Chapter 4

Adoption of Improved Wheat Varieties in Developing Countries

In this chapter, we review the adoption of semidwarf varieties in developing countries between 1966 and 1997. We then assess CIMMYT's contribution to varieties planted in farmers' fields and present several alternative methods to measure these contributions. The chapter concludes with a brief assessment of the slow rates at which newer varieties have replaced older varieties in farmers' fields in many developing countries. Slow replacement rates dilute the impact of international and national wheat breeding programs.

Spread of Semidwarf Varieties

Since the introduction of semidwarf wheat varieties in the 1960s, adoption has grown steadily, although at different rates in different parts of the world. In 1970, semidwarf varieties covered a substantial percentage of the total wheat area only in South Asia. The rate of diffusion was particularly rapid in Latin America during the 1970s. By the late 1990s, semidwarfs covered over 80% of all developing country wheat area, with adoption rates of 90% or more in South Asia and Latin America. Adoption of semidwarfs in China initially lagged behind, but by 1997 stood at just under 80%. In 1997, more than 60% of the total wheat area in WANA and sub-Saharan Africa was planted to semidwarf wheat varieties. In the aggregate, adoption of semidwarf varieties in the developing world continued to increase during the 1990s (Figure 4.1).

Nearly 70% of the developing world's spring bread wheat area is found in Asia, so adoption there dominates the aggregate results. Adoption of semidwarfs is highest for spring bread wheat varieties (nearly 90% of total spring bread wheat area); there is little variation in adoption rates for this wheat type across all regions. As in 1990, in 1997 the adoption of semidwarf spring bread wheat was lowest in sub-Saharan Africa (Figure 4.2).

Spring durum wheat production is highly concentrated, with over 80% found in the WANA region. In that region, semidwarfs increased from about 60% of the area in 1990 to around 75% in 1997 (Figure 4.2). The proportion of durum wheat

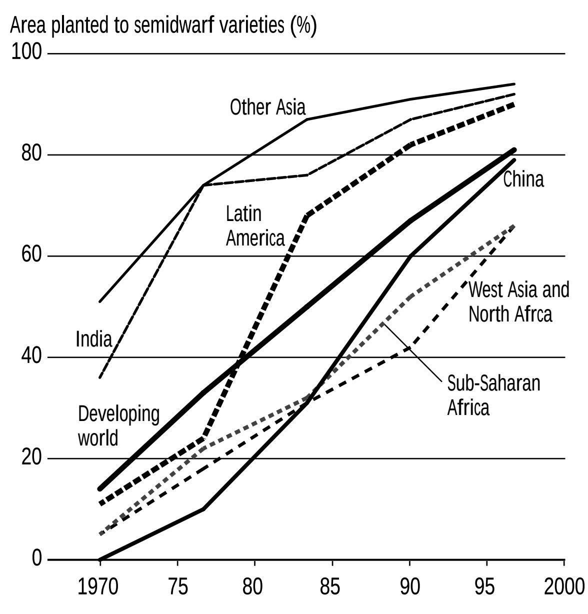

Figure 4.1. Percentage of wheat area planted to semidwarfs in developing countries, 1970-97.

area planted to semidwarfs in Latin America also increased substantially between 1990 and 1997, but adoption of semidwarfs in sub-Saharan Africa's durum region (found only in Ethiopia) remained low. Adoption of semidwarf spring durum wheat in Asia (found only in India) appears to have increased substantially between 1990 and 1997, but total durum area decreased notably (Figure 4.2). Asia has the smallest durum wheat area in the developing world (Byerlee and Moya 1993).

Over 60% of the developing world's winter bread wheat area is found in China, and another third is found in the WANA region. Adoption of semidwarfs appears to be higher for winter bread wheat in China than for spring bread wheat. In contrast, adoption of semidwarfs is low for winter bread wheat in WANA and South Africa. South Africa is the only country in sub-Saharan Africa where winter bread wheat is grown; all of the winter bread wheat in that country is planted to improved varieties. In Latin America, with limited winter area in the Southern Cone, adoption of semidwarfs is high. Turkey is the only country in which winter durum wheat is grown, and adoption of semidwarfs is very low (10%) for that wheat type and country (Figure 4.2).

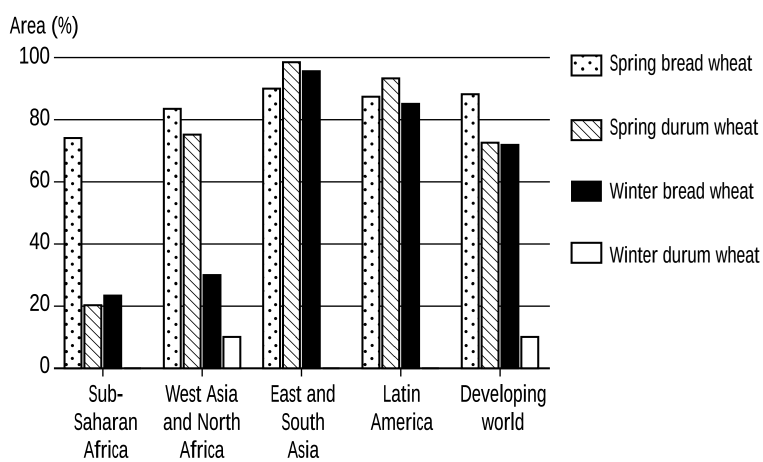

Figure 4.2. Percentage of wheat area planted to semidwarf varieties by wheat type and region, 1997.

Adoption of modern varieties (MVs) carrying dwarfing genes has been very high in irrigated areas and low in rainfed areas (Byerlee and Moya 1993). However, adoption of MVs increased rapidly in rainfed areas in the 1980s, despite modest yield gains there as compared with irrigated areas (Byerlee and Morris 1993). In more recent years, adoption of MVs has continued to increase in some rainfed areas. For example, semidwarfs now appear to be grown on nearly 100% of rainfed area of Argentina and Syria and around 85% of the rainfed area in Pakistan (Byerlee and Moya 1993).

Area Planted to CIMMYT-Related Germplasm

Table 4.1 summarizes the area planted in 1997 to varieties of different origins. As noted previously, spring bread wheat is the dominant type of wheat grown in the developing world, and spring bread wheat releases dominate all releases. In the countries surveyed for this report (including China), 69 million hectares were planted to spring bread wheat in 1997. Of this, about 60 million hectares were planted to semidwarfs, nearly 53 million hectares (88%) of which were sown to CIMMYT-related varieties. CIMMYT or NARS crosses with at least one CIMMYT parent covered about 40 million hectares, and another 12 million hectares were planted to varieties with some earlier CIMMYT ancestor.

In the countries surveyed, spring durum wheat covered about 6.5 million hectares. More than two-thirds of this area was planted to CIMMYT-related varieties and more than one-half to CIMMYT crosses. Landraces covered 1.5 million hectares, representing over 20% of the spring durum area.

Winter bread wheat covers considerably more area than spring durum wheat: in 1997, about 26 million hectares were sown to winter bread wheats. Of these, about 6 million hectares (24% of the total area planted) were planted to varieties related to CIMMYT, mainly varieties in which CIMMYT germplasm had been incorporated in earlier generations. Semidwarf varieties unrelated to CIMMYT covered about 12 million hectares, while landraces covered about 3 million hectares (Table 4.1).

The adoption of CIMMYT-related spring bread wheat in 1997 is disaggregated in greater regional detail in Figure 4.3. Excluding China, 80-90% of the spring bread wheat area in the developing world's major wheat-growing regions was planted to CIMMYT-related material. The use of CIMMYT crosses was greatest in WANA and Latin America, where about 50% of the spring bread wheat area was planted to CIMMYT crosses. In China, about one-third of the spring bread wheat area was planted to CIMMYT-related germplasm, and an additional 40% was planted to semidwarf wheats that did not contain CIMMYT germplasm.

Spring durum wheat area, which is relatively small compared to the area sown to other wheat types, is predominantly sown to CIMMYT-related semidwarf varieties. As is the case in adoption of spring bread wheats, Latin America and WANA have been major adopters of CIMMYT crosses in spring durum wheat (Figure 4.4). In WANA, where over 80% of the developing world's durum wheat is grown, more than 50% of spring durum wheat area was planted to CIMMYT crosses. In Latin America, the percentage of area planted to CIMMYT crosses was more than 90%.

Table 4.1. Area (million ha) sown to different wheat types, classified by origin of germplasm, 1997.

		NARS crosses						
Wheat type	CIMMYT cross	CIMMYT parent	CIMMYT ancestor	Other semidwarf	Tall	Land races	Unknown cultivars	All
Spring bread wheat	18.2	22.4	12.6	7.7	5.2	2.2	1.0	69.4
Spring durum wheat	3.4	1.2	<0.1	0.1	0.3	1.5	0.1	6.6
Winter bread wheat	0.2	1.8	4.2	11.6	2.3	3.2	2.6	25.9
Winter durum wheat	0.0	0.0	0.0	0.1	1.0	0.1	0.0	1.2
All	21.8	25.5	16.8	19.5	8.8	7.0	3.8	103.1

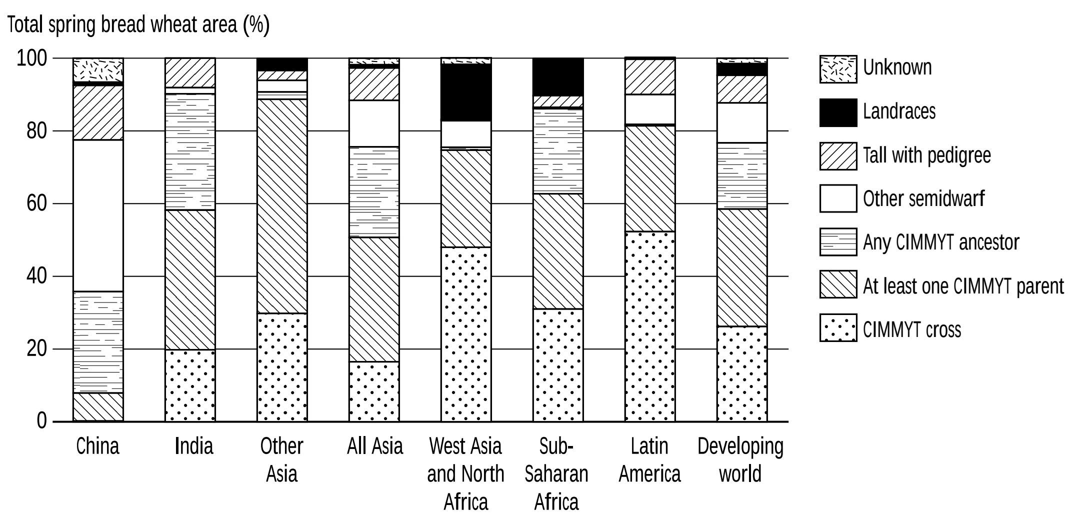

Figure 4.3. Area planted to spring bread wheat in developing countries, 1997.

In contrast to areas planted to spring bread and spring durum wheat, the area planted to winter bread wheat is dominated by semidwarf wheats that are unrelated to CIMMYT wheats. These are overwhelmingly Chinese winter wheat varieties. Among the regions where winter wheat is grown, Latin America was the only region where CIMMYT material was dominant (Figure 4.5). In China, nearly two-thirds of the winter bread wheat area (36% of the total wheat area) consisted of non-CIMMYT winter semidwarfs. In WANA, a region with a large winter wheat area, about 35% of the winter wheat area was planted to varieties with some CIMMYT ancestry. In South Africa, the only country in sub-Saharan Africa where winter wheat is grown, two-thirds of the wheat area was planted to tall varieties with pedigrees (i.e., tall varieties known to have originated with a scientific wheat breeding program).

Unlike spring bread wheat area, large proportions of both spring durum and winter bread wheat areas were still planted to landraces in 1997. Seven million hectares of the developing world's wheat area were sown to landraces, and 3.8 million

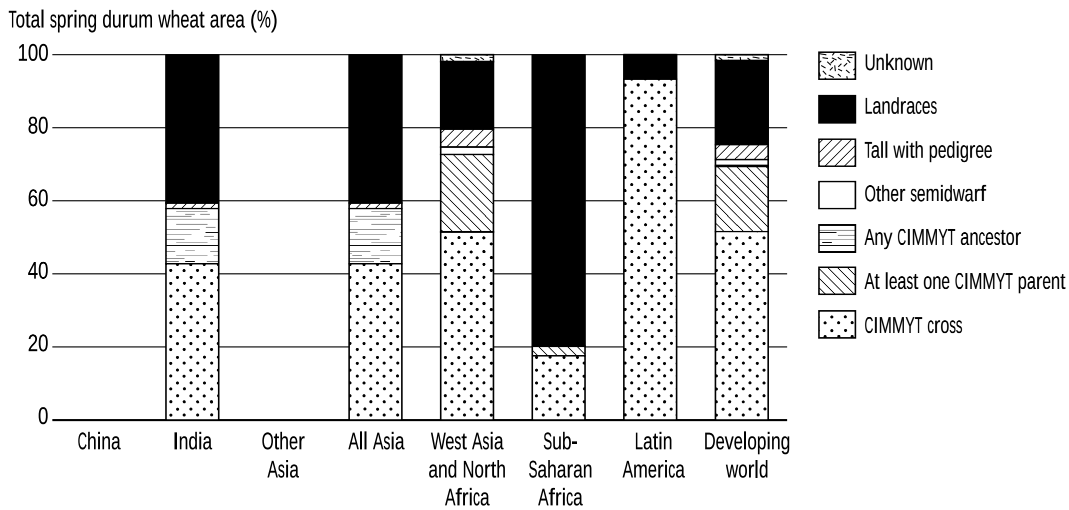

Figure 4.4. Area planted to spring durum wheat in developing countries, 1997.

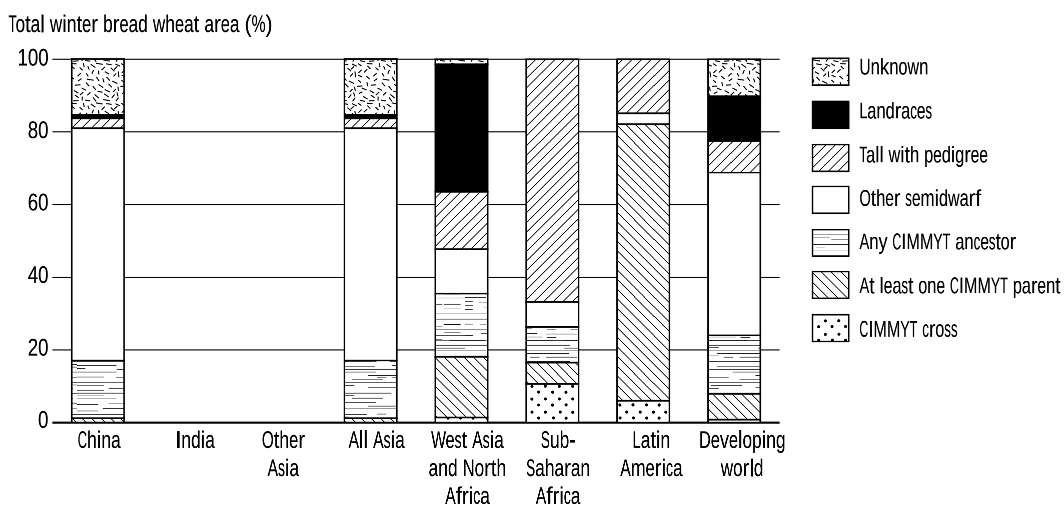

Figure 4.5. Area planted to winter bread wheat in developing countries, 1997.

hectares were planted to cultivars whose pedigrees and origin were unknown. It is possible that some of these unknown cultivars also had CIMMYT ancestry. Landraces tended to be concentrated in WANA, covering slightly less than 20% of the spring durum area and nearly 40% of the winter wheat area. In Ethiopia, the only country in sub-Saharan Africa where durum wheat is grown, landraces covered about 80% of wheat area (Figures 4.4 and 4.5).

Taking into account all wheat types, in 1997 62% of wheat area in the developing world was planted to wheat varieties with some CIMMYT content; without China, this figure rises to 75% (Figure 4.6). Slightly less than half of the wheat area in the developing world was planted to varieties produced from crosses made by CIMMYT or that had at least one CIMMYT parent. More than 80% of the wheat area planted in Asia (outside of China) and Latin America was sown to CIMMYT-related varieties.

Table 4.2 summarizes the total area sown in 1997 to varieties derived from popular CIMMYT spring wheat crosses. Sonalika remained the most popular CIMMYT cross released before 1980. Of the varieties released during the 1980s, Veery remained the most popular cross. About three million hectares were planted to Veery in 1997, similar to the area sown in 1990. The areas planted to both Bittern and Frigate (durum) crosses were about the same for 1990 and 1997. In contrast, the area sown to the Bobwhite cross in 1997 was significantly higher than in 1990. Kauz and Attila[21] crosses, which covered about one million hectare each in 1997, were the two most popular recent crosses. In both 1990 and 1997, the area sown to varieties based on recent CIMMYT crosses was much lower than the area sown to varieties released earlier. This was related to the rate of varietal replacement in developing countries, which will be discussed further at the end of this chapter.

Byerlee and Moya (1993) reported that in 1990 varieties from many crosses were grown on smaller areas. This was still the case in 1997. In addition to the specific crosses shown in Table 4.2, about 200 CIMMYT crosses were sown on more than 10 million hectares. Of this area, 6 million hectares were planted to 73 crosses (varieties)

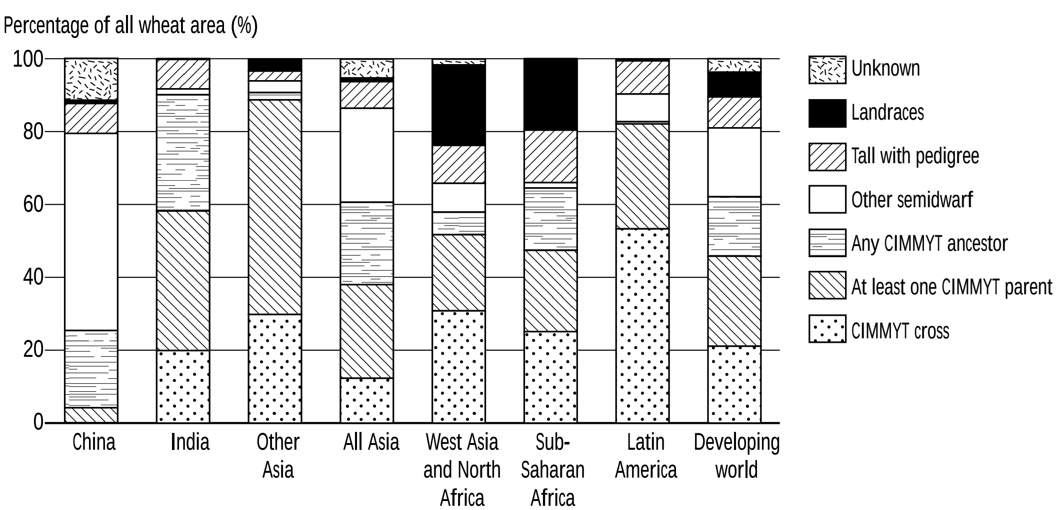

Figure 4.6. Area planted to all wheat in developing countries, 1997.

[21] By 2001, Attila probably covered more than 5 million ha in India alone.

released since 1980, and about 3 million hectares were sown to 85 recent crosses (varieties) released since 1990. Although the total area sown to the most popular CIMMYT crosses declined in 1997, the use of CIMMYT germplasm as a parent in NARS crosses rose throughout the 1990s.

In both 1990 and 1997, India, Pakistan, Argentina, and Morocco had the largest wheat area sown to varieties developed from CIMMYT crosses (Table 4.3). The wheat area grown to varieties developed from CIMMYT crosses decreased between 1990 and 1997 in some countries (e.g. India, Pakistan, Brazil, and Mexico). However, in most of these countries, a substantial area was sown to varieties with considerable CIMMYT content, though they resulted from several generations of crossing and selection by NARS or private-sector scientists. In India and Pakistan, for example, farmers planted large areas to varieties with at least one CIMMYT parent. In Brazil and Mexico, the area planted to CIMMYT-related varieties declined because the total wheat area declined.

For the countries listed in Table 4.3, we also estimated the percentage of area covered by varieties derived from CIMMYT crosses, relative to the total wheat area planted (Figure 4.7). This shows how shifts in area planted to varieties derived from CIMMYT crosses can be offset by changes in total wheat area. As an example, even though the area planted to CIMMYT-derived varieties declined in Brazil in absolute terms, about 35% of the total wheat area in Brazil was planted to CIMMYT crosses in both 1990 and 1997.

In a number of countries (notably those in the WANA region as well as Argentina), the proportion of total wheat area sown to varieties

Table 4.2 Area sown to varieties derived from popular CIMMYT spring wheat crosses, 1997.

Cross	Average year of varieties from cross released	Area sown (000 ha)	Main country of release
Released before 1980			
Sonalika	1972	1224	Bangladesh, India, Nepal, Yemen
II8156	1972	293	Afghanistan, Morocco, Nigeria, Syria, Yemen Rep.
Other (30 crosses)		1,275	
Subtotal		2,791	
Released 1980-89			
Veery	1988	3,351	Afghanistan, Bolivia, Brazil Chile, Egypt, Ethiopia, India, Iran, Morocco, Nepal, Nigeria, Pakistan, Paraguay, South Africa, Tanzania, Turkey, Uruguay, Yemen, Zambia, Zimbabwe
Bobwhite	1988	1,643	Argentina, Ethiopia, Paraguay, Turkey, Uruguay
Bittern (durum)	1984	963	Chile, Egypt, Morocco, Tunisia, Turkey
Frigate (durum)	1988	584	Algeria, Lebanon, Syria
Buckbuck	1989	421	Kenya, Pakistan
Pavon	1982	323	Bolivia, Ethiopia, Mexico, Nigeria, Pakistan, Peru Tanzania, Yemen
Gallareta (durum)	1984	361	Mexico
Other (73 crosses)		5,905	
Subtotal		13,551	
Released since 1990			
Kauz	1994	1,092	Afghanistan, Chile, India, Iran, Pakistan , Turkey
Attila	1996	1,006	India, Iran
Loxia	1992	416	Argentina, Paraguay
Other (85 crosses)		2,993	
Subtotal		5,508	
Total		**21,851**	

Table 4.3. Countries having the largest wheat area (million ha) sown to varieties developed from CIMMYT crosses, 1990 and 1997.

Country	Area sown to wheat varieties developed from CIMMYT crosses 1990	1997
India	6.8	5.1
Pakistan	5.5	2.5
Argentina	1.9	3.1
Morocco	1.4	1.9
Turkey	0.9	0.5
Brazil	0.9	0.5
Mexico	0.9	0.7
Iran	0.8	1.4
Syria	0.7	1.4
Egypt	0.6	0.9
Algeria	0.4	0.7

Source: Byerlee and Moya (1993); CIMMYT Wheat Impacts database.

released from CIMMYT crosses was larger in 1997 compared to 1990. In another instance, the large decline in the percentage area planted to CIMMYT crosses in Pakistan was due largely to a single shift in varieties grown. In the mid-1990s, following a change in stripe rust virulence, farmers switched from a CIMMYT cross that dominated Pakistan's wheat area during the late 1980s and throughout much of the 1990s to a cross with a CIMMYT parent (and considerable CIMMYT germplasm on both sides of the pedigree) (Figure 4.7).

Alternative Measures of CIMMYT Contribution to Wheat Varieties Planted in the Developing World

The methods of analyzing the origin of cultivars released and planted in the developing world were not discussed in the preceding and current chapter. In this section, we look more explicitly at ways of measuring the contributions of different wheat breeding programs, and more specifically at CIMMYT's contribution to wheat varieties planted in 1997.

The broadest way to define CIMMYT's contribution is to use an "any ancestor" rule. More restrictive definitions can be used, such as "varieties with CIMMYT parents" and "crosses made by CIMMYT." The last category, "crosses made by CIMMYT," constitutes the narrowest definition. Pardey et al. (1996) summarized these and other measures that have been used by researchers to apportion contributions of different breeding programs to pedigree-bred crops and proposed several new measures.

In the following discussion and Figures 4.8-4.11, we apply four rules to our database on wheat planted in developing countries.

1. The "geometric" rule developed by Pardey et al. (1996).
2. The "any ancestor" rule.
3. A "CIMMYT cross or parent" rule similar to the one used by Byerlee and Moya (1993).
4. The "CIMMYT cross" rule.

These rules are applied to individual varieties, and then aggregate measures of CIMMYT's contribution are determined by calculating area-weighted proportions.[22]

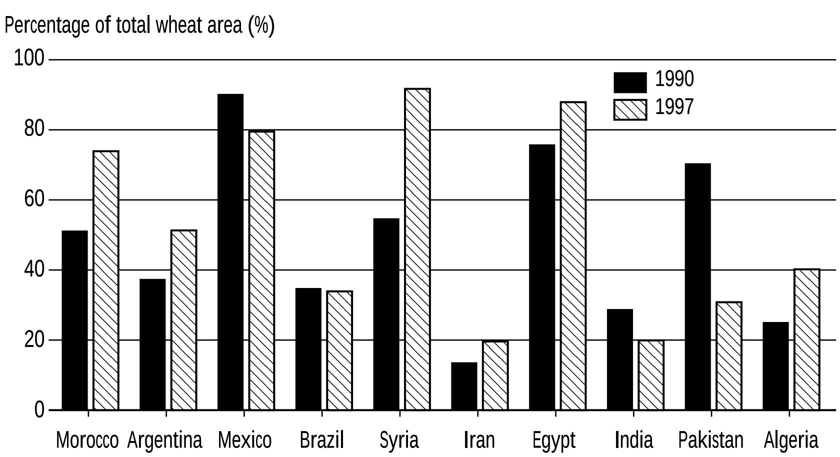

Figure 4.7. Percentage of wheat area sown to CIMMYT crosses in selected countries, 1990 and 1997.

[22] This was the implicit methodology of the simple measures applied earlier in this chapter.

The geometric rule analyzes a variety's pedigree by applying geometrically declining weights to each level of crossing for as many generations as desired. Hence, it gives a weight of 1/2 to the cross itself, 1/8 to each of the two crosses used as parents, 1/32 to each of the four crosses used as grandparents, and so on back. In the earliest generation considered, weights are doubled to make all weights sum to 1. In our calculations, we included five generations. In addition, wheat areas planted to landraces and unknown varieties were included in the calculations. For these areas, the CIMMYT contribution was set to zero. For the 1997 data, we report results with and without China, primarily for the purpose of allowing comparison with 1990. This is because only a few spring bread wheat zones in China were covered in the 1990 survey.

During the 1990s, the area planted to spring bread wheat varieties with some CIMMYT content increased at the same time that the area planted to CIMMYT crosses decreased. Combining these effects, apportionment of CIMMYT content by the geometric rule declined slightly between 1990 and 1997 when China was excluded (Figure 4.8).

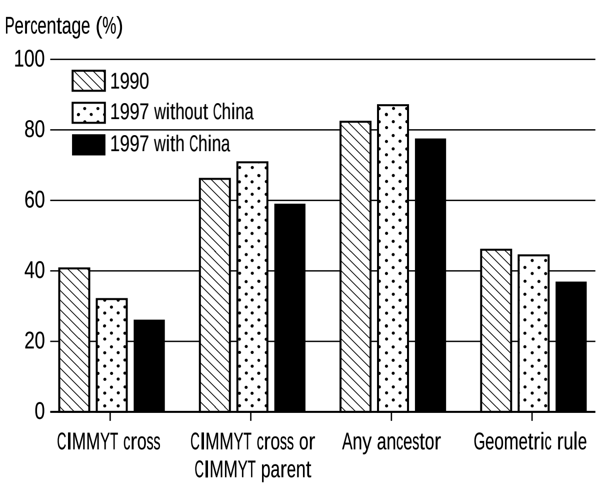

Figure 4.8. Percentage of CIMMYT contribution to spring bread wheat planted in developing countries, 1990 and 1997.

These results conceal a number of regional differences, some of which are not evident in Figure 4.8. Outside of China, all four indicators of CIMMYT content presented here—geometric rule, any ancestor rule, CIMMYT cross or parent, or CIMMYT cross—increased between 1990 and 1997 in the spring bread wheat areas of WANA, Latin America, and sub-Saharan Africa. In South Asia, although the area planted to wheat with some CIMMYT content increased between 1990 and 1997, areas apportioned according to the geometric rule or CIMMYT cross rule fell significantly. This change was enough to drive the aggregate estimates down for the developing world (excluding China) (Figure 4.8). At the same time, the percentage area planted to wheat varieties with some CIMMYT ancestry is higher in South Asia (as discussed earlier) than in any other region of the developing world. In other words, CIMMYT germplasm is present in nearly all spring bread wheat grown in South Asia today, particularly in India, where substantial areas are sown to varieties from several generations of crossing and selection by local scientists in wheats with a large amount of CIMMYT germplasm. Wheat scientists in Asia have also incorporated improved tall varieties into their germplasm base.

As expected, when China is included, CIMMYT's contribution to improved wheat released in developing countries declines by all measures. The decline is proportionately lowest when using the any ancestor rule (compare the two 1997 indicators in Figure 4.8). As the figures indicate, China's wheat genetic improvement program has made less use of CIMMYT germplasm than other programs in the developing world, both for historical reasons and because China's wheat growing environments differ substantially from those found elsewhere in the developing world.[23]

[23] These include large areas sown to winter habit area, some area sown to high-latitude spring wheat, and special disease problems even in the areas sown to low-latitude spring wheat (Byerlee and Moya 1993).

Even so, a significant amount of Chinese spring bread wheat area (around 4.7 million hectares in 1997) is sown to wheat varieties with some CIMMYT ancestry, and about a million hectare of this area is sown to spring bread wheat varieties that have a CIMMYT parent rather than a more distant CIMMYT ancestor.

Figure 4.9 shows CIMMYT's contribution to spring durum wheat planted in developing countries. Little spring durum wheat is grown in China, so the analysis focuses only on CIMMYT's contribution in major developing country spring durum wheat producers in 1990 and 1997. Regardless of the measure used, CIMMYT's contribution to spring durum wheat planted in the developing world was higher in 1997 than in 1990. Using the CIMMYT parent or the any ancestor rule, over two-thirds of spring durum wheat planted in the developing world in 1997 could be attributed to CIMMYT. Using the CIMMYT cross or the geometric rule, CIMMYT's contribution to spring durum wheat planted in 1997 was slightly more than 50%.

The data on releases and area planted show that CIMMYT has made a smaller contribution to winter wheat breeding in developing countries compared to spring bread or spring durum wheat breeding. This can be attributed both to the late start of winter wheat breeding by CIMMYT (Chapter 2) and to China's dominance of the total winter wheat area. Even so, CIMMYT's contribution to winter wheat has grown substantially since 1990. No CIMMYT winter crosses were planted in 1990; in 1997, a small area was planted to such crosses (Figure 4.10). Excluding China, the proportion of winter wheat planted to varieties with some CIMMYT content tripled between 1990 and 1997. Within China, a little more than 10% of the winter wheat area was planted to varieties with some CIMMYT ancestry in 1997. By the geometric rule, CIMMYT contribution to winter wheat planted in developing countries increased from 2% to 5% between 1990 and 1997. Including China, the aggregate figure would again be slightly greater than 2% in 1997.

To a large extent, the pattern of CIMMYT's contribution to all wheat planted follows that of spring bread. As with spring bread wheat, the aggregate area planted to CIMMYT crosses for all wheat types declined between 1990 and 1997, while the area planted to NARS crosses with at

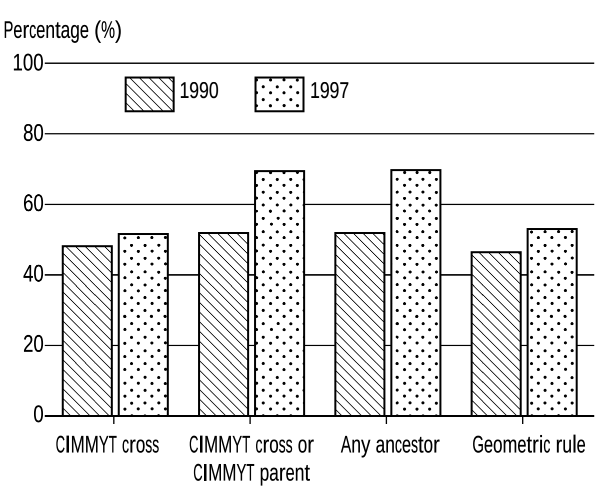

Figure 4.9. Percentage of CIMMYT contribution to spring durum wheat planted in developing countries, 1990 and 1997.

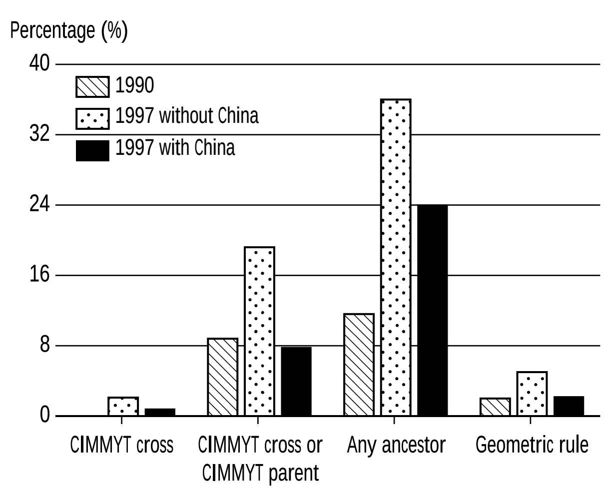

Figure 4.10. Percentage of CIMMYT contribution to winter bread wheat planted in developing countries, 1990 and 1997.

least one CIMMYT parent and NARS varieties with some CIMMYT ancestry increased. By the geometric rule, however, the increased contributions in spring durum and winter wheat offset the decline for spring bread wheat, and so the aggregate estimate for CIMMYT contributions for all wheat types increased slightly between 1990 and 1997. Again, by the geometric rule, CIMMYT accounted for nearly 40% of genetic contribution to all wheat planted in the developing world (excluding China) in 1990 and 1997. When China was included, CIMMYT's contribution to all wheat planted in 1997 was slightly less than 30% (Figure 4.11).

Lags in Adoption of MVs

A significant proportion of total wheat area was still planted to older improved varieties in 1997. This is consistent with the results reported in 1990 study by Byerlee and Moya (1993). Despite the fact that farmers in developing countries have widely adopted improved varieties, the rate at which older varieties are replaced by newer varieties remains unacceptably slow. As long as they continue to grow old varieties, farmers benefit neither from the improved yield potential of newer varieties nor from their superior disease resistance. Although many economic studies of returns to agricultural research make assumptions about adoption lags, such lags have not been given a great deal of analytical attention. Nonetheless, long adoption lags are important factors that reduce returns to wheat breeding research.

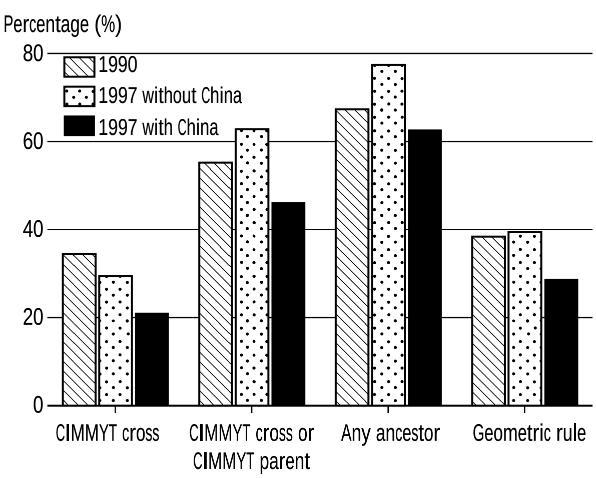

Figure 4.11. Percentage of CIMMYT contribution to all wheat planted in developing countries, 1990 and 1997.

A measure of the rate at which varieties are being replaced is the age of varieties in farmers' fields. This is measured in years since release and weighted by the area planted to each variety (Brennan and Byerlee 1991). Based on this indicator, varietal replacement accelerated between 1990 and 1997 in only 12 of the 31 countries for which comparisons could be made.

The weighted average age of improved varieties planted in farmers' fields in 1997 is given in Table 4.4. Note that only improved wheat varieties (semidwarfs and improved tall varieties) are included in these calculations. Zimbabwe and Afghanistan were the only two developing countries where the average age of varieties in farmers' fields was less than six years. This length of time is notable because it is roughly equivalent to the longevity of rust resistance derived from a single resistance gene (Kilpatrick 1975). Rust is the most important disease of wheat worldwide. In Zimbabwe, the private sector's involvement in wheat research may have played a role in the rapid turnover of wheat varieties. In Afghanistan, external aid following the Russian withdrawal

Table 4.4. Weighted average age (years) of improved varieties in farmers' fields, 1997.

Age	Country
< 6	Zimbabwe, Afghanistan
6 - 8	China, Pakistan, Guatemala, Chile, Argentina, Brazil
8 - 10	Zambia, Nigeria, Iran, Colombia, Bolivia, Uruguay
10 - 12	Paraguay, Ecuador, South Africa, Morocco, Tanzania
12 - 14	Syria, Yemen, Lebanon, India, Kenya, Mexico
> 14	Sudan, Ethiopia, Egypt, Algeria, Tunisia, Jordan, Bangladesh, Nepal, Peru, Turkey

included widespread distribution of wheat seed; otherwise wheat varietal turnover in Afghanistan would undoubtedly have been much slower.

With the exception of Peru and Mexico, farmers in most Latin American countries replace their varieties more rapidly than farmers in other developing countries. This is consistent with earlier findings (Byerlee and Moya 1993). In Mexico, varietal replacement seems to be decelerating (Brennan and Byerlee 1991). This deceleration in the rate of varietal turnover resulted primarily from a shift from bread wheat to older improved durum wheat varieties in major wheat-growing areas of northwestern Mexico. In addition, Mexican policy has increasingly focused on high industrial quality and protein levels, as well as high and stable yields. This shift has led to incentives for the substitution of durum varieties for bread wheat varieties.

In contrast to Latin America, the weighted average ages of varieties in most nations of the WANA region exceeds 12 years. Interestingly, even large wheat-producing countries such as India have weighted varietal ages exceeding 12 years, although wheat varieties are replaced much more rapidly in some regions, particularly northwestern India (Byerlee and Moya 1993). Factors affecting the rate of varietal replacement in wheat are discussed from a theoretical perspective by Heisey and Brennan (1991). Empirical evidence on varietal replacement is presented by Heisey (1990) and Mwangi and colleagues (see, for example, Alemu Hailye et al. 1998; Regassa E. et al. 1998; and Hailu B., Verkuijl, and Mwangi 1998).