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E C O N O M I C S

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The views expressed in this paper are the authors' and do not necessarily reflect the positions of CIMMYT, the USDA, or those organizations that provided data for the study.

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Contents

Abstract

This paper describes and analyzes some of the impacts of wheat improvement research in seven countries in the Eastern and Southern regions of Africa. The countries—South Africa, Ethiopia, Sudan, Kenya, Zimbabwe, Tanzania, and Zambia—produce nearly 99% of all the wheat grown in the region and 97% of all wheat grown in sub-Saharan Africa. The first section of the paper is a brief review of wheat production in the region, concentrating on production levels and growing environments. The second section analyzes the wheat improvement research effort. The third section looks at the pattern of release of wheat varieties over time, as well as the use of wheat germplasm from CIMMYT. The fourth section presents data about varieties that are currently grown in farmers' fields. The fifth section considers some of the organizational issues involved in making wheat breeding research more efficient. The paper concludes that many of the wheat improvement research programs in Eastern and Southern Africa have been successful. However, the small amount of wheat produced in many countries raises the question of whether the same results could have been obtained at lower cost through greater efficiencies in research organization and even greater reliance on research spill-ins.

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International Wheat Breeding Research in Eastern and Southern Africa, 1966-97

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Introduction

In 1990, the International Maize and Wheat Improvement Center (CIMMYT) undertook a survey of all the wheat varieties released by NARS in developing countries between 1966 and 1990. This survey, along with supplementary data, was used to describe and analyze the impacts of wheat improvement research in the developing world. Two major objectives of the study were to provide feedback to researchers on the acceptance or rejection of new technologies and the reasons for farmer response, and to document the benefits of wheat research for those who fund it (Byerlee and Moya 1993).

In 1997, the Economics and Wheat Programs of CIMMYT launched another survey to update the data and analysis from the previous study. Objectives were quite similar: to increase the efficiency of research resource allocation, to aid research institutions in formulating effective strategies for the deployment of new technology, to provide support for fund-raising efforts, and to create greater public awareness of the achievements of CIMMYT and its partners. Questionnaires were sent to the 41 developing countries producing more than 20,000 metric tons of wheat per year, and responses were received from 36 of those countries, representing nearly 99% of the developing world's wheat production.

This paper reports some of the results of this study for seven countries in Eastern and Southern Africa.[1] These countries, South Africa, Ethiopia, Sudan, Kenya, Zimbabwe, Tanzania, and Zambia, produce nearly 99% of all the wheat grown in the region and 97% of all wheat grown in sub-Saharan Africa.

The first section is a very brief review of wheat production in the region, concentrating on production levels and growing environments. The second section analyzes the wheat improvement research effort, describing the number of researchers, one measure of research intensity, the division of wheat breeding research between public and private sectors, and the disciplinary backgrounds of public sector scientists engaged in wheat improvement programs. The third section looks at the pattern of release of wheat varieties over time, as well as the use of wheat germplasm from CIMMYT. The fourth section presents data about varieties that are currently being grown in farmers' fields. The fifth section considers some of the organizational issues involved in making wheat breeding research more efficient. The final section offers some conclusions.

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[1] Of the eight countries in sub-Saharan Africa producing more than 20,000 metric tons of wheat annually, only Nigeria is not located in Eastern and Southern Africa.

Wheat in Eastern and Southern Africa

This section presents a very brief overview of wheat production in the region, focusing particularly on issues relevant to questions of efficiency of wheat breeding programs. Payne, Tanner and Abdalla (1996) have made a far more comprehensive survey of wheat production and research issues in the region.

Although many countries in sub-Saharan Africa grow a small amount of wheat, the region as a whole is responsible for less than 2% of all wheat produced in the developing world. Seventy percent of the countries growing wheat in the region produce less than 20,000 metric tons annually; at the other end of the scale, none of the sub-Saharan countries have output greater than 2.5 million metric tons (Figure 1). Outside of sub-Saharan Africa, nearly one-quarter of the wheat producers have production larger than this threshold.

Despite the generally smaller production levels, Eastern and Southern Africa—the focus of this study and the area in which the vast majority of sub-Saharan African wheat is produced—has a wide variety of wheat types and wheat growing environments (Table 1). Although spring bread wheat is the predominant type, accounting for about two-thirds of the total wheat area, both spring durum wheat (concentrated in Ethiopia, the second largest producer in the region) and facultative wheat (concentrated in South Africa, the largest producer) can be found (Table 2). Note the difference in the estimate of area planted to facultative wheat as reported in the general mega-environment survey conducted by Payne, Tanner, and Abdalla (1996) and the estimate stemming from the results of the 1997 global wheat research impacts study. The latter estimate was based on comparing identification of

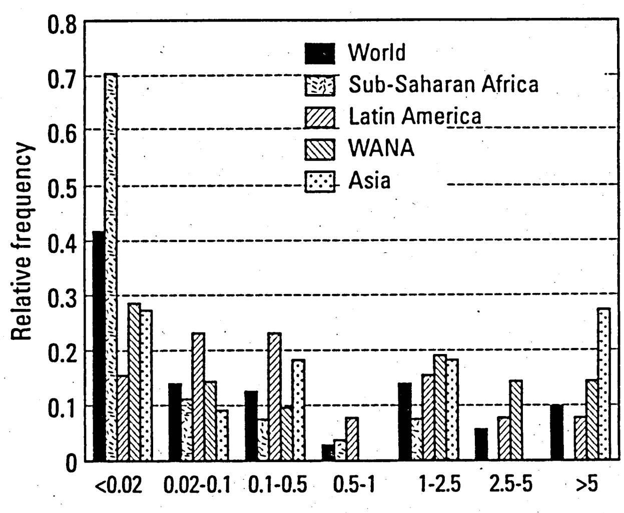

Figure 1. Proportion of countries with given levels of wheat production.

* West Asia/North Africa

Table 1. Wheat mega-environments in Eastern and Southern Africa

ME	Percent of wheat area, study countries	Percent of wheat area, all countries
2	43.3	43.0
4A	12.9	12.7
5B	9.3	9.1
1	4.2	4.2
3	1.4	1.8
4C	0.0	0.1
Subtotal, spring wheat	71.0	71.0
9	29.0	29.0
Subtotal, facultative/ winter wheat	29.0	29.0
TOTAL	100.0	100.0

Source: Modified from Payne, Tanner, and Abdalla (1996) by incorporating additional information for Sudan individual wheat varieties as facultative/winter types with estimates of actual areas planted to individual varieties.It is fairly consistent with estimates of the area planted to facultative wheat in South Africa reported by several participants at the Tenth Regional Wheat Workshop for Eastern, Central, and Southern Africa (CIMMYT, 1999).[2]

Spring wheat in the region is usually characterized as dominated by ME 2 (high rainfall, moderate temperature environment), although this environment accounts for about 60% of the spring wheat area. One-third of the ME 2 wheat is durum wheat grown in Ethiopia. The remainder is bread wheat grown throughout the region. The other major spring wheat environments are ME 4A (winter rain followed by "Mediterranean"-type drought), scattered across the region, and ME 5B (high temperature, low humidity, irrigated), found solely in Sudan. South Africa, Zimbabwe, and Zambia produce some high-yielding irrigated wheat in ME 1 (irrigated, moderate temperature); in the latter two countries ME 1 is the near-universal environment.

Table 2. Area distribution of wheat by wheat type, Eastern and Southern Africa, 1997

Type	Percent of total wheat area
Spring bread	65.1
Spring durum	16.3
Facultative/winter	18.6
Total	100.0

The Structure of Wheat Improvement Research

As small wheat producers, the countries in Eastern and Southern Africa tend to have high wheat improvement research intensities, measured by the number of wheat researchers per million metric tons of wheat production (Table 3). The inverse relationship between production level and

Table 3. Human resources in wheat improvement research and research intensity, Eastern and Southern Africa, 1997

Country	Wheat production, 1995-97 average ('000 mt)	Full-time equivalent scientists in wheat improvement	Public sector researchers	% researchers in the public sector	Wheat improvement researchers per million mt of production
Ethiopia	1,867	17	17	100	9.1
Kenya	305	17	15	88	55.7
South Africa	2,328	23	16	70	9.9
Sudan	539	17.75	17.75	100	32.9
Tanzania	61	19	18	95	309.8
Zambia	57	4	3	75	70.6
Zimbabwe	221	3	2	67	13.6
All study countries	5,377	100.75	88.75	88	18.7
Excluding South Africa	3,050	77.75	72.75	94	25.5

2 Actual area planted to facultative wheat in South Africa may fluctuate over time, as in the cooler, dry growing environment of the Orange Free State in which facultative wheat predominates, spring habit wheat can sometimes be sown if the planting date is late enough.

research intensity, visible in these regional data, is observable throughout the developing world (Byerlee and Moya 1993). In the countries studied in this paper, 1997 research intensities in South Africa, Ethiopia, Zimbabwe, and Zambia were lower than the worldwide averages for their production size class as reported by Byerlee and Moya. Research intensities for Sudan, Kenya, and Tanzania were higher. In other words, although the number of wheat improvement researchers for the amount of wheat produced may appear to be high in Eastern and Southern Africa, this is primarily the result of the generally small production levels in the region. Research efficiency, particularly for small programs, is a very important issue (Maredia and Byerlee 1999), and the question is crucial for countries in Eastern and Southern Africa. However, countries in the region appear no more prone to inflate the number of wheat researchers than other developing countries.

Comparing these estimates of the number of wheat improvement researchers and wheat research intensity with estimates from earlier periods (Bohn, Byerlee, and Maredia 1999; Payne, Tanner, and Abdalla 1996; Byerlee and Moya 1993) does not reveal any marked trends in research intensity during the 1990s. It is fairly likely that some variation in these estimates may be caused by ways in which questions were posed. For example, most of the surveys that focused on wheat breeding asked respondents to identify the number of scientist-years spent by scientists *in wheat improvement*, even when they represented disciplines other than plant breeding. We suspect that in some cases this could lead to an overestimate of the effort devoted to wheat improvement, as opposed, for example, to wheat crop management.

The vast majority of the wheat improvement researchers in the study countries are in the public sector, a finding that has not changed much since 1990. Private sector wheat research, however, appears to be particularly important in South Africa and Zimbabwe, judging from the patterns of varietal releases in those countries. It is also interesting to note that Kenya and Zambia, countries in which there were no private sector wheat researchers in 1990, had small private sector wheat research involvement by 1997.

Despite measurement problems, it is instructive to look at the disciplines represented in wheat improvement research in the study countries. All of the public sector wheat improvement programs in these countries have plant breeders and agronomists, and all but Zambia and Zimbabwe employ plant pathologists. On the other hand, physiology, genetic resources, and biotechnology in general are for the most part not represented in wheat improvement programs (Table 4). In a relatively large producer with a fairly extensive university system, South Africa, this finding partly reflects the definition of a

Table 4. Disciplines represented in wheat improvement research in study countries, Eastern and Southern Africa, 1997

Discipline	Number of countries (out of 7)
Plant breeding	7
Agronomy	7
Plant pathology/Crop protection	5
Cereal chemistry	4
Physiology	1
Genetic resources	1
Biotechnology	0

NARS. Some South African university scientists within these less represented disciplines actually spend a good deal of their time working on wheat, and would have been included in a more comprehensive survey.

Roughly 60% of the public sector wheat improvement scientists held advanced degrees (M.Sc. or Ph.D.) in 1997. There was not a great deal of change in this figure between 1990 and 1997, although it fell somewhat. In Sudan, the total number of wheat improvement researchers was considerably higher in 1997 than in 1990, but the number with advanced degrees was about the same. It is difficult to say whether this apparent shift was caused by an expansion in the wheat improvement program, or simply by differing judgments on the part of the respondents on who was actually involved in wheat improvement research.

Wheat Releases in the Study Countries

The pattern of wheat releases over time is shown for six of the seven study countries in Figures 2 and 3.[3] The rate of release is measured as the number of releases per million hectares of wheat per year, with two modifications. First, for each country we corrected for the number of distinct major wheat environments, as distinguished by wheat type and mega-environment. For example, we assumed that to be comparable to a hypothetical country with the same wheat area but only spring bread wheat, Ethiopia, which produces spring bread and spring durum wheat, would have to release varieties at twice the rate of

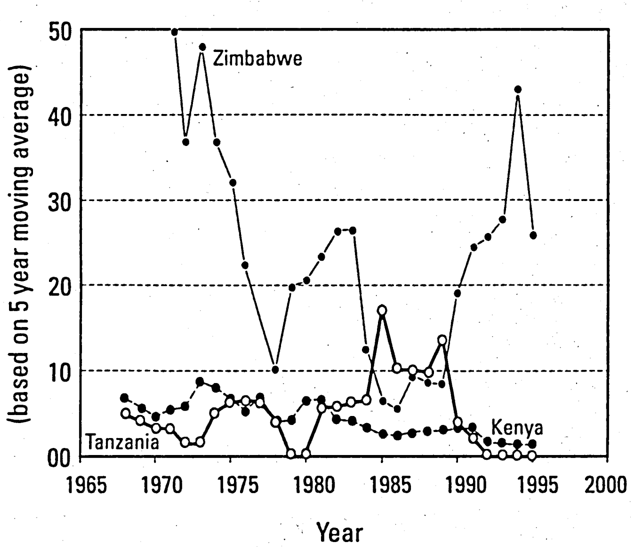

Figure 2. Number of releases per million ha per year, corrected for number of environments.

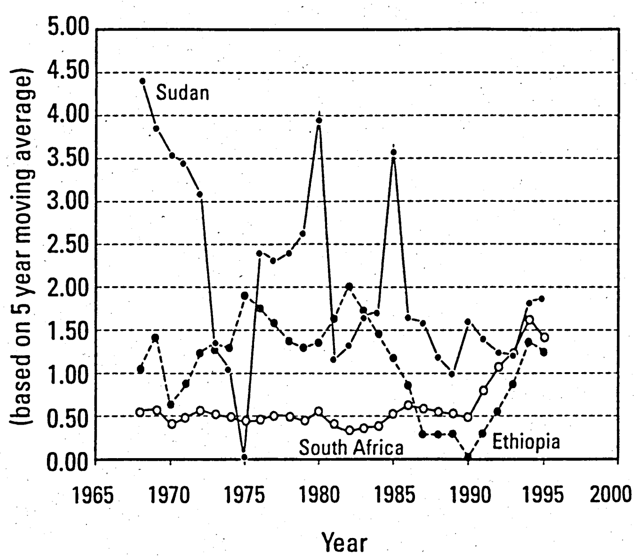

Figure 3. Number of releases per million ha per year, corrected for number of environments.

3 For much of the period depicted in Figures 2 and 3, Zambia had little wheat improvement research, very limited wheat production, or both. As a result, the number of releases per million hectares per year in Zambia fluctuated even more widely than it did in the other study countries, and at times was extremely high, which would have required yet another scaling of the y-axis to represent.

the hypothetical country.[4] Second, because of the vagaries in varietal development and release procedures, the rate of varietal release is reported in Figures 2 and 3 as five-year moving averages. Even with this smoothing procedure, it is striking how variable the rate of varietal release can be over time in some countries.

Despite this variability, some observations are still possible. First, there is a general inverse relationship between the size of a country's wheat area and the rate of varietal release. In other words, countries with relatively large wheat areas tend to release fewer varieties per unit area over time, and countries with small wheat areas tend to release varieties at a much faster rate relative to area, if not in absolute numbers. Second, to the extent trends are visible, the rate of release can fall over time as wheat improvement programs mature and gain the ability to focus their material more closely on the environments they are targeting. Third, in individual country cases it is possible to hazard guesses about some of the likely factors driving changes in the rate of varietal release. For example, the fall in the rate of release in Ethiopia in the late 1980s may have been partially caused by the appearance of new rust races that made much of the Ethiopian germplasm base vulnerable. Increases in the rate of release in South Africa and Zimbabwe since about 1990 could be associated with increasing private sector activity in the development of new varieties.

Over the 30-year period from 1966 to 1997, the number of varietal releases reflected very closely the types of wheat actually grown in the region. The percentage of total releases that were spring bread wheat was even greater than the percentage of spring bread wheat area in the region; on the other hand, fewer durum varieties were released than would be predicted by a strict congruence with area alone. The percentage of releases of the facultative type was roughly equivalent to the share of facultative wheat in the wheat area of Eastern and Southern Africa (Table 5; see also Table 2).

Over the years, spring bread wheat releases shifted from being almost 60% tall to being almost 95% semidwarf. This change has been congruent with the rising importance of material that has some genetic component stemming from CIMMYT. In the last decade or more, nearly all the spring bread wheat releases in Eastern and Southern Africa have been crosses made by CIMMYT, crosses with at least one parent from CIMMYT, or in a few cases crosses that have CIMMYT ancestors further back in the pedigree (Figure 4). The same tendencies

Table 5. Types of varieties released in study countries, 1966-97

	Number	Percent
Spring bread wheat	209	75.7
Spring durum wheat	18	6.5
Facultative/winter bread wheat	44	15.9
Facultative/winter durum wheat	1	0.4
Triticale	3	1.1
Unknown	1	0.4
Total	276	100.0

[4] Similarly South Africa, with ME's 9C, 4A, and 1, would have to release varieties at three times the rate of a country with comparable wheat area but only one mega-environment. This is still an oversimplification, for at least two reasons. First, there might be some possibilities for varietal spillovers from one mega-environment to another. Second, if within a given country one mega-environment is considerably larger than another, not much breeding effort might be targeted at the smaller environment.

are visible in spring durum wheat, although the changes are much less smooth, as only a few durum varieties were released in any given five-year period (Figure 5). There were somewhat more facultative bread wheat releases than spring durum releases over the past 30 years, but the pattern of semidwarf use and CIMMYT parentage is completely different in facultative wheat than in spring bread or spring durum wheat. Up to the present, most of the facultative releases have been tall (Figure 6). CIMMYT material has been used in facultative releases only in the last decade, and then only in a small proportion of the varieties released.

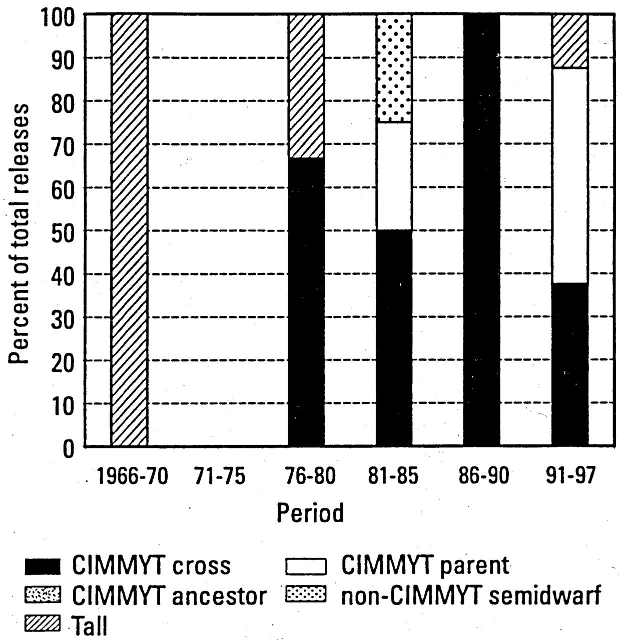

Figure 5. Origin of spring durum wheat releases, Eastern and Southern Africa, 1966-97.

Wheat Varieties in Farmers' Fields

What is the fate of the varieties that have been released by the wheat improvement programs in Eastern and Southern Africa? It is difficult to estimate what proportion of wheat releases are successful, because recent releases may not have had sufficient time to reach some threshold criterion for success. Using the criteria that a variety is successful if it is planted on at least 25,000 hectares or

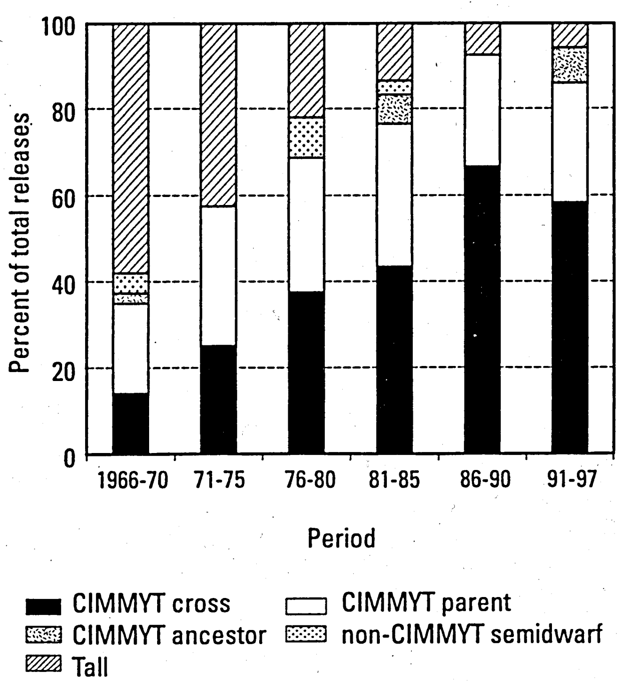

Figure 4. Origin of spring bread wheat releases, Eastern and Southern Africa, 1966-97.

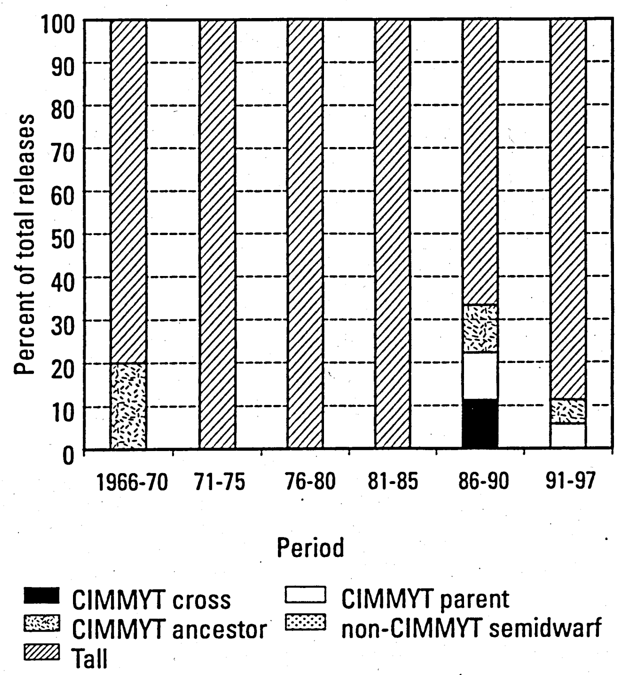

Figure 6. Origin of facultative/winter bread wheat releases, Eastern and Southern Africa, 1966-97.

5% of national wheat area, whichever is smaller, Byerlee and Moya (1993) estimated that 63% of wheat releases in sub-Saharan Africa were successful over the period 1966-90. This is notably higher than the rate of 44% they estimated for the entire developing world. Payne, Tanner, and Abdalla estimated a success rate of 67% in Eastern and Southern Africa for varieties released since 1980, and an even higher rate of 75% over six of the seven countries included in the present study.[5]

Figure 7 shows that over half the wheat area in the region is now planted to semidwarf varieties. A further quarter of the area is sown to improved tall varieties. Though over half of this area consists of improved tall facultative varieties grown in South Africa, there are also areas planted to improved tall spring wheat in Ethiopia and Sudan. The remaining 20% of the wheat area is planted to land races; again this area is concentrated in Ethiopia and Sudan.

Table 6 indicates the coverage of improved varieties by wheat type. Wheat that is the product of formal wheat improvement programs covers 100% of the facultative wheat area in South Africa, and therefore the region. As seen from the pattern of releases, however, most of these varieties are tall. Seventy-eight percent of the facultative wheat area is planted to improved tall varieties, and the remaining area to semidwarfs. Ninety percent of the spring bread wheat area in the region is planted to improved varieties. Seventy-four percent comprises semidwarf varieties and 16% improved tall varieties. In Ethiopia, and therefore the region, only 20% of the spring durum area is sown to improved cultivars; 5% to semidwarfs and 15% to improved tall varieties.

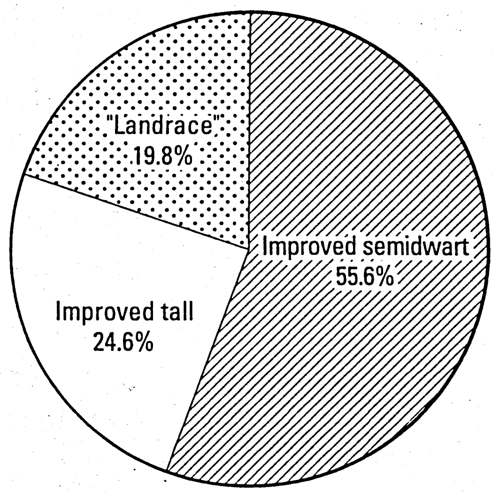

Figure 7. Area planted to improved varieties, Eastern and Southern Africa, 1997.

Table 6. Area planted to improved varieties by wheat type, Eastern and Southern Africa, 1997

Type	Percent of wheat area planted to improved varieties
Spring bread	89.6
Spring durum	20.2
Facultative/winter	100.0
All wheat	80.2

As would be expected from the pattern of releases, the NARS-CIMMYT collaboration has played a major role in the area planted to improved wheat in both spring bread and spring durum classes. One-third of the area planted to improved spring bread wheat varieties in the region is planted to CIMMYT crosses. About 85% of the area is planted to varieties to which CIMMYT has made a genetic contribution, often by contributing

[5] Payne, Tanner and Abdalla's survey covered Ethiopia, Kenya, South Africa, Tanzania, Zambia, and Zimbabwe, but not Sudan.

one or both parents to the cross involved. Other ways of measuring CIMMYT genetic contributions to individual varieties have been used by Pardey, et al. (1996). We applied several of these rules, and here present results of a geometric rule, in which a variety's pedigree is analyzed by applying geometrically declining weights that sum to 1 to each level of crossing for as many generations as desired.[6] According to this geometric rule, just under one-half of the genetic contribution to the improved spring bread wheat varieties planted in Eastern and Southern Africa could be attributed to CIMMYT. The CIMMYT contribution to the improved spring durum wheats planted by farmers is even greater. In contrast, but again reflecting the release data, CIMMYT's contribution to improved facultative wheat planted in South Africa is relatively limited (Figure 8).

Despite the high success rates for varieties released in the region, and the high adoption rates for improved cultivars in spring bread wheat and facultative bread wheat, a continuing problem appears to be the very slow diffusion of improved varieties into farmers' fields. In 1990 varietal turnover, as measured by the average ages of varieties weighted by area, was very slow in Ethiopia and Kenya (Table 7). In 1997, varietal change was no more rapid in these countries. In other countries in which varietal replacement was somewhat more rapid in 1990, the rate of varietal change appears to have slowed by 1997. Only in Zimbabwe, where wheat varieties have been almost completely replaced since 1990, has the rate of varietal turnover gotten even faster over the past few years. Zimbabwe has the advantage of having a small number of relatively homogeneous wheat producers, coming from the large farm sector that is accustomed to articulating its needs and communicating with the suppliers of agricultural inputs. Elsewhere, a number of constraints to varietal replacement include the lack of an effective seed distribution and extension system, especially where small-scale farmers are predominant. These issues are explored in greater detail in a number of other papers in CIMMYT (1999).

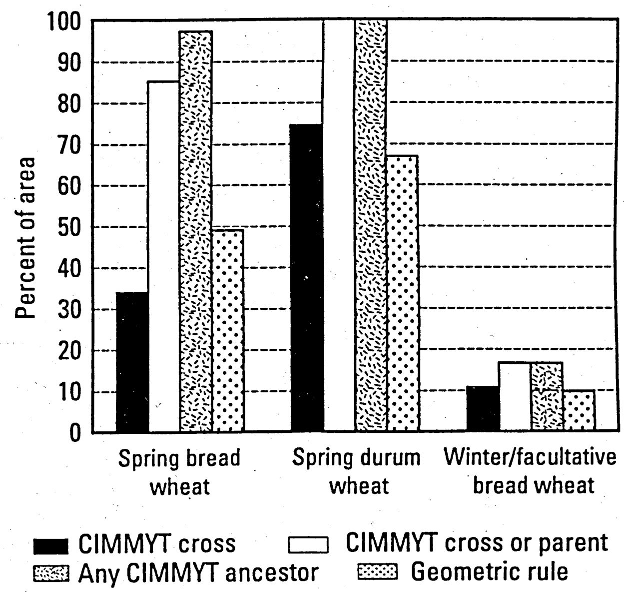

Figure 8. CIMMYT contribution to improved varieties planted in farmers' fields Eastern and Southern Africa, 1997.

Table 7. Weighted average age of varieties planted in farmers' fields, Eastern and Southern Africa (excluding land races)

Country	1990	1997
Ethiopia	12-16	15.9
Kenya	12-16	13.5
South Africa	NA	11.0
Sudan	8-12	14.5
Tanzania	6-8	12.0
Zambia	<6	9.8
Zimbabwe	6-8	2.6

6 For example if the analysis were carried back to the level of great-grandparents, the source of the final cross would be given a weight of _, the source of each of the parents would be given a weight of 1/8, and the source of each of the grandparents would be given a weight of 1/32. The next fraction in this series is 1/128, but the source of each of the great-grandparents would be given a weight of 1/64 to ensure that the weights sum to 1.

Efficiency in Wheat Breeding Programs

Under any circumstances, agricultural research programs must strive to be as efficient as possible in achieving social objectives. In an era of stagnant or even declining real research budgets, this becomes even more important. Small wheat research programs, like many of those in Eastern and Southern Africa, must be especially conscious of efficiency. Maredia and Byerlee (forthcoming) have done a thorough analysis of many wheat breeding programs from throughout the world, and found that overinvestment in small programs is a common phenomenon. Using economic criteria, they suggest, for example, that if a country produces less than 15,000 tons of wheat annually, a research program for wheat improvement is unjustified. If spill-in research is available from other NARS, a country should probably only test varieties obtained from elsewhere if its annual production level is greater than 15,000 tons but less than 100,000 metric tons. Above that level, an adaptive breeding program in which the NARS makes some crosses itself appears economic. If spill-in research is available both from other NARS and from an international organization such as CIMMYT, this threshold moves up to around 300,000 metric tons.

Maredia and Byerlee list several factors that can qualify these conclusions. Their calculations were based on a diffusion lag of five years, in other words the average length of time from varietal release until a variety reaches peak adoption. In many developing countries, including many of the study countries in this paper, diffusion lags are considerably longer. Raising the diffusion lag to 11 years *doubles* the threshold production levels mentioned in the previous paragraph. In other words, the longer it takes varieties to reach farmers, the smaller the economic justification for larger and more complicated wheat breeding programs. This implies that many countries in the region should take serious steps to improve the diffusion of new wheat varieties to farmers before investing more in wheat improvement programs themselves. On the other hand, if locally developed varieties command a price premium, perhaps based on superior quality in the local market, threshold production levels for different levels and types of investment in wheat breeding are lowered. Furthermore, Maredia and Byerlee's results regarding spill-ins from CIMMYT apply most to favorable mega-environments, e.g. ME 1 and ME 2. Threshold levels would be somewhat lower in more marginal environments, e.g., ME 3, ME 4, or ME 5.

Another factor affecting the allocation of research resources to wheat improvement programs in Eastern and Southern Africa is that all of the countries in the region are net importers. The standard theory of distribution of research benefits between consumers and producers suggests that when the wheat price is exogenous, rather than set by supply and demand conditions within a country, research benefits are received by producers (Alston, Norton, and Pardey 1995). This suggests that if equity as well as efficiency is an objective of research, countries in which wheat producers are large commercial farmers might invest relatively less in wheat research than countries in which the majority of wheat producers are small farmers.

Using a somewhat different modeling approach, however, Mutangadura and Norton (1997) analyzed and prioritized the allocation of research resources to all commodities in Zimbabwe, where wheat is produced by large farmers. Although not the highest ranked research commodity, wheat was still ranked sixth out of 57 even when extra weight was given to smallholder farmers.[7]

All in all, general prescriptions about achieving efficiency in wheat improvement programs will be modified in each country depending on individual circumstances. For example, both South Africa and Zimbabwe need to consider the appropriate roles of public and private sector wheat improvement research, and to forecast the likelihood that strong private sector wheat research will continue. Like many other countries in the region, Ethiopia must more effectively tackle the problem of slow diffusion of wheat varieties to farmers. In durum wheat, appropriate policies need to be devised that allow wider diffusion of improved varieties at the same time that feasible *in situ* conservation of durum wheat genetic resources is not threatened. Despite its relatively small wheat production levels, Kenya has a diversity of wheat growing environments, and needs to consider how effectively it can target these environments. Very small producers like Zambia and Tanzania must be particularly conscious of the likely benefits of streamlining and limiting the scope of their wheat research programs.

Conclusions

Though Eastern and Southern Africa is a small region, in terms of wheat production, it features a number of different countries and a diversity of wheat growing environments. Allocation of research resources in such circumstances is particularly challenging.

Based on varietal release data and the use of improved wheat varieties in farmers' fields, many of the wheat improvement research programs in Eastern and Southern Africa have been successful. The seven study countries account for over 98% of the wheat production in the region. Within these study countries, around 80% of the wheat area is planted to improved varieties; 56% is planted to semidwarfs. At the same time, the small amount of wheat produced in many countries raises the question of whether the same results could have been obtained at lower cost through greater efficiencies in research organization and even greater reliance on research spill-ins. The slow rate of varietal diffusion in many instances is a particular concern, because it means research benefits reach farmers later than they should, and because the rate of diffusion influences the optimal size of a wheat research program.

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7 With more weight given to smallholder farmers in Mutangadura and Norton's analysis, the large farmer commodities that were most seriously affected were dairy and soybeans.

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