer an annual welfare loss of nearly US$ 7 billion (1990 dollars) in 2020 compared to the baseline forecast; this loss would occur in the wheat sub-sector alone and would be the result of both higher prices and larger imports. When one considers all commodities, food security (as measured by the predicted number of malnourished children) is only marginally improved by 2020—even in the baseline scenario. In the low-investment/slow-growth scenario it is predicted to be considerably worse than it is today. Both scenarios predict that food security will continue to be a problem in South Asia, where wheat is a major consumption item of the poor, and in sub-Saharan Africa, where it is less important (Rosegrant, Agcaoili-Sombilla, and Perez 1995).

Part 3

Selected Wheat Statistics

Pedro Aquino, Victor Hernández, and Roderick M. Rejesus

The tables that follow present statistics related to wheat production, trade, utilization, input use, and prices, as well as some basic economic indicators. These statistics reflect the latest information available at the time of publication.

Countries are classified as either "developing" or "high-income" based on the criteria used by the World Bank in its *World Development Report* (1996). This classification is based on a cut-off for GNP per capita of approximately US$ 9,000. Countries in the transitional economies of Eastern Europe and the former Soviet Union (F.S.U.) are treated separately. Traditionally included as "developed" countries in FAO statistics, most of these countries would be classified as developing countries by per capita GNP criteria.

Countries are also classified as either wheat consumers or wheat producers. Developing countries are classified as wheat producers if they produce more than 100,000 tons of wheat per year, regardless of import and consumption levels. Developing countries producing less than 100,000 tons, whose production accounts for at least 50% of their total wheat consumption, are also classified as producers. All other developing countries that consume over 100,000 tons per year are defined as wheat consumers. High-income countries and countries in the transitional economies of Eastern Europe and the F.S.U. that produce more than 1 million tons are classified as producers. If these countries produce less than 1 million tons, but their production accounts for at least 50% of their total wheat consumption, they are also classified as producers. Other high-income and transitional economy countries that consume over 1 million tons per year are defined as wheat consumers. A three-year average of the latest data available was used in the classification.

Unless otherwise indicated, the regional aggregates for variables 1 and 4-27 include data from all the countries in a particular region, including those countries for which data have not been reported individually. For a list of countries belonging to each region, see Appendix D. Regional aggregates were calculated by summing the values for all countries in a region in each year and then taking the mean or total value; thus they may not exactly equal the sum of the average values presented for each country. Data continue to be aggregated for former Czechoslovakia and former Yugoslavia. Disaggregated data are presented for some of the countries of the F.S.U., but they are more incomplete than for most other countries of the world. Regional aggregates for variables 2 and 3 are based on those countries in the region for which data are presented in the tables. Regional aggregates for variables 28 and 29 are also based on data for countries forming a subset of the countries in the region; they are only presented if these countries accounted for at least 50% of the wheat area in the region.

Notes on the variables

Variable 1: The data source is the FAO Agrostat population statistics (1996).

Variables 2-3: These data were obtained from the World Bank *World Development Reports* (1995 and 1996).

Variables 4, 5, 9-20, 23: The data sources are the FAO Agrostat production statistics (1996) and the FAO publication: *1948-1985 World Crop and Livestock Statistics* (1987). Growth rates were calculated using the log-linear regression model:

$$\ln Y = \alpha + \beta t + \varepsilon,$$

where $\ln Y$ is the natural logarithm of Y, t is time (year), α is a constant, β is the growth rate of Y, and ε is the error term. The function describes a variable, Y, which displays a constant proportional rate of growth ($\beta > 0$) or decay ($\beta < 0$). β may be interpreted as the annual percentage change in Y.

Variables 6-8, 21, 22: The data source is the FAO Agrostat production statistics (1996). Yield was computed by dividing production by the area harvested.

Variables 24-25: The data source is the FAO Agrostat trade statistics (1996). Net imports are defined as the amount of imports less exports.

Variables 26-27: The data source is the FAO Agrostat Food Balance Sheets (1996). Total consumption was calculated as the sum (in kg) of the amounts used for each type of wheat utilization (i.e., food, feed, seed). The growth rate was calculated using the regression model given above.

Variables 28-29: These data were collected through a general country survey of wheat scientists and economists. The term "modern varieties" as used in the past in this publication has been replaced explicitly by "semidwarf," meaning they carry one or more dwarfing genes. Other varieties planted by farmers (e.g. in such countries as Canada) may be "modern" in that they are recent releases by a plant breeding program, but may not carry any dwarfing genes. Other varieties may be older releases from a scientific crossing program, and in some cases, landrace material is still planted by farmers on some wheat area. Nitrogen applied per hectare of wheat area is presented as kilograms of nutrient per hectare. Estimated application rates for wheat area that receives nitrogen were adjusted to reflect the average consumption over all wheat area, including that which receives no nitrogen. In a few cases, data were estimated by CIMMYT staff based on secondary sources.

Variables 30-32: These data were collected through the same general country survey of wheat scientists and economists as the data in variables 28 and 29. The data refer to an important producing region within each country. Data for the majority of the countries refer to the wheat crop harvested in 1994. The wheat price is the average post-harvest price received by farmers. The nitrogen price is usually the price paid by farmers for the most common nitrogenous fertilizer (most commonly urea). In some countries, only the price of compound fertilizer was available; in these cases the variable refers to the average price of all nutrients, whether N, P_2O_5, and/or K_2O. In a few cases, data were estimated by CIMMYT staff based on secondary sources.

Eastern and Southern Africa

		PRODUCERS					
		Ethiopia	Kenya	South Africa	Sudan	Zambia	Zimbabwe
General indicators	1. Estimated population, 1995 (million)	58.6	28.3	41.5	28.1	9.5	11.3
	2. Estimated growth rate of population, 1993-2000 (%/yr)	3.0	2.5	2.2	2.7	2.6	2.2
	3. Per capita income 1994 (US $)	100	250	3040	...	350	500
	4. Average per capita cereal production, 1993-95 (kg/yr)	134	117	298	147	139	191
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	0.7	-3.2	-4.4	0.7	-6.5	-11.2
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	884	155	1166	325	18	41
	7. Average wheat yield, 1993-95 (t/ha)	1.4	1.6	1.7	1.5	3.1	4.9
	8. Average wheat production 1993-95 (000 t)	1270	252	1983	483	55	199
	9. Growth rate of wheat area 1951-66 (%)	-0.1	-0.9	2.0	8.4	...	...
	10. Growth rate of wheat area 1966-77 (%)	-3.4	-1.1	4.6	13.4	27.6	19.8
	11. Growth rate of wheat area 1977-1985 (%)	5.6	-0.4	1.4	-17.9	13.5	-7.5
	12. Growth rate of wheat area 1985-95 (%)	2.3	0.5	-7.4	16.3	15.2	-2.0
	13. Growth rate of wheat yield 1951-66 (%)	4.1	1.2	-0.8	-0.4	...	...
	14. Growth rate of wheat yield 1966-77 (%)	1.9	1.1	4.0	0.0	8.0	4.4
	15. Growth rate of wheat yield 1977-85 (%)	1.3	1.9	-0.2	5.2	1.2	4.5
	16. Growth rate of wheat yield 1985-95 (%)	3.0	-0.6	4.6	2.1	-3.5	-4.4
	17. Growth rate of wheat production, 1951-66 (%)	4.0	0.3	1.2	8.0	...	...
	18. Growth rate of wheat production, 1966-77 (%)	-1.5	0.0	8.6	13.4	35.6	24.3
	19. Growth rate of wheat production, 1977-85 (%)	6.9	1.5	1.3	-12.7	14.7	-2.9
	20. Growth rate of wheat production, 1985-95 (%)	5.4	-0.1	-2.8	18.5	11.7	-6.4
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	16	9	18	4	2	2
	22. Average yield of all cereals, 1993-95 (t/ha)	1.4	1.8	1.9	0.5	1.7	1.2
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	1.9	1.2	1.3	-1.4	2.4	1.1
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	391	215	557	460	28	90
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	7	8	14	17	3	8
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	34	16	61	45	11	31
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	0.9	-2.7	-1.8	3.6	-2.6	-0.6
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	15	95	80	85	100	100
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	5	23	60	87	62	160
	30. Farm prices of wheat, 1993-94 (US $/ton)	192	225	213	150	275	173
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	2.4	4.8	4.7	2.9	1.8	2.4
	32. Farm wage in kg of wheat per day, 1993-94	4	8	40	3	5	7

Eastern and Southern Africa (cont'd)

		CONSUMERS				Regional total or average
		Angola	Mozambique	Somalia	Tanzania	
General indicators	1. Estimated population, 1995 (million)	11.1	16.0	9.3	29.7	313.0
	2. Estimated growth rate of population, 1993-2000 (%/yr)	...	3.3	2.9	2.8	2.7
	3. Per capita income 1994 (US $)	...	90	...	140	677
	4. Average per capita cereal production, 1993-95 (kg/yr)	29	58	31	139	141
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-3.9	-0.6	-11.6	-2.7	-2.5
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	3	2	3	46	2685
	7. Average wheat yield, 1993-95 (t/ha)	1.2	1.1	0.4	1.4	1.6
	8. Average wheat production 1993-95 (000 t)	4	2	1	64	4362
	9. Growth rate of wheat area 1951-66 (%)	...	...	...	3.8	1.1
	10. Growth rate of wheat area 1966-77 (%)	...	...	...	2.0	2.5
	11. Growth rate of wheat area 1977-1985 (%)	...	...	...	1.6	1.1
	12. Growth rate of wheat area 1985-95 (%)	...	...	...	-0.2	-2.2
	13. Growth rate of wheat yield 1951-66 (%)	...	...	...	5.0	1.0
	14. Growth rate of wheat yield 1966-77 (%)	...	...	...	4.1	3.2
	15. Growth rate of wheat yield 1977-85 (%)	...	...	...	-0.3	0.2
	16. Growth rate of wheat yield 1985-95 (%)	...	...	...	-1.6	3.3
	17. Growth rate of wheat production, 1951-66 (%)	...	...	...	8.8	2.1
	18. Growth rate of wheat production, 1966-77 (%)	...	...	...	6.2	5.7
	19. Growth rate of wheat production, 1977-85 (%)	...	...	...	1.3	1.2
	20. Growth rate of wheat production, 1985-95 (%)	...	...	...	-1.8	1.2
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	<1	<1	<1	1	8
	22. Average yield of all cereals, 1993-95 (t/ha)	0.3	0.6	0.4	1.3	1.2
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	-2.1	-1.9	1.3	1.7	0.7
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	167	164	117	85	2826
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	16	11	13	3	10
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	17	11	13	5	26
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	-0.2	4.7	-1.8	-1.8	-0.1
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	...	...	60
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	...	44
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	...	...
	32. Farm wage in kg of wheat per day, 1993-94	...	...	...	...	...

Western and Central Africa

		CONSUMERS				
		Cameroon	Côte d'Ivoire	Ghana	Guinea	Mauritania
General indicators	1. Estimated population, 1995 (million)	13.2	14.3	17.5	6.7	2.3
	2. Estimated growth rate of population, 1993-2000 (%/yr)	2.8	3.3	2.9	3.0	2.5
	3. Per capita income 1994 (US $)	680	610	410	520	480
	4. Average per capita cereal production, 1993-95 (kg/yr)	82	117	100	115	94
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-0.5	1.3	3.8	-0.8	2.0
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	...	...	...	...	...
	7. Average wheat yield, 1993-95 (t/ha)	...	...	...	...	...
	8. Average wheat production 1993-95 (000 t)	...	...	...	...	...
	9. Growth rate of wheat area 1951-66 (%)	...	...	...	...	...
	10. Growth rate of wheat area 1966-77 (%)	...	...	...	...	...
	11. Growth rate of wheat area 1977-1985 (%)	...	...	...	...	...
	12. Growth rate of wheat area 1985-95 (%)	...	...	...	...	...
	13. Growth rate of wheat yield 1951-66 (%)	...	...	...	...	...
	14. Growth rate of wheat yield 1966-77 (%)	...	...	...	...	...
	15. Growth rate of wheat yield 1977-85 (%)	...	...	...	...	...
	16. Growth rate of wheat yield 1985-95 (%)	...	...	...	...	...
	17. Growth rate of wheat production, 1951-66 (%)	...	...	...	...	...
	18. Growth rate of wheat production, 1966-77 (%)	...	...	...	...	...
	19. Growth rate of wheat production, 1977-85 (%)	...	...	...	...	...
	20. Growth rate of wheat production, 1985-95 (%)	...	...	...	...	...
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	...	...	...	...	...
	22. Average yield of all cereals, 1993-95 (t/ha)	1.2	1.1	1.3	1.1	0.8
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	1.2	1.5	0.8	0.9	2.1
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	246	206	201	107	165
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	20	15	12	17	76
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	22	15	12	17	86
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	6.1	-4.5	7.3	2.8	2.5
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	...	...	...
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	...	...
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	...	...
	32. Farm wage in kg of wheat per day, 1993-94	...	...	...	...	...

Western and Central Africa (cont'd)

		CONSUMERS			Regional total or average
		Nigeria	Senegal	Zaire	
General indicators	1. Estimated population, 1995 (million)	111.7	8.3	43.9	282.6
	2. Estimated growth rate of population, 1993-2000 (%/yr)	2.9	2.6	...	2.9
	3. Per capita income 1994 (US $)	280	600	...	374
	4. Average per capita cereal production, 1993-95 (kg/yr)	186	127	40	140
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	1.7	-3.2	1.2	0.9
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	23	...	...	38
	7. Average wheat yield, 1993-95 (t/ha)	1.5	...	...	1.4
	8. Average wheat production 1993-95 (000 t)	35	...	...	54
	9. Growth rate of wheat area 1951-66 (%)	...	...	...	6.3
	10. Growth rate of wheat area 1966-77 (%)	-0.1	...	...	1.1
	11. Growth rate of wheat area 1977-1985 (%)	6.2	...	...	4.3
	12. Growth rate of wheat area 1985-95 (%)	4.0	...	...	1.5
	13. Growth rate of wheat yield 1951-66 (%)	...	...	...	4.1
	14. Growth rate of wheat yield 1966-77 (%)	-0.6	...	...	-1.4
	15. Growth rate of wheat yield 1977-85 (%)	-0.2	...	...	1.1
	16. Growth rate of wheat yield 1985-95 (%)	-2.6	...	...	-0.4
	17. Growth rate of wheat production, 1951-66 (%)	...	...	...	10.4
	18. Growth rate of wheat production, 1966-77 (%)	-0.7	...	...	-0.3
	19. Growth rate of wheat production, 1977-85 (%)	6.0	...	...	5.4
	20. Growth rate of wheat production, 1985-95 (%)	1.5	...	...	1.1
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	<1	...	<1	<1
	22. Average yield of all cereals, 1993-95 (t/ha)	1.1	0.8	0.8	0.9
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	1.7	1.4	-0.2	1.0
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	1005	188	168	2907
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	10	24	4	11
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	10	25	5	11
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	1.8	4.2	-6.6	-0.4
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	...	...
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	...
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	...
	32. Farm wage in kg of wheat per day, 1993-94	...	...	...	...

North Africa

	PRODUCERS					Regional total or average
	Algeria	Egypt	Libya	Morocco	Tunisia	
General indicators						
1. Estimated population, 1995 (million)	27.9	62.9	5.4	27.0	8.9	132.2
2. Estimated growth rate of population, 1993-2000 (%/yr)	2.2	1.7	...	1.9	1.6	1.8
3. Per capita income 1994 (US $)	1650	720	...	1140	1790	1089
4. Average per capita cereal production, 1993-95 (kg/yr)	56	257	61	180	124	182
5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-5.3	5.1	-1.3	-9.1	-2.3	0.5
Production of wheat and all cereals						
6. Average wheat area harvested, 1993-95 (000 ha)	1183	952	161	2443	750	5488
7. Average wheat yield, 1993-95 (t/ha)	0.9	5.3	1.0	1.1	1.1	1.8
8. Average wheat production 1993-95 (000 t)	110	4997	166	2729	815	9817
9. Growth rate of wheat area 1951-66 (%)	0.2	-1.8	1.5	0.7	-1.5	-0.1
10. Growth rate of wheat area 1966-77 (%)	1.5	0.1	-0.4	-0.2	2.8	0.9
11. Growth rate of wheat area 1977-1985 (%)	-3.3	-1.1	-0.6	0.4	-0.3	-1.1
12. Growth rate of wheat area 1985-95 (%)	-2.0	7.7	-3.6	1.3	0.9	1.1
13. Growth rate of wheat yield 1951-66 (%)	-0.9	2.3	9.0	1.8	4.4	1.3
14. Growth rate of wheat yield 1966-77 (%)	0.3	3.4	3.0	0.9	0.7	1.2
15. Growth rate of wheat yield 1977-85 (%)	4.4	1.9	13.9	4.6	5.7	4.4
16. Growth rate of wheat yield 1985-95 (%)	2.4	3.1	3.2	-6.1	0.0	2.5
17. Growth rate of wheat production, 1951-66 (%)	-0.7	0.5	10.5	2.5	2.9	1.2
18. Growth rate of wheat production, 1966-77 (%)	1.8	3.5	2.6	0.7	3.5	2.1
19. Growth rate of wheat production, 1977-85 (%)	1.1	0.8	13.3	5.0	5.4	3.2
20. Growth rate of wheat production, 1985-95 (%)	0.4	10.9	-0.4	-4.9	0.9	3.6
21. Wheat area as percent of total cereal area (average), 1993-95 (%)	63	36	35	48	68	49
22. Average yield of all cereals, 1993-95 (t/ha)	0.8	6.0	0.7	0.9	0.9	2.1
23. Growth rate of yield of all cereals, 1951-95 (%/yr)	0.6	2.1	4.1	0.9	2.5	2.0
Trade and utilization						
24. Average net imports of wheat, 1992-94 (000 t)	4622	5949	1246	2123	690	14630
25. Average net imports of wheat per capita, 1992-94 (kg/yr)	173	99	247	82	81	116
26. Average per capita wheat consumption, 1992-94 (kg/yr)	226	177	248	204	224	199
27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	1.1	0.4	1.5	0.4	-0.1	0.6
Prices and input use						
28. Percent of total wheat area under semidwarf wheat varieties, 1994	53	90	...	...	...	...
29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	55	178	...	...	...	...
30. Farm prices of wheat, 1993-94 (US $/ton)	365	200	...	...	...	...
31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	1.9	...	...	...	...
32. Farm wage in kg of wheat per day, 1993-94	13	12	...	...	...	...

West Asia

		PRODUCERS					
		Afghanistan	Iran	Iraq	Saudi Arabia	Syria	Turkey
General indicators	1. Estimated population, 1995 (million)	20.1	67.3	20.4	17.9	14.7	61.9
	2. Estimated growth rate of population, 1993-2000 (%/yr)	...	2.8	...	3.1	3.3	1.8
	3. Per capita income 1994 (US $)	...	...	...	7050	...	2500
	4. Average per capita cereal production, 1993-95 (kg/yr)	167	256	147	256	397	477
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-3.7	1.8	0.1	3.2	5.3	-1.7
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	1620	7179	1785	603	1527	9772
	7. Average wheat yield, 1993-95 (t/ha)	1.3	1.5	0.7	4.5	2.5	1.9
	8. Average wheat production 1993-95 (000 t)	2053	10918	1283	2703	3841	18848
	9. Growth rate of wheat area 1951-66 (%)	1.3	5.3	0.7	6.6	-0.1	2.6
	10. Growth rate of wheat area 1966-77 (%)	1.1	1.1	-1.0	-1.4	5.2	1.3
	11. Growth rate of wheat area 1977-1985 (%)	-4.2	1.6	-1.6	29.0	-3.6	-0.3
	12. Growth rate of wheat area 1985-95 (%)	-0.5	1.5	5.6	0.1	3.3	0.6
	13. Growth rate of wheat yield 1951-66 (%)	-0.1	-1.5	1.5	1.3	1.8	0.4
	14. Growth rate of wheat yield 1966-77 (%)	1.7	2.2	0.5	-0.4	2.8	3.5
	15. Growth rate of wheat yield 1977-85 (%)	0.7	0.3	3.7	9.7	3.8	0.4
	16. Growth rate of wheat yield 1985-95 (%)	0.3	4.1	-2.4	1.4	6.6	-0.3
	17. Growth rate of wheat production, 1951-66 (%)	1.2	3.8	2.2	7.9	1.7	3.0
	18. Growth rate of wheat production, 1966-77 (%)	2.8	3.3	-0.5	-1.8	8.1	4.8
	19. Growth rate of wheat production, 1977-85 (%)	-3.5	1.9	2.1	38.7	0.2	0.1
	20. Growth rate of wheat production, 1985-95 (%)	-0.2	5.6	3.2	1.5	9.9	0.3
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	68	74	49	59	42	69
	22. Average yield of all cereals, 1993-95 (t/ha)	1.3	1.7	0.8	4.4	1.6	2.0
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	0.7	1.2	0.4	3.0	1.6	1.9
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	107	2954	1072	-1154	631	-1884
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	6	46	55	-67	46	-32
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	115	200	113	106	267	304
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	-4.0	1.5	-9.9	1.1	1.4	-0.9
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	20	...	...	...	88	56
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	...	81	60
	30. Farm prices of wheat, 1993-94 (US $/ton)	354	...	...	...	...	186
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	1.5	...	...	...	...	3.6
	32. Farm wage in kg of wheat per day, 1993-94	4	...	...	...	9	38

West Asia (cont'd)

Section	Indicator	Yemen (Consumers)	Jordan (Consumers)	Lebanon (Consumers)	Oman (Consumers)	Regional total or average
General indicators	1. Estimated population, 1995 (million)	14.5	5.5	3.0	2.2	228.1
	2. Estimated growth rate of population, 1993-2000 (%/yr)	3.3	3.3	...	4.0	2.6
	3. Per capita income 1994 (US $)	280	1440	...	5140	3012
	4. Average per capita cereal production, 1993-95 (kg/yr)	59	20	25	3	285
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-1.2	0.0	4.1	5.6	-0.4
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	103	62	22	...	22675
	7. Average wheat yield, 1993-95 (t/ha)	1.6	1.0	2.1	...	1.8
	8. Average wheat production 1993-95 (000 t)	167	63	46	...	39924
	9. Growth rate of wheat area 1951-66 (%)	6.0	-0.3	-0.2	...	2.6
	10. Growth rate of wheat area 1966-77 (%)	9.8	-5.1	-3.7	...	1.3
	11. Growth rate of wheat area 1977-1985 (%)	-1.6	-5.7	-14.7	...	-0.1
	12. Growth rate of wheat area 1985-95 (%)	4.3	-2.0	1.3	...	1.3
	13. Growth rate of wheat yield 1951-66 (%)	0.5	1.1	1.5	...	0.2
	14. Growth rate of wheat yield 1966-77 (%)	-0.8	-0.4	3.4	...	2.8
	15. Growth rate of wheat yield 1977-85 (%)	-1.9	9.9	1.8	...	1.2
	16. Growth rate of wheat yield 1985-95 (%)	2.3	4.2	3.6	...	1.2
	17. Growth rate of wheat production, 1951-66 (%)	6.5	0.8	1.3	...	2.8
	18. Growth rate of wheat production, 1966-77 (%)	9.0	-5.6	-0.3	...	4.1
	19. Growth rate of wheat production, 1977-85 (%)	-3.6	4.2	-12.9	...	1.1
	20. Growth rate of wheat production, 1985-95 (%)	6.6	2.2	4.9	...	2.5
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	14	53	59	22	64
	22. Average yield of all cereals, 1993-95 (t/ha)	1.1	1.0	1.9	2.2	1.8
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	0.5	1.6	1.8	2.2	1.6
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	1653	582	396	146	4586
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	125	113	141	73	21
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	124	119	145	0	203
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	2.4	0.2	0.9	...	-0.9
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	...	...	...
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	...	...
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	...	...
	32. Farm wage in kg of wheat per day, 1993-94	...	...	...	...	...

South Asia

Section	Indicator	PRODUCERS: Bangladesh	India	Myanmar	Nepal	Pakistan	CONSUMER: Sri Lanka	Regional total or average
General indicators	1. Estimated population, 1995 (million)	120.4	935.7	46.5	21.9	140.5	18.4	1285.4
	2. Estimated growth rate of population, 1993-2000 (%/yr)	1.8	1.8	2.1	2.5	2.7	1.2	1.9
	3. Per capita income 1994 (US $)	220	320	...	200	430	640	326
	4. Average per capita cereal production, 1993-95 (kg/yr)	229	230	414	259	173	148	229
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-0.6	1.0	0.8	-1.0	-0.4	-0.6	0.7
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	634	24961	122	619	8168	...	34511
	7. Average wheat yield, 1993-95 (t/ha)	1.8	2.4	1.1	1.4	2.0	...	2.3
	8. Average wheat production 1993-95 (000 t)	1169	59783	131	860	16124	...	78072
	9. Growth rate of wheat area 1951-66 (%)	3.5	2.3	14.5	-1.1	1.7	...	2.1
	10. Growth rate of wheat area 1966-77 (%)	7.9	4.3	-4.0	8.8	1.1	...	3.5
	11. Growth rate of wheat area 1977-1985 (%)	17.3	1.6	4.9	5.4	2.0	...	2.0
	12. Growth rate of wheat area 1985-95 (%)	0.5	0.8	0.9	1.1	1.2	...	0.9
	13. Growth rate of wheat yield 1951-66 (%)	0.9	1.4	4.8	2.1	0.5	...	1.1
	14. Growth rate of wheat yield 1966-77 (%)	6.0	4.0	2.6	-0.7	5.1	...	4.3
	15. Growth rate of wheat yield 1977-85 (%)	3.4	3.9	10.2	2.2	1.8	...	3.4
	16. Growth rate of wheat yield 1985-95 (%)	-0.9	2.7	-5.6	1.9	2.0	...	2.5
	17. Growth rate of wheat production, 1951-66 (%)	4.3	3.7	19.3	1.1	2.2	...	3.2
	18. Growth rate of wheat production, 1966-77 (%)	13.9	8.3	-1.3	8.2	6.2	...	7.8
	19. Growth rate of wheat production, 1977-85 (%)	20.7	5.5	15.1	7.6	3.8	...	5.4
	20. Growth rate of wheat production, 1985-95 (%)	-0.4	3.5	-4.7	3.0	3.2	...	3.4
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	6	25	2	20	67	...	26
	22. Average yield of all cereals, 1993-95 (t/ha)	2.5	2.1	2.9	1.8	1.9	2.9	2.2
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	1.5	2.4	2.0	-0.1	2.5	1.9	2.2
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	1132	502	19	12	2268	853	4812
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	10	1	<1	1	17	48	4
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	21	63	3	41	141	48	65
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	-4.6	0.8	-5.8	0.2	2.7	2.7	1.1
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	99	90	...	90	93	...	91
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	49	85	...	29	88	...	84
	30. Farm prices of wheat, 1993-94 (US $/ton)	178	119	...	120	131	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	1.6	2.1	...	2.1	2.5	...	...
	32. Farm wage in kg of wheat per day, 1993-94	5	12	...	5	17	...	...

South Asia and Pacific

		CONSUMERS					Regional total or average
		Indonesia	Malaysia	Philippines	Thailand	Vietnam	
General indicators	1. Estimated population, 1995 (million)	197.6	20.1	67.6	58.8	74.5	441.6
	2. Estimated growth rate of population, 1993-2000 (%/yr)	1.4	2.3	2.0	0.9	2.1	1.6
	3. Per capita income 1994 (US $)	880	3480	950	2410	200	1106
	4. Average per capita cereal production, 1993-95 (kg/yr)	285	110	224	416	336	289
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	1.0	-0.1	-0.5	-1.3	2.7	0.5
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	...	...	...	1	...	1
	7. Average wheat yield, 1993-95 (t/ha)	...	...	...	0.7	...	0.8
	8. Average wheat production 1993-95 (000 t)	...	...	...	1	...	1
	9. Growth rate of wheat area 1951-66 (%)	...	...	...	...	...	...
	10. Growth rate of wheat area 1966-77 (%)	...	...	...	...	...	...
	11. Growth rate of wheat area 1977-1985 (%)	...	...	...	...	...	...
	12. Growth rate of wheat area 1985-95 (%)	...	...	...	...	...	...
	13. Growth rate of wheat yield 1951-66 (%)	...	...	...	...	...	...
	14. Growth rate of wheat yield 1966-77 (%)	...	...	...	...	...	...
	15. Growth rate of wheat yield 1977-85 (%)	...	...	...	...	...	...
	16. Growth rate of wheat yield 1985-95 (%)	...	...	...	...	...	...
	17. Growth rate of wheat production, 1951-66 (%)	...	...	...	...	...	...
	18. Growth rate of wheat production, 1966-77 (%)	...	...	...	...	...	...
	19. Growth rate of wheat production, 1977-85 (%)	...	...	...	...	...	...
	20. Growth rate of wheat production, 1985-95 (%)	...	...	...	...	...	...
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	0	0	0	<1	0	0
	22. Average yield of all cereals, 1993-95 (t/ha)	3.9	3.0	2.2	2.3	3.4	3.0
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	2.8	1.3	2.2	1.3	1.9	2.1
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	2808	946	1939	608	352	6940
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	15	49	30	11	5	16
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	14	48	31	10	5	16
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	7.3	5.1	10.2	15.1	4.3	7.9
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	...	...	...	...
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	...	...	...
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	...	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	...	...	...
	32. Farm wage in kg of wheat per day, 1993-94	...	...	...	...	...	...

East Asia

		PRODUCERS			CONSUMER	Regional total or average
		China	North Korea	Mongolia	South Korea	
General indicators	1. Estimated population, 1995 (million)	1221.5	23.9	2.4	45.0	1292.8
	2. Estimated growth rate of population, 1993-2000 (%/yr)	0.9	...	2.0	0.9	0.9
	3. Per capita income 1994 (US $)	530	...	300	8260	804
	4. Average per capita cereal production, 1993-95 (kg/yr)	335	210	151	159	327
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	0.6	-5.7	-13.7	-3.6	0.4
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	29360	90	425	1	29876
	7. Average wheat yield, 1993-95 (t/ha)	3.5	1.4	0.8	2.8	3.5
	8. Average wheat production 1993-95 (000 t)	102636	124	343	2	103106
	9. Growth rate of wheat area 1951-66 (%)	-0.3	8.7	24.7	...	-0.1
	10. Growth rate of wheat area 1966-77 (%)	1.4	-6.3	-0.7	...	1.3
	11. Growth rate of wheat area 1977-1985 (%)	0.2	0.0	2.9	...	0.3
	12. Growth rate of wheat area 1985-95 (%)	0.1	0.4	-1.5	...	0.1
	13. Growth rate of wheat yield 1951-66 (%)	0.9	-7.8	2.8	...	0.9
	14. Growth rate of wheat yield 1966-77 (%)	4.4	8.4	5.0	...	4.4
	15. Growth rate of wheat yield 1977-85 (%)	8.4	2.1	9.2	...	8.3
	16. Growth rate of wheat yield 1985-95 (%)	2.0	-1.2	-7.1	...	1.9
	17. Growth rate of wheat production, 1951-66 (%)	0.6	0.9	27.5	...	0.7
	18. Growth rate of wheat production, 1966-77 (%)	5.8	2.1	4.3	...	5.7
	19. Growth rate of wheat production, 1977-85 (%)	8.6	2.1	12.1	...	8.6
	20. Growth rate of wheat production, 1985-95 (%)	2.1	-0.8	-8.6	...	2.0
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	33	6	93	<1	33
	22. Average yield of all cereals, 1993-95 (t/ha)	4.6	3.3	0.8	5.8	4.6
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	3.2	2.1	1.1	2.7	3.2
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	8754	181	72	4844	13851
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	7	8	31	110	11
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	93	...	235	104	93
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	0.3	...	-4.3	3.1	0.4
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	70	...	97	...	70
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	150	...	<1	...	148
	30. Farm prices of wheat, 1993-94 (US $/ton)	214	...	78	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	1.9	...	4.1	...	...
	32. Farm wage in kg of wheat per day, 1993-94	4	...	13	...	...

Mexico, Central America, and the Caribbean

		PRODUCER	CONSUMERS				
		Mexico	Costa Rica	Cuba	Dominican Republic	El Salvador	Guatemala
General indicators	1. Estimated population, 1995 (million)	93.7	3.4	11.0	7.8	5.8	10.6
	2. Estimated growth rate of population, 1993-2000 (%/yr)	1.8	1.9	...	1.7	2.2	2.8
	3. Per capita income 1994 (US $)	4180	2400	...	1330	1360	1200
	4. Average per capita cereal production, 1993-95 (kg/yr)	284	56	17	69	149	140
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-1.3	-9.8	-15.3	-3.0	0.9	-1.9
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	930	...	...	...	...	23
	7. Average wheat yield, 1993-95 (t/ha)	4.1	...	...	...	...	1.1
	8. Average wheat production 1993-95 (000 t)	3848	...	...	...	...	27
	9. Growth rate of wheat area 1951-66 (%)	1.1	...	...	...	...	-0.9
	10. Growth rate of wheat area 1966-77 (%)	-0.2	...	...	...	...	2.6
	11. Growth rate of wheat area 1977-1985 (%)	7.0	...	...	...	...	-5.6
	12. Growth rate of wheat area 1985-95 (%)	-2.4	...	...	...	...	-5.0
	13. Growth rate of wheat yield 1951-66 (%)	7.3	...	...	...	...	4.4
	14. Growth rate of wheat yield 1966-77 (%)	3.9	...	...	...	...	3.2
	15. Growth rate of wheat yield 1977-85 (%)	2.6	...	...	...	...	7.8
	16. Growth rate of wheat yield 1985-95 (%)	-0.2	...	...	...	...	-5.4
	17. Growth rate of wheat production, 1951-66 (%)	8.4	...	...	...	...	3.6
	18. Growth rate of wheat production, 1966-77 (%)	3.8	...	...	...	...	5.7
	19. Growth rate of wheat production, 1977-85 (%)	9.6	...	...	...	...	2.2
	20. Growth rate of wheat production, 1985-95 (%)	-2.6	...	...	...	...	-10.4
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	9	...	...	...	...	3
	22. Average yield of all cereals, 1993-95 (t/ha)	2.6	2.9	1.4	4.3	1.9	1.6
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	2.9	2.6	1.6	2.7	1.8	2.5
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	1427	134	1055	250	210	265
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	16	41	97	33	38	26
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	59	35	97	33	42	29
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	-1.9	-3.3	-5.3	-1.5	6.7	3.8
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	100	...	...	...	...	...
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	153	...	...	...	...	...
	30. Farm prices of wheat, 1993-94 (US $/ton)	175	...	...	...	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	3.3	...	...	...	...	...
	32. Farm wage in kg of wheat per day, 1993-94	36	...	...	...	...	...

Mexico, Central America, and the Caribbean (cont'd)

	CONSUMERS				Regional total or average
	Haiti	Honduras	Jamaica	Trinidad & Tobago	
General indicators					
1. Estimated population, 1995 (million)	7.2	5.7	2.4	1.3	158.2
2. Estimated growth rate of population, 1993-2000 (%/yr)	...	2.8	0.8	1.1	2.0
3. Per capita income 1994 (US $)	230	600	1540	3740	3133
4. Average per capita cereal production, 1993-95 (kg/yr)	53	132	2	15	204
5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-4.6	1.4	-7.1	10.4	-1.4
Production of wheat and all cereals					
6. Average wheat area harvested, 1993-95 (000 ha)	...	1	...	...	954
7. Average wheat yield, 1993-95 (t/ha)	...	0.6	...	...	4.1
8. Average wheat production 1993-95 (000 t)	...	1	...	...	3875
9. Growth rate of wheat area 1951-66 (%)	...	...	...	...	1.0
10. Growth rate of wheat area 1966-77 (%)	...	...	...	...	0.0
11. Growth rate of wheat area 1977-1985 (%)	...	...	...	...	6.4
12. Growth rate of wheat area 1985-95 (%)	...	...	...	...	-2.5
13. Growth rate of wheat yield 1951-66 (%)	...	...	...	...	7.3
14. Growth rate of wheat yield 1966-77 (%)	...	...	...	...	3.8
15. Growth rate of wheat yield 1977-85 (%)	...	...	...	...	3.0
16. Growth rate of wheat yield 1985-95 (%)	...	...	...	...	-0.2
17. Growth rate of wheat production, 1951-66 (%)	...	...	...	...	8.3
18. Growth rate of wheat production, 1966-77 (%)	...	...	...	...	3.8
19. Growth rate of wheat production, 1977-85 (%)	...	...	...	...	9.5
20. Growth rate of wheat production, 1985-95 (%)	...	...	...	...	-2.7
21. Wheat area as percent of total cereal area (average), 1993-95 (%)	...	<1	...	...	7
22. Average yield of all cereals, 1993-95 (t/ha)	0.9	1.4	1.3	3.5	2.4
23. Growth rate of yield of all cereals, 1951-95 (%/yr)	0.3	1.4	1.1	1.4	2.7
Trade and utilization					
24. Average net imports of wheat, 1992-94 (000 t)	217	169	136	110	4316
25. Average net imports of wheat per capita, 1992-94 (kg/yr)	31	32	56	86	28
26. Average per capita wheat consumption, 1992-94 (kg/yr)	31	34	66	80	54
27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	0.5	5.0	-0.9	-2.4	-2.0
Prices and input use					
28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	...	...	100
29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	...	153
30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	...	...
31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	...	...
32. Farm wage in kg of wheat per day, 1993-94	...	...	...	...	...

Andean Region, South America

		PRODUCERS		CONSUMERS			
		Bolivia	Peru	Colombia	Ecuador	Venezuela	Regional total or average
General indicators	1. Estimated population, 1995 (million)	7.4	23.8	35.1	11.5	21.8	101.0
	2. Estimated growth rate of population, 1993-2000 (%/yr)	2.4	1.9	1.4	2.0	2.1	1.8
	3. Per capita income 1994 (US $)	770	2110	1670	1280	2760	1886
	4. Average per capita cereal production, 1993-95 (kg/yr)	147	94	104	178	91	115
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-0.2	-1.9	-0.3	5.2	-3.5	-0.4
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	124	95	48	33	1	301
	7. Average wheat yield, 1993-95 (t/ha)	1.0	1.3	2.0	0.7	0.3	1.2
	8. Average wheat production 1993-95 (000 t)	119	120	94	22	0	355
	9. Growth rate of wheat area 1951-66 (%)	6.8	-0.5	-3.8	3.5	...	-0.2
	10. Growth rate of wheat area 1966-77 (%)	2.5	-1.9	-10.0	-3.8	...	-2.7
	11. Growth rate of wheat area 1977-1985 (%)	0.8	-3.3	5.4	-6.4	...	-0.9
	12. Growth rate of wheat area 1985-95 (%)	3.1	-0.5	0.8	1.1	...	1.2
	13. Growth rate of wheat yield 1951-66 (%)	-0.3	0.1	2.0	2.8	...	0.7
	14. Growth rate of wheat yield 1966-77 (%)	3.1	0.6	-0.1	-0.8	...	-0.1
	15. Growth rate of wheat yield 1977-85 (%)	1.7	0.8	6.0	0.4	...	2.2
	16. Growth rate of wheat yield 1985-95 (%)	2.7	0.0	1.6	-3.9	...	0.7
	17. Growth rate of wheat production, 1951-66 (%)	6.5	-0.5	-1.8	6.4	...	0.5
	18. Growth rate of wheat production, 1966-77 (%)	5.5	-1.3	-10.1	-4.6	...	-2.8
	19. Growth rate of wheat production, 1977-85 (%)	2.4	-2.6	11.4	-6.0	...	1.3
	20. Growth rate of wheat production, 1985-95 (%)	5.8	-0.5	2.5	-2.8	...	2.0
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	18	12	3	3	<1	6
	22. Average yield of all cereals, 1993-95 (t/ha)	1.5	2.7	2.5	2.0	2.7	2.4
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	1.0	2.5	2.7	1.9	2.5	2.3
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	362	1021	857	382	1123	3836
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	51	45	25	35	54	39
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	73	52	28	26	53	43
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	1.6	-0.9	1.3	-4.2	-1.8	-0.6
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	76	68	40	30	...	63
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	1	39	27	50	...	23
	30. Farm prices of wheat, 1993-94 (US $/ton)	205	201	238	200	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	3.8	4.8	3.4	2.6	...	...
	32. Farm wage in kg of wheat per day, 1993-94	15	17	32	18	...	...

Southern Cone, South America

Section	Indicator	Argentina	Brazil	Chile	Paraguay	Uruguay	Regional total or average
		PRODUCERS					
General indicators	1. Estimated population, 1995 (million)	34.6	161.8	14.3	5.0	3.2	218.8
	2. Estimated growth rate of population, 1993-2000 (%/yr)	1.2	1.6	1.5	2.5	0.6	1.5
	3. Per capita income 1994 (US $)	8110	2970	3520	1580	4660	3815
	4. Average per capita cereal production, 1993-95 (kg/yr)	720	290	191	215	458	353
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-1.6	0.2	-1.2	4.5	3.8	-0.5
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	4812	1278	382	202	201	6876
	7. Average wheat yield, 1993-95 (t/ha)	2.1	1.5	3.5	2.2	2.0	2.0
	8. Average wheat production 1993-95 (000 t)	9874	1922	1326	442	400	13963
	9. Growth rate of wheat area 1951-66 (%)	1.1	-1.3	-0.1	12.7	-3.8	0.3
	10. Growth rate of wheat area 1966-77 (%)	-1.3	13.9	-1.8	3.5	1.1	2.1
	11. Growth rate of wheat area 1977-1985 (%)	5.2	-6.0	-4.6	16.8	-3.3	1.1
	12. Growth rate of wheat area 1985-95 (%)	-0.9	-12.0	-4.9	6.1	-0.5	-4.0
	13. Growth rate of wheat yield 1951-66 (%)	1.8	-0.4	1.9	1.4	0.2	1.7
	14. Growth rate of wheat yield 1966-77 (%)	3.1	-1.2	-1.2	-0.7	0.1	0.8
	15. Growth rate of wheat yield 1977-85 (%)	3.4	7.9	2.4	1.6	9.3	5.7
	16. Growth rate of wheat yield 1985-95 (%)	2.3	-1.1	3.5	4.3	4.2	2.1
	17. Growth rate of wheat production, 1951-66 (%)	2.9	-1.7	1.9	14.1	-3.6	1.9
	18. Growth rate of wheat production, 1966-77 (%)	1.8	12.7	-3.0	2.8	1.3	2.8
	19. Growth rate of wheat production, 1977-85 (%)	8.6	1.8	-2.2	18.4	6.0	6.8
	20. Growth rate of wheat production, 1985-95 (%)	1.4	-13.1	-1.4	10.3	3.7	-1.9
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	56	7	63	41	37	23
	22. Average yield of all cereals, 1993-95 (t/ha)	2.8	2.4	4.4	2.1	2.7	2.6
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	2.1	1.3	2.8	1.1	3.2	1.6
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	-5943	5475	614	25	115	286
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	-176	35	44	5	36	1
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	136	48	140	81	132	70
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	-1.2	-1.8	-1.1	6.7	2.1	-1.4
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	95	80	95	80	90	92
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	10	15	62	16	40	15
	30. Farm prices of wheat, 1993-94 (US $/ton)	133	106	246	111	150	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	5.8	4.6	8.8	6.4	4.5	...
	32. Farm wage in kg of wheat per day, 1993-94	125	18	24	57	53	...

Eastern Europe and the Former Soviet Union*

		PRODUCERS						
		Albania	Azerbaijan	Bulgaria	Former Czechoslovakia	Hungary	Kazakhstan**	Kyrgyzstan
General indicators	1. Estimated population, 1995 (million)	3.4	7.6	8.8	15.6	10.2	17.1	4.7
	2. Estimated growth rate of population, 1993-2000 (%/yr)	1.0	1.1	-0.5	0.3	-0.4	0.6	1.6
	3. Per capita income 1994 (US $)	380	500	1250	2877	3840	1160	630
	4. Average per capita cereal production, 1993-95 (kg/yr)	196	136	672	647	1016	951	243
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-8.5	...	-1.6	-1.7	-3.8	...	...
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	157	460	1200	1233	1049	12635	334
	7. Average wheat yield, 1993-95 (t/ha)	2.7	1.6	3.0	4.4	4.0	0.7	1.8
	8. Average wheat production 1993-95 (000 t)	428	734	3643	5484	4165	9222	616
	9. Growth rate of wheat area 1951-66 (%)	1.0	...	-1.7	0.5	-2.1	...	...
	10. Growth rate of wheat area 1966-77 (%)	4.0	-1.3	-2.1	3.3	1.0	-0.2	-3.5
	11. Growth rate of wheat area 1977-1985 (%)	-0.7	-3.8	2.7	-0.6	1.0	-1.2	-3.9
	12. Growth rate of wheat area 1985-95 (%)	-4.0	6.6	0.7	0.1	-3.3	-2.6	5.2
	13. Growth rate of wheat yield 1951-66 (%)	-0.2	...	3.1	2.0	2.7	...	...
	14. Growth rate of wheat yield 1966-77 (%)	6.1	5.2	3.3	3.9	5.3	-1.3	4.8
	15. Growth rate of wheat yield 1977-85 (%)	3.8	3.2	-1.0	3.2	3.2	-4.2	0.0
	16. Growth rate of wheat yield 1985-95 (%)	-2.0	-5.4	-1.7	-1.0	-2.0	-3.4	-5.1
	17. Growth rate of wheat production, 1951-66 (%)	0.8	...	1.4	2.5	0.6	...	...
	18. Growth rate of wheat production, 1966-77 (%)	10.1	3.9	1.3	7.2	6.4	-1.5	1.3
	19. Growth rate of wheat production, 1977-85 (%)	3.1	-0.6	1.7	2.7	4.2	-5.4	-3.9
	20. Growth rate of wheat production, 1985-95 (%)	-6.0	1.3	-1.0	-1.0	-5.4	-6.0	0.0
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	58	71	56	50	38	62	57
	22. Average yield of all cereals, 1993-95 (t/ha)	2.5	1.6	2.8	4.1	3.7	0.8	1.9
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	3.1	2.7	2.4	2.5	3.0	0.7	2.2
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	462	318	-136	-8	-705	-7800	610
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	136	43	-15	0	-68	-461	134
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	244	...	390	295	264	410	...
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	1.7	...	-1.9	-3.7	-5.5	...	...
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	80	90	60	60	...
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	70	57	95	2	...
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	53	115	91	70	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	8.4	3	4.4	5.3	...
	32. Farm wage in kg of wheat per day, 1993-94	...	...	57	67	50	71	...

*** Variables 26 and 27 exclude most of the former Soviet Union due to unavailability of data.**
**** Variable 24 for Kazakhstan comes from 1992 only.**

Eastern Europe and the Former Soviet Union* (cont'd)

		PRODUCERS					
		Latvia	Lithuania	Moldova Republic	Poland	Romania	Russian Federation
General indicators	1. Estimated population, 1995 (million)	2.6	3.7	4.4	38.6	22.7	147.0
	2. Estimated growth rate of population, 1993-2000 (%/yr)	-0.8	-0.1	0.3	0.2	-0.1	-0.3
	3. Per capita income 1994 (US $)	2320	1350	870	2410	1270	2650
	4. Average per capita cereal production, 1993-95 (kg/yr)	352	654	480	608	785	535
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	...	...	...	-1.3	-1.2	...
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	105	312	325	2430	2392	23588
	7. Average wheat yield, 1993-95 (t/ha)	1.9	2.3	3.3	3.4	2.7	1.5
	8. Average wheat production 1993-95 (000 t)	206	724	1060	8190	6372	35264
	9. Growth rate of wheat area 1951-66 (%)	...	...	...	0.4	0.7	...
	10. Growth rate of wheat area 1966-77 (%)	2.2	6.3	-2.7	0.6	-2.4	-1.9
	11. Growth rate of wheat area 1977-1985 (%)	6.0	7.4	-7.7	-0.4	0.6	-4.0
	12. Growth rate of wheat area 1985-95 (%)	-0.4	2.1	3.4	2.4	-1.0	-0.8
	13. Growth rate of wheat yield 1951-66 (%)	...	...	...	3.8	2.9	...
	14. Growth rate of wheat yield 1966-77 (%)	5.8	7.1	7.7	3.3	4.6	0.5
	15. Growth rate of wheat yield 1977-85 (%)	3.5	1.9	-1.9	2.5	-0.4	-1.1
	16. Growth rate of wheat yield 1985-95 (%)	-2.7	-1.7	-0.5	-0.9	-0.4	-1.1
	17. Growth rate of wheat production, 1951-66 (%)	...	...	...	4.2	3.5	...
	18. Growth rate of wheat production, 1966-77 (%)	8.0	13.5	4.9	3.9	2.2	-1.4
	19. Growth rate of wheat production, 1977-85 (%)	9.5	9.3	-9.6	2.1	0.2	-5.0
	20. Growth rate of wheat production, 1985-95 (%)	-3.1	0.4	2.9	1.5	-1.3	-1.9
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	21	26	50	29	38	43
	22. Average yield of all cereals, 1993-95 (t/ha)	1.8	2.1	3.1	2.8	2.8	1.4
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	2.4	2.2	1.0	2.2	2.6	0.8
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	33	122	139	393	858	8667
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	13	33	32	10	38	59
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	...	...	...	225	259	341
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	...	...	...	-1.3	-0.7	...
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	...	100	77	30
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	71	36	6
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	146	147	184
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	3.2	3.4	2.6
	32. Farm wage in kg of wheat per day, 1993-94	...	...	...	46	16	...

*** Variables 26 and 27 exclude most of the former Soviet Union due to unavailability of data.**

Eastern Europe and the Former Soviet Union* (cont'd)

		PRODUCERS			CONSUMERS		Regional total or average*
		Ukraine	Uzbekistan	Former Yugoslavia	Belarus	Turkmenistan	
General indicators	1. Estimated population, 1995 (million)	51.4	22.8	22.9	10.1	4.1	414.6
	2. Estimated growth rate of population, 1993-2000 (%/yr)	-0.2	2.1	0.6	-0.2	2.1	0.5
	3. Per capita income 1994 (US $)	1910	960	3156	2160	...	2158
	4. Average per capita cereal production, 1993-95 (kg/yr)	699	110	564	635	303	560
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	...	...	-3.2	...	...	-2.6
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	5245	936	1355	134	366	54670
	7. Average wheat yield, 1993-95 (t/ha)	3.3	1.4	3.5	2.7	2.2	1.9
	8. Average wheat production 1993-95 (000 t)	17320	1305	4801	362	788	101231
	9. Growth rate of wheat area 1951-66 (%)	...	...	0.5	...	...	2.4
	10. Growth rate of wheat area 1966-77 (%)	-0.7	-2.4	-1.6	-4.8	-10.0	-1.2
	11. Growth rate of wheat area 1977-1985 (%)	-3.7	-3.2	-1.8	5.2	8.1	-2.5
	12. Growth rate of wheat area 1985-95 (%)	-1.6	10.4	-0.8	-3.0	23.0	-0.9
	13. Growth rate of wheat yield 1951-66 (%)	...	...	5.5	...	...	1.5
	14. Growth rate of wheat yield 1966-77 (%)	3.0	-0.9	3.7	7.6	11.5	1.8
	15. Growth rate of wheat yield 1977-85 (%)	-2.7	-0.1	1.7	-2.5	0.5	-0.2
	16. Growth rate of wheat yield 1985-95 (%)	0.4	5.9	-0.4	1.5	4.1	-0.7
	17. Growth rate of wheat production, 1951-66 (%)	...	...	6.0	...	...	3.9
	18. Growth rate of wheat production, 1966-77 (%)	2.2	-3.3	2.1	2.8	1.6	0.6
	19. Growth rate of wheat production, 1977-85 (%)	-6.4	-3.2	-0.1	2.7	8.6	-2.8
	20. Growth rate of wheat production, 1985-95 (%)	-1.2	16.3	-1.2	-1.5	27.1	-1.6
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	41	63	36	5	68	44
	22. Average yield of all cereals, 1993-95 (t/ha)	2.8	1.7	3.4	2.5	2.3	1.9
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	1.2	3.0	2.9	2.9	3.8	2.0
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	1500	3917	163	1195	1020	12895
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	29	181	7	117	263	31
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	437	...	171	167	...	...
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	...	...	-4.4	...	...	-2.5
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	...	...	...	49
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	...	...	...	15
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	...	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	...	...	...
	32. Farm wage in kg of wheat per day, 1993-94	...	...	...	...	...	...

*** Variables 26 and 27 exclude most of the former Soviet Union due to unavailability of data.**

Western Europe, North America, and Other High-Income Countries

		PRODUCERS					
		Australia	Austria	Belgium/ Luxembourg	Canada	Denmark	Finland
General indicators	1. Estimated population, 1995 (million)	18.1	8.1	10.5	29.5	5.2	5.1
	2. Estimated growth rate of population, 1993-2000 (%/yr)	1.3	0.5	0.3	1.1	0.1	0.4
	3. Per capita income 1994 (US $)	18000	24630	23513	19510	27970	18850
	4. Average per capita cereal production, 1993-95 (kg/yr)	1278	544	219	1692	1599	660
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-2.0	-3.1	-0.3	-1.2	0.4	0.0
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	8746	246	216	11489	605	96
	7. Average wheat yield, 1993-95 (t/ha)	1.6	4.8	7.0	2.2	6.9	3.7
	8. Average wheat production 1993-95 (000 t)	14002	1191	1513	25262	4160	358
	9. Growth rate of wheat area 1951-66 (%)	5.1	2.5	1.0	1.1	4.2	5.2
	10. Growth rate of wheat area 1966-77 (%)	0.2	-1.1	-1.2	-1.0	2.3	-2.4
	11. Growth rate of wheat area 1977-1985 (%)	2.4	1.9	0.0	4.2	15.1	4.7
	12. Growth rate of wheat area 1985-95 (%)	-2.5	-3.2	1.3	-2.0	7.0	-5.8
	13. Growth rate of wheat yield 1951-66 (%)	1.0	2.3	1.3	0.3	1.0	1.3
	14. Growth rate of wheat yield 1966-77 (%)	0.0	2.4	2.5	1.7	1.2	3.3
	15. Growth rate of wheat yield 1977-85 (%)	2.0	3.6	4.6	-0.9	3.7	5.5
	16. Growth rate of wheat yield 1985-95 (%)	1.1	0.7	1.2	2.6	1.4	3.2
	17. Growth rate of wheat production, 1951-66 (%)	6.2	4.9	2.3	1.4	5.2	6.5
	18. Growth rate of wheat production, 1966-77 (%)	0.2	1.3	1.3	0.7	3.6	0.9
	19. Growth rate of wheat production, 1977-85 (%)	4.4	5.4	4.6	3.3	18.8	10.1
	20. Growth rate of wheat production, 1985-95 (%)	-1.4	-2.5	2.4	0.6	8.5	-2.7
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	64	30	62	62	42	10
	22. Average yield of all cereals, 1993-95 (t/ha)	1.7	5.3	6.6	2.7	5.8	3.5
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	1.1	2.8	1.9	1.5	1.3	1.9
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	-10202	-348	448	-21278	-820	-45
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	-579	-44	43	-738	-158	-9
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	147	115	144	269	513	79
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	-3.5	-0.7	-0.3	1.5	5.6	-2.6
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	91	...	...	3	100	...
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	8	...	...	36	165	...
	30. Farm prices of wheat, 1993-94 (US $/ton)	99	...	...	110	176	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	5.5	...	...	3.9	4	...
	32. Farm wage in kg of wheat per day, 1993-94	511	...	...	439	667	...

Western Europe, North America, and Other High-Income Countries (cont'd)

		PRODUCERS					
		France	Germany	Greece*	Ireland	Italy	Netherlands
General indicators	1. Estimated population, 1995 (million)	58.0	81.6	10.5	3.6	57.2	15.5
	2. Estimated growth rate of population, 1993-2000 (%/yr)	0.4	0.2	0.3	0.3	0.0	0.6
	3. Per capita income 1994 (US $)	23420	25580	7700	13530	19300	22010
	4. Average per capita cereal production, 1993-95 (kg/yr)	939	458	475	471	340	95
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-0.1	-0.4	-0.6	-2.2	0.9	2.0
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	4612	2472	883	75	2383	126
	7. Average wheat yield, 1993-95 (t/ha)	6.6	6.8	2.5	7.6	3.4	8.6
	8. Average wheat production 1993-95 (000 t)	30226	16688	2187	566	8095	1076
	9. Growth rate of wheat area 1951-66 (%)	0.1	1.5	1.5	-4.3	-0.8	5.1
	10. Growth rate of wheat area 1966-77 (%)	0.4	2.1	-2.0	-4.7	-2.9	-2.3
	11. Growth rate of wheat area 1977-1985 (%)	2.7	0.2	-1.0	6.2	0.1	1.0
	12. Growth rate of wheat area 1985-95 (%)	-0.4	0.5	-0.1	1.5	-3.1	0.7
	13. Growth rate of wheat yield 1951-66 (%)	3.4	1.4	2.8	2.1	1.8	1.3
	14. Growth rate of wheat yield 1966-77 (%)	2.6	1.6	3.1	1.4	1.0	2.2
	15. Growth rate of wheat yield 1977-85 (%)	3.8	3.4	-0.1	4.8	2.3	3.4
	16. Growth rate of wheat yield 1985-95 (%)	1.6	1.6	0.4	2.4	2.5	2.2
	17. Growth rate of wheat production, 1951-66 (%)	3.5	2.9	4.3	-2.2	1.0	6.4
	18. Growth rate of wheat production, 1966-77 (%)	3.0	3.7	1.1	-3.3	-1.9	-0.1
	19. Growth rate of wheat production, 1977-85 (%)	6.5	3.6	-1.1	11.0	2.4	4.4
	20. Growth rate of wheat production, 1985-95 (%)	1.3	2.0	0.4	3.8	-0.6	2.9
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	55	39	66	27	58	66
	22. Average yield of all cereals, 1993-95 (t/ha)	6.5	5.9	3.7	6.2	4.7	7.7
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	3.2	2.2	3.2	2.4	2.3	2.3
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	-18073	-4108	-606	199	3325	1235
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	-314	-51	-58	56	58	81
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	242	153	168	236	182	117
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	1.2	-2.2	-0.3	1.2	-1.1	0.4
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	98	98	...	100	88	100
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	160	150	...	180	100	180
	30. Farm prices of wheat, 1993-94 (US $/ton)	143	164	...	192	236	175
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	4.3	4.3	...	4.6	3.2	3.1
	32. Farm wage in kg of wheat per day, 1993-94	366	462	...	...	455	484

*** Greece is an upper middle-income country but is included here for greater geographical consistency with previous *Wheat Facts and Trends.***

Western Europe, North America, and Other High-Income Countries (cont'd)

		PRODUCERS					
		New Zealand	Norway	Spain	Sweden	Switzerland	United Kingdom
General indicators	1. Estimated population, 1995 (million)	3.6	4.4	39.6	8.8	7.2	58.5
	2. Estimated growth rate of population, 1993-2000 (%/yr)	1.1	0.4	0.1	0.5	0.9	0.3
	3. Per capita income 1994 (US $)	13350	26390	13440	23530	37930	18340
	4. Average per capita cereal production, 1993-95 (kg/yr)	235	316	373	552	177	351
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-4.3	0.8	-4.7	-2.7	1.5	-1.4
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	39	69	2031	268	104	1810
	7. Average wheat yield, 1993-95 (t/ha)	6.0	4.8	2.0	5.8	5.8	7.5
	8. Average wheat production 1993-95 (000 t)	232	336	4078	1548	596	13535
	9. Growth rate of wheat area 1951-66 (%)	5.6	-13.0	-0.2	-3.4	0.8	0.2
	10. Growth rate of wheat area 1966-77 (%)	-2.0	20.8	-4.5	4.9	-2.0	2.5
	11. Growth rate of wheat area 1977-1985 (%)	-4.4	7.7	-2.7	-0.5	1.1	6.9
	12. Growth rate of wheat area 1985-95 (%)	-8.4	5.9	-0.5	-1.4	1.0	-1.0
	13. Growth rate of wheat yield 1951-66 (%)	1.6	2.4	1.1	4.3	1.4	2.8
	14. Growth rate of wheat yield 1966-77 (%)	-0.1	2.7	2.4	2.4	1.3	1.6
	15. Growth rate of wheat yield 1977-85 (%)	3.2	2.7	5.3	3.4	4.7	4.4
	16. Growth rate of wheat yield 1985-95 (%)	4.5	1.6	-3.4	1.4	0.7	2.2
	17. Growth rate of wheat production, 1951-66 (%)	7.1	-10.6	0.9	0.9	2.2	3.0
	18. Growth rate of wheat production, 1966-77 (%)	-2.1	23.4	-2.1	7.3	-0.7	4.1
	19. Growth rate of wheat production, 1977-85 (%)	-1.1	10.5	2.6	2.9	5.8	11.3
	20. Growth rate of wheat production, 1985-95 (%)	-3.9	7.5	-3.9	0.1	1.7	1.2
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	27	20	31	24	50	59
	22. Average yield of all cereals, 1993-95 (t/ha)	5.7	3.9	2.3	4.4	6.1	6.7
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	1.8	1.4	2.3	2.0	2.1	2.3
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	199	281	758	-177	236	-2521
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	57	65	19	-20	33	-43
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	110	116	131	165	121	177
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	0.6	0.1	-1.1	4.7	-0.3	-1.5
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	...	...	88	95	100	95
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	...	...	135	124	140	175
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	199	143	...	185
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	2.3	...	...	2.5
	32. Farm wage in kg of wheat per day, 1993-94	...	...	154	500	...	354

Western Europe, North America, and Other High-Income Countries (cont'd)

		PRODUCERS	CONSUMERS			Regional total or average
		USA	Israel	Japan	Portugal	
General indicators	1. Estimated population, 1995 (million)	263.3	5.5	125.1	9.8	843.3
	2. Estimated growth rate of population, 1993-2000 (%/yr)	0.9	2.1	0.2	0.0	0.6
	3. Per capita income 1994 (US $)	25880	14530	34630	9320	24288
	4. Average per capita cereal production, 1993-95 (kg/yr)	1142	36	107	149	682
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	-0.8	-3.9	-2.0	-0.8	-0.7
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	25020	85	165	248	61794
	7. Average wheat yield, 1993-95 (t/ha)	2.5	2.2	3.6	1.5	3.1
	8. Average wheat production 1993-95 (000 t)	62628	187	594	381	189458
	9. Growth rate of wheat area 1951-66 (%)	-1.9	4.4	-2.8	-1.3	-0.1
	10. Growth rate of wheat area 1966-77 (%)	3.1	1.6	-17.2	-4.3	0.6
	11. Growth rate of wheat area 1977-1985 (%)	0.7	-1.1	12.0	0.0	1.8
	12. Growth rate of wheat area 1985-95 (%)	0.3	-0.4	-5.2	-2.4	-0.8
	13. Growth rate of wheat yield 1951-66 (%)	3.3	5.9	0.8	-1.2	2.2
	14. Growth rate of wheat yield 1966-77 (%)	1.1	3.8	0.2	2.8	1.6
	15. Growth rate of wheat yield 1977-85 (%)	3.0	-1.6	1.4	7.5	2.7
	16. Growth rate of wheat yield 1985-95 (%)	0.5	0.9	0.1	-0.7	1.5
	17. Growth rate of wheat production, 1951-66 (%)	1.4	10.3	-2.0	-2.5	2.1
	18. Growth rate of wheat production, 1966-77 (%)	4.2	5.4	-17.0	-1.6	2.2
	19. Growth rate of wheat production, 1977-85 (%)	3.7	-2.7	13.5	7.6	4.5
	20. Growth rate of wheat production, 1985-95 (%)	0.8	0.5	-5.1	-3.1	0.7
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	41	84	7	35	47
	22. Average yield of all cereals, 1993-95 (t/ha)	4.8	1.9	5.5	2.1	4.3
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	2.4	2.1	1.2	2.2	2.1
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	-32749	1019	5618	926	-75695
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	-127	193	45	94	-91
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	125	262	54	125	142
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	0.7	8.3	0.8	1.5	0.1
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	45	...	...	91	56
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	175	...	...	100	117
	30. Farm prices of wheat, 1993-94 (US $/ton)	124	...	...	187	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	3.5	...	...	4.1	...
	32. Farm wage in kg of wheat per day, 1993-94	409	...	...	196	...

Regional Aggregates

		Developing Countries	Eastern Europe and the former Soviet Union	Western Europe North America, and other	World *
General indicators	1. Estimated population, 1995 (million)	4453.6	414.6	843.3	5711.5
	2. Estimated growth rate of population, 1993-2000 (%/yr)	2.1	0.5	0.6	1.5
	3. Per capita income 1994 (US $)	991	2158	24288	4757
	4. Average per capita cereal production, 1993-95 (kg/yr)	256	560	682	341
	5. Growth rate of per capita cereal production, 1985-95 (%/yr)	0.1	-2.6	-0.7	-0.8
Production of wheat and all cereals	6. Average wheat area harvested, 1993-95 (000 ha)	103406	54670	61794	219870
	7. Average wheat yield, 1993-95 (t/ha)	2.5	1.9	3.1	2.5
	8. Average wheat production 1993-95 (000 t)	253530	101231	189458	544219
	9. Growth rate of wheat area 1951-66 (%)	1.0	2.4	-0.1	1.2
	10. Growth rate of wheat area 1966-77 (%)	2.0	-1.2	0.6	0.5
	11. Growth rate of wheat area 1977-1985 (%)	0.8	-2.5	1.8	0.1
	12. Growth rate of wheat area 1985-95 (%)	0.3	-0.9	-0.8	-0.3
	13. Growth rate of wheat yield 1951-66 (%)	1.0	1.5	2.2	1.5
	14. Growth rate of wheat yield 1966-77 (%)	3.4	1.8	1.6	2.1
	15. Growth rate of wheat yield 1977-85 (%)	5.1	-0.2	2.7	3.0
	16. Growth rate of wheat yield 1985-95 (%)	1.9	-0.7	1.5	1.2
	17. Growth rate of wheat production, 1951-66 (%)	2.0	3.9	2.1	2.6
	18. Growth rate of wheat production, 1966-77 (%)	5.3	0.6	2.2	2.6
	19. Growth rate of wheat production, 1977-85 (%)	5.9	-2.8	4.5	3.1
	20. Growth rate of wheat production, 1985-95 (%)	2.2	-1.6	0.7	0.9
	21. Wheat area as percent of total cereal area (average), 1993-95 (%)	24	44	47	32
	22. Average yield of all cereals, 1993-95 (t/ha)	2.5	1.9	4.3	2.8
	23. Growth rate of yield of all cereals, 1951-95 (%/yr)	2.2	2.0	2.1	2.1
Trade and utilization	24. Average net imports of wheat, 1992-94 (000 t)	58990	12895	-75695	...
	25. Average net imports of wheat per capita, 1992-94 (kg/yr)	14	31	-91	...
	26. Average per capita wheat consumption, 1992-94 (kg/yr)	72	...	142	103
	27. Growth rate of per capita wheat consumption, 1985-94 (%/yr)	0.3	-2.5**	0.1	-0.2**
Prices and input use	28. Percent of total wheat area under semidwarf wheat varieties, 1994	78	49	56	64
	29. Nitrogen applied per hectare of wheat harvested, 1993-94 (kg nutrients/ha)	97	15	117	84
	30. Farm prices of wheat, 1993-94 (US $/ton)	...	...	...	...
	31. Ratio of farm level nitrogen price to wheat price, 1993-94	...	...	...	...
	32. Farm wage in kg of wheat per day, 1993-94	...	...	...	...

*** The world aggregates are not exactly equal to the FAO estimates because the method of aggregation may have differed.**
**** Variable 27 excludes the former Soviet Union.**

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Appendix A
Glossary

Allele
One of the possible forms of a particular gene. Alleles of a given gene occupy the same position (locus) on paired (homologous) chromosomes. Each homologous chromosome carries the same genes as the other member of the pair, but not necessarily the same alleles for a particular gene.

Crossing block
The nursery containing the parental stocks for a breeder's crossing program.

Cultivar
A cultivated variety of a plant produced by selective breeding for agricultural or horticultural purposes.

Gene
A hereditary unit on a chromosome which determines or conditions one or more characteristics.

Gene pool
The *primary gene pool* (GP-1) corresponds to the traditional concept of a biological species. The GP-1 consists of the cultivated races of a species, as well as the spontaneous races (wild and/or weedy). Within this pool, crossing is easy and hybrids are generally fertile. The *secondary gene pool* (GP-2) includes all species that will cross with a crop. Crosses at this level are more difficult to achieve, however, and the hybrids tend to be sterile. The *tertiary gene pool* (GP-3) represents the outer limit of the potential gene pool of a crop. Crosses can be made, but the hybrids tend to be anomalous or completely sterile. Gene transfer is not possible without radical techniques (see Harlan and de Wet 1971).

Genotype
An organism's genetic makeup.

Landrace
A cultivated form of a crop species, which has evolved over generations of selection by farmers.

Marginal value
The value of an additional unit.

Multiline
A cultivar composed of multiple lines, each of which may differ with respect to genes of interest, but which may share a similar phenotype.

Pairwise distance
The distance between two elements or members of a pair.

Partial resistance
Resistance expressed by a reduced rate of infection, though symptom expression and macroscopic development of the pathogen are similar to those on a susceptible genotype.

Phenotype
The appearance of an organism as determined by the interaction of the genotype and the environment.

Public goods
A product or service with two defining characteristics: (1) consumption of a unit of it by one individual detracts from the consumption opportunities of others, and (2) once provided, it becomes available to all, and excluding individuals from sharing in its benefits becomes difficult.

Variety
A subdivision of a species below subspecies, and in classical taxonomy a heterogeneous grouping, including nongenetic variations of the phenotype, morphs, and races.

Wide cross
A cross between two plants that do not hybridize without the use of special techniques. Examples include a cross between two genera (e.g., wheat and rye) or between a cultivated crop species and its wild relatives (e.g., bread wheat and the *Triticum* grass species).

Wild relative
A relative of a crop species that grows in the wild and is not used for agricultural purposes.

Appendix B

Data Sources Used in Part 1

Major sources of data for this report are the CIMMYT Wheat Impacts Survey and the CIMMYT Wheat Pedigree Management System. In 1990, CIMMYT's Wheat and Economics Programs conducted a survey of wheat research programs in 38 developing countries that produce about 80% of all low-latitude spring wheat.[1] This survey collected information on the output of wheat breeding programs, including: (a) the names, pedigrees, and origins of all 1,216 spring wheat varieties released in the period from 1966 to 1990; and (b) the estimated area under individual varieties in 1990. Area estimates were based on annual government surveys in some countries, special surveys at a regional or country level, seed sales in some countries, and estimates by wheat researchers. The survey data have been analyzed extensively and reported by Byerlee and Moya (1993).

In this report, the data on varietal distributions by area have been combined with detailed pedigree information compiled by CIMMYT's Wheat Pedigree Management System.[2] In this database, all wheat varieties are identified by cross numbers or landrace identifiers. Multiple selections (sisters) from the same cross are also distinguished by identification numbers. Cultivars are traced back to their parental landraces or to lines of unknown pedigree. A computer program was developed to transform the pedigree information for a set of cultivars into a matrix of genealogical characteristics such as those presented in the report.

Additional data were collected by a 1995 survey, developed among CIMMYT scientists and distributed personally or by mail to 168 wheat scientists working in the breeding programs of 52 countries. About one-third of the respondents work in high-income countries. The results of this survey are reported in Rejesus, van Ginkel, and Smale (1996), and highlights are summarized in Box 6. Other data sources are secondary and are thus reported in the references.

Table B1 presents a country-by-country breakdown of regions discussed in Part 1.

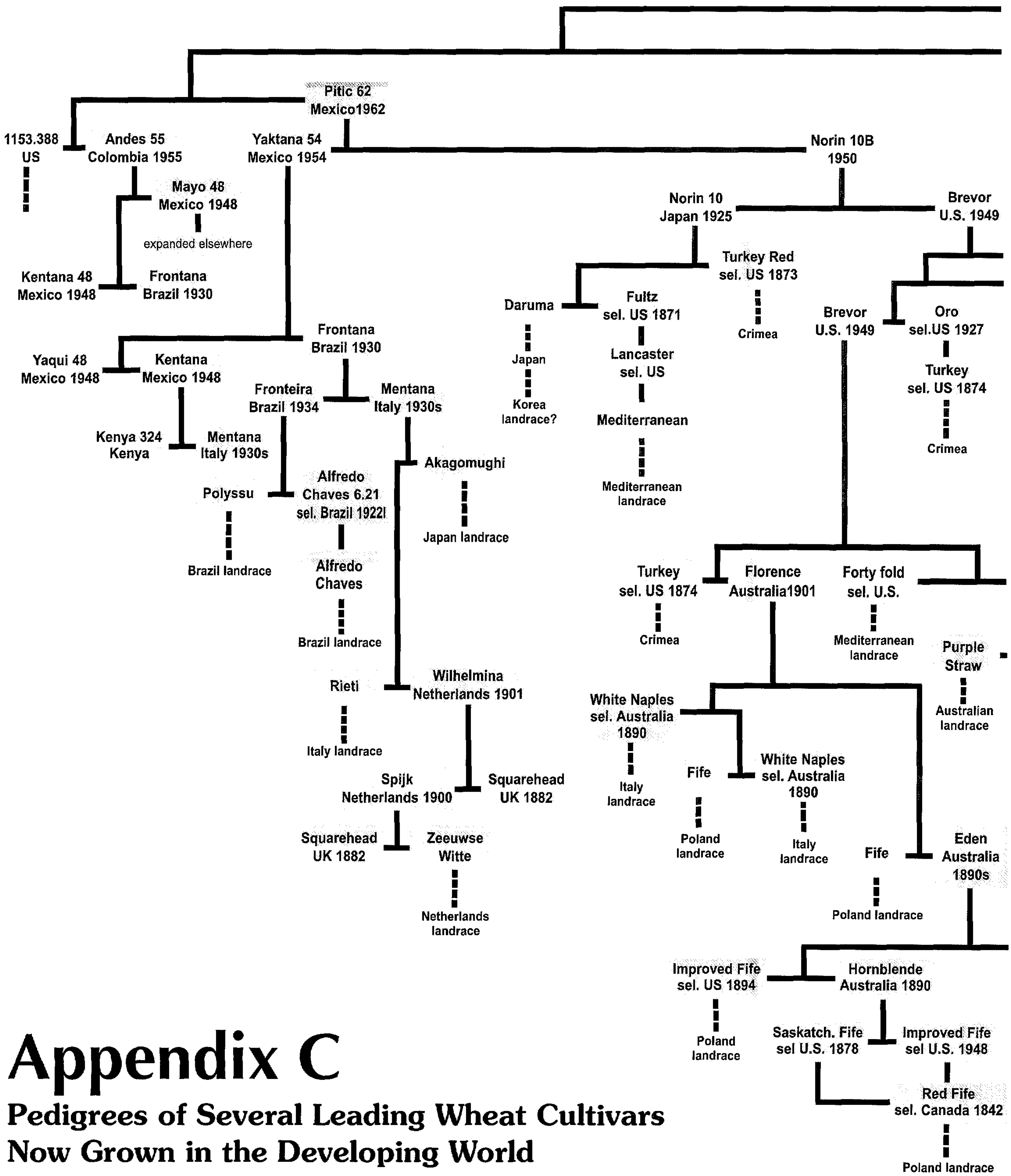
Table B1. Country-by-country breakdown of regions discussed in Part 1

Sub-Saharan Africa	West Asia	North Africa	South Asia	Mexico/ Guatemala	Andean Region	Southern Cone of S. America
Ethiopia	Afghanistan	Algeria	Bangladesh	Mexico	Peru	Argentina
Kenya	Iran	Egypt	India	Guatemala	Bolivia	Brazil
Sudan	Iraq	Libya	Nepal		Colombia	Chile
Tanzania	Saudi Arabia	Morocco	Pakistan		Ecuador	Paraguay
Zambia	Syria	Tunisia	Myanmar			Uruguay
Zimbabwe	Turkey					
Burundi	Jordan					
Nigeria	Lebanon					
	Yemen					

[1] Most of China is excluded from this analysis. See Box 5 and Section III.

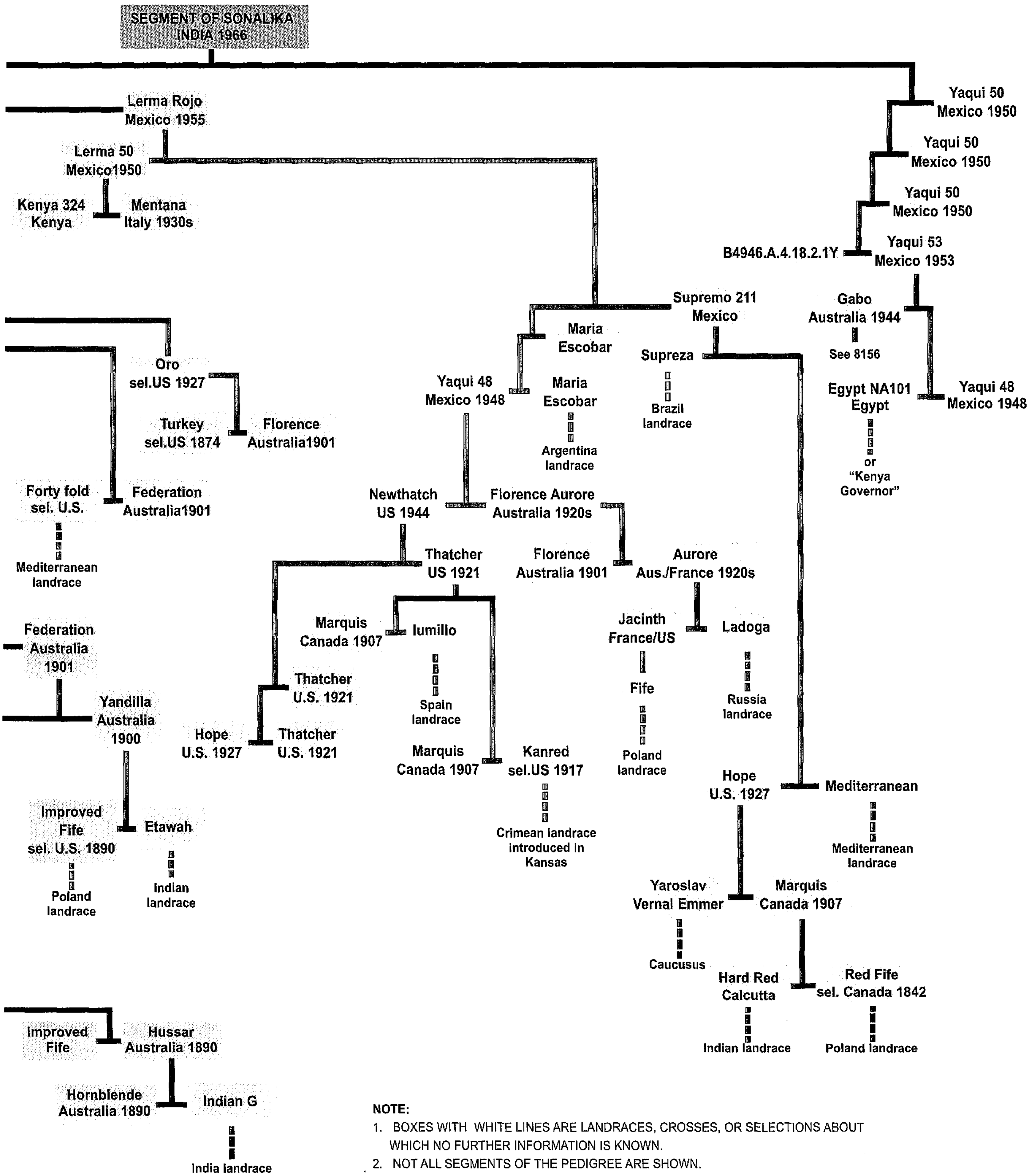
[2] The Wheat Pedigree Management System is a component of CIMMYT's International Wheat Information System, which also includes data from international trials, national trials, germplasm collections, industrial quality and pathology laboratories, and molecular studies. See Fox and Skovmand (1996) for details on the system.

Figure C1. Segment of Sonalika.



Appendix C

Pedigrees of Several Leading Wheat Cultivars Now Grown in the Developing World



NOTE:

1. BOXES WITH WHITE LINES ARE LANDRACES, CROSSES, OR SELECTIONS ABOUT WHICH NO FURTHER INFORMATION IS KNOWN.
2. NOT ALL SEGMENTS OF THE PEDIGREE ARE SHOWN.
3. DATES MAY REFER TO RELEASE DATE OR CROSS DATE, AND ARE APPROXIMATE.

Figure C2. Segment of Veery.

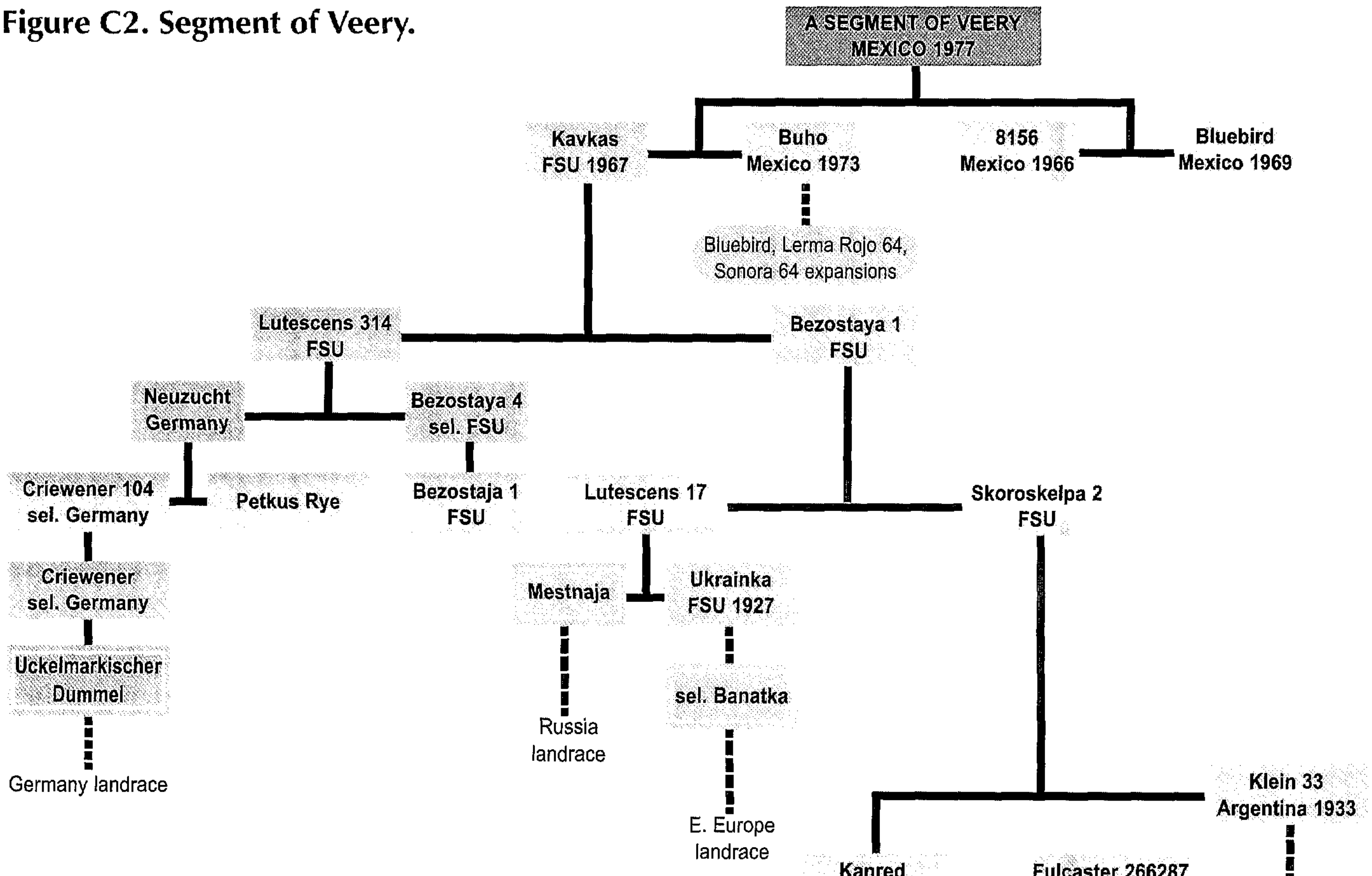
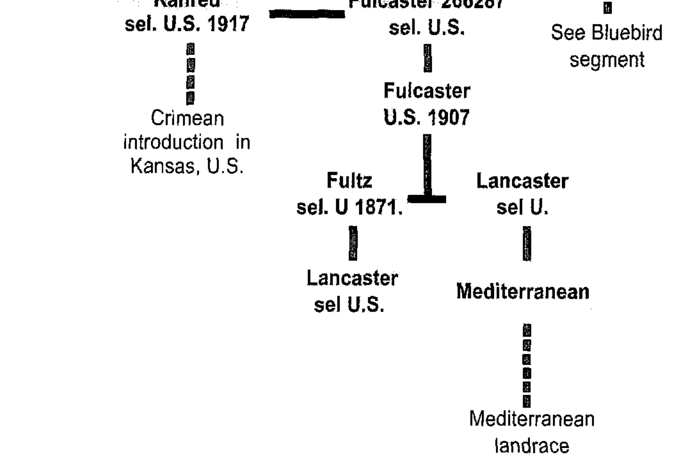
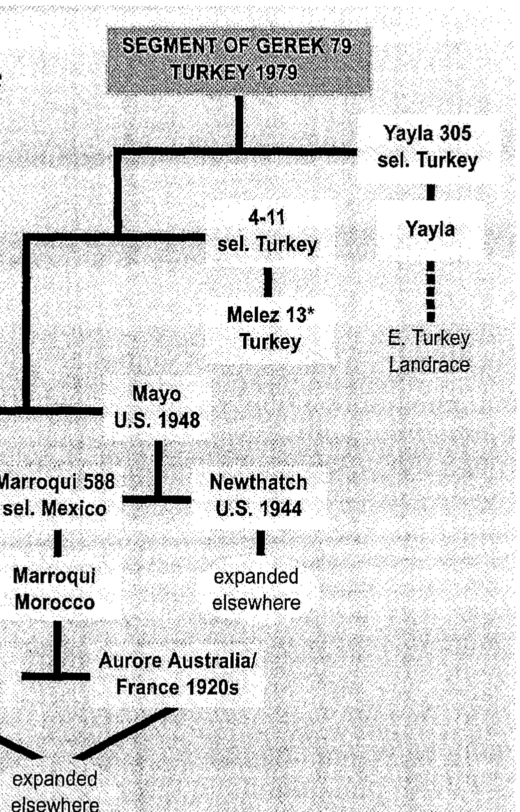



Figure C3. Segment of Gerek 79.



* A mixture of crosses between Mentana and Turkish landraces.

NOTE:

1. BOXES WITH WHITE LINES ARE LANDRACES, CROSSES, OR SELECTIONS ABOUT WHICH NO FURTHER INFORMATION IS KNOWN.
2. NOT ALL SEGMENTS OF THE PEDIGREE ARE SHOWN.
3. DATES MAY REFER TO RELEASE DATE OR CROSS DATE, AND ARE APPROXIMATE.

Appendix D

Regions of the World

Developing Countries

Eastern and Southern Africa

Angola
Botswana
Burundi
Comoros
Djibouti
Ethiopia
Kenya
Lesotho
Madagascar
Malawi
Mauritius
Mozambique
Namibia
Rwanda
Seychelles
Somalia
South Africa
Sudan
Swaziland
Tanzania
Uganda
Zambia
Zimbabwe

Western and Central Africa

Benin
Burkina Faso
Cameroon
Cape Verde
Central Africa Republic
Chad
Congo
Côte d'Ivoire
Equatorial Guinea
Gambia
Ghana
Guinea
Guinea-Bissau
Liberia
Mali
Mauritania
Niger
Nigeria
Reunion
Sao Tome
Senegal
Sierra Leone
St. Helena
Togo
Zaire

North Africa

Algeria
Egypt
Libya
Morocco
Tunisia

West Asia

Afghanistan
Bahrain
Iran
Iraq
Jordan
Lebanon
Oman
Saudi Arabia
Syria
Turkey
Yemen Republic

South Asia

Bangladesh
Bhutan
India
Maldives
Myanmar
Nepal
Pakistan
Sri Lanka

Southeast Asia and the Pacific

American Samoa
Cook Islands
East Timor
Fiji
French Polynesia
Guam
Indonesia
Kiribati
Laos
Macau
Malaysia
Nauru
New Caledonia
Niue
Norfolk Island
Papua New Guinea
Philippines
Samoa
Solomon Islands
Thailand
Tokelau
Tonga
Tuvalu
Vanuatu
Vietnam
Wallis and Futuna Island

East Asia

China
Mongolia
North Korea
South Korea

Mexico, Central America, and the Caribbean

Antigua
Barbados
Belize
Cayman Islands
Costa Rica
Cuba
Dominica
Dominican Republic
El Salvador
Grenada
Guadeloupe
Guatemala
Haiti
Honduras
Jamaica
Martinique
Mexico
Montserrat
Netherlands Antiles
Nicaragua
Panama
St. Christopher and Nevis
St. Lucia
St. Pierre Miquelon
St. Vincent Grenadines
Trinidad and Tobago
U.K. Virgin Islands
U.S. Virgin Islands

Andean Region

Bolivia
Colombia
Ecuador
French Guiana
Guyana
Peru
Suriname
Venezuela

Southern Cone, South America

Argentina
Brazil
Chile
Falkland Islands
Paraguay
Uruguay

Eastern Europe and the Former Soviet Union

Albania
Armenia
Azerbaijan
Belarus
Bulgaria
Former Czechoslovakia
Estonia
Georgia
Hungary
Kazakhstan
Kyrgyzs Republic
Latvia
Lithuania
Moldova
Poland
Romania
Russian Federation
Tajikistan
Turkmenistan
Ukraine
Uzbekistan
Former Yugoslavia

Western Europe, North America, and Other High-Income Countries

Australia
Austria
Bahamas
Belgium-Luxembourg
Brunei
Canada
Cyprus
Denmark
Faeroe Island
Finland
France
Germany
Greece
Greenland
Iceland
Ireland
Israel
Italy
Japan
Kuwait
Malta
Netherlands
New Zealand
Norway
Portugal
Qatar
Singapore
Spain
Sweden
Switzerland
United Arab Emirates
United Kingdom
United States