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Charting the CGIAR's Future – A New Vision for 2010

IAEG Study: CGIAR's Impact on Germplasm Improvement

Attached is the paper prepared by Dr. Robert Evenson of Yale University on *Crop Genetic Improvement and Agricultural Development* with a foreword by Dr. Hans Gregersen, Chair, IAEG/SPIA. The paper provides a synthesis of results of a major impact assessment study that was undertaken under the auspices of the IAEG in close collaboration with eight CGIAR Centres and several NARS. The paper will be introducedby Dr. Evenson and discussed in plenary under Agenda Item 5 – Impact of the CGIAR.

SPIA

Foreword

Dr. Robert Evenson and his collaborators at the centers and in NARS have done a masterful job of tracing as best possible the crop germplasm improvement (CGI) outputs of the IARCs right on through use in NARS, adoption by farmers, production increases and on to the economic impacts (see figure 1). Evenson and the assessment group working with him managed to bring together a wealth of data and have created information to address some basic impact questions of concern to the CGIAR System and to the broader development community.

The attached synthesis report builds on impact assessment work undertaken by individual centers and their NARS colleagues in monitoring and documenting released varieties, adoption rates, and production gains for individual commodities. In addition, country case studies have been completed for China, Brazil and India that add further insights into the impacts of the CGIAR CGI activities. What is described in Evenson's paper provides only a hint of the wealth of data and analysis that lie behind the synthesis presented. This is a milestone study, in the sense that it is the first time that a Systemwide perspective is emerging on the question of impacts of the IARC CGI activities on the crop producers and consumers of the world.

Getting from produced varieties to economic impacts of the CGIAR required Evenson and his colleagues to trace through four interlinked questions or objectives, as indicated in Figure 1:

- First, they needed to establish the **nature and magnitude of outputs** of the various CGI programs, including those of the NARS and private sector; they also needed to establish the **investments** involved to get at the cost side of the picture;
- Second, given the total output, they needed to estimate the varietal content of the released varieties in order to establish the indirect as well as direct CGIAR content of such varieties. This gave them an estimate of the **CGIAR contribution to all released varieties**
- Third, they needed to estimate adoption of the different varieties by the farmers of the world and then estimate the production gains between the newly adopted varieties and those replaced. This gave them measures of **production gains related to the CGIAR contribution**
- Fourth, they introduced these production gains into economic market (both national and international) models to estimate economic gains or impacts on consumers and producers through changes in prices, production, trade, consumption and nutrition.

Another, related objective (what Evenson lists as study objective 4) was to assess as best possible the IARC program effects on NARS and private sector investments in CGI programs. This provided the basis for establishing the counterfactual situation, i.e., what might have happened without the CGIAR input, which is information needed in order to attempt to isolate out the CGIAR impacts from the overall impacts of CGI activity, i.e., to answer the question: what would likely have been the situation if the CGIAR had not existed.

Evenson and the team of researchers involved in this monumental effort recognize the heroic assumptions and extrapolations that were required to reach the relevant conclusions presented. No one denies that with better baseline data and records over time, a more refined set of conclusions could have been reached. At the same time, SPIA emphasizes that this step along the path to fully understanding the tremendous impacts of the CGIAR is a significant one. The study provides a landmark for future, more refined studies that will be possible with improved monitoring and record keeping.

Recognizing that in some cases there are marked differences between crops and between conclusions for different regions, as explained in the report and further documented in the individual studies underlying the report, the basic overall conclusions of this assessment program can be summarized as follows:

- The growth of investments in CGI activity in the NARS has paralleled that of the Centers. While there is no evidence for direct linkages between the two, Evenson speculates that there is an indirect linkage not only in the countries where NARS programs were non-existent or where there was little capacity in the 1960s, but also in the more developed country and crop programs, where, presumably, there were strong interactions between the national and IARC programs.

- There is a continuing high level of NARS and IARC production of improved varieties. The data available do not support the contention that strong diminishing returns to varietal production are taking place.

- With regard to IARC contribution to overall varietal releases, Evenson concludes that "preparations of direct IARC products has remained roughly constant at 33 percent of all releases." Further, "in recent years 20 percent of NARS varieties were based on IARC-crossed parents and 15 percent on other IARC-crossed ancestors." Evenson emphasizes that "...these indirect indexes do not actually measure the true germplasmic effect of the IARCs. A much more complex statistical estimation of a breeding function for NARS programs must be estimated." Using such a model, Evenson concludes that, for all crops pooled, the resulting statistically significant coefficients imply:
    - That NARS breeding activity is subject to diminishing returns. From 1965 to 1980, NARS breeding were approximately doubled in size. This would have produced an increase in NARS varietal production of approximately 60%. Actual NARS varietal production approximately doubled, however, from the 1970s to the 1990s.
    - That the IARC germplasm effect made NARS more productive by approximately 30 percent. Thus, the combined effect of the increase in NARS breeding effect and the IARC germplasm effect produced an approximate doubling of NARS varietal production. The IARC germplasm effect approximately offset the diminishing returns effect. (IARC parents were present in 33 percent of NARS varieties and other IARC ancestors in 22 percent of NARS varieties. Thus, the IARC germplasm indicator overstates the real IARC germplasm effect.)

- The direct contribution of IARC programs (to varietal production) relative to the investment of resources is impressive. In the 1980s and 1990s the proportion of total varieties produced by IARCs was well above their proportion of total resources invested in such production.

- With regard to adoption, the Evenson team found that, as expected, the percentage of "area planted to crop" that is planted to "improved" or "modern" varieties was low in 1970 (except for wheat in Asia) and grew steadily since then to a point where improved varieties are dominant in most crops.

- Further, "IARC-content varieties are considered by farmers to be as valuable as, or more valuable than, non-IARC-content improved varieties.

- With regard to production impacts, the Team approached them in two ways, first, using IARC prepared studies addressing the issue; and second, using the insights derived from three country case studies (Brazil, India and China). In the paper, Evenson explains the procedures used for each approach, including how the counterfactual was derived and used in obtaining the final estimates. The basic conclusions are that:
    - Without the IARCs, released varieties would have been anywhere from 45 to 60 percent less, depending on assumptions. Evenson used the more conservative figure in calculating IARC related production gains;
    - adjusted estimates of productivity gains due to CGI were in the 1-1.5 percent range;

- Inserting the various estimates, including the counterfactual (i.e., without IARCs) estimates derived from the previous steps into an IFPRI based (IMPACT) model, Evenson derives the following estimates of what would have happened without the CGIAR input:
    - prices for grain crops would have been between 27 to 41 percent higher over the 25 year period, depending on the crop;
    - imports of food in developing countries would have been 9 percent higher (reflecting the advantage that the counterfactual confers to developed countries relative to developing ones);
    - the area planted to crop would have been significantly higher in the counterfactual situation, i.e., without the IARC input.
    - there would have been a higher number of malnourished children.

- In terms of the basic poverty alleviation goal, the poor would have been hurt more by the higher prices in the absence of the CGIAR because (a) they spend a higher fraction of their income on food; (b) in poorer economies a higher proportion of food is consumed in non-processed form, thus the price effect is greater than in an economy where the farm value of food is low relative to the consumer value (i.e., where high levels of processing contribute to the price the consumer pays); and (c) "...between 1.5 and 2 percent fewer children (from the poor in most cases) from developing countries malnourished than would been the case without IARC CGI investment."

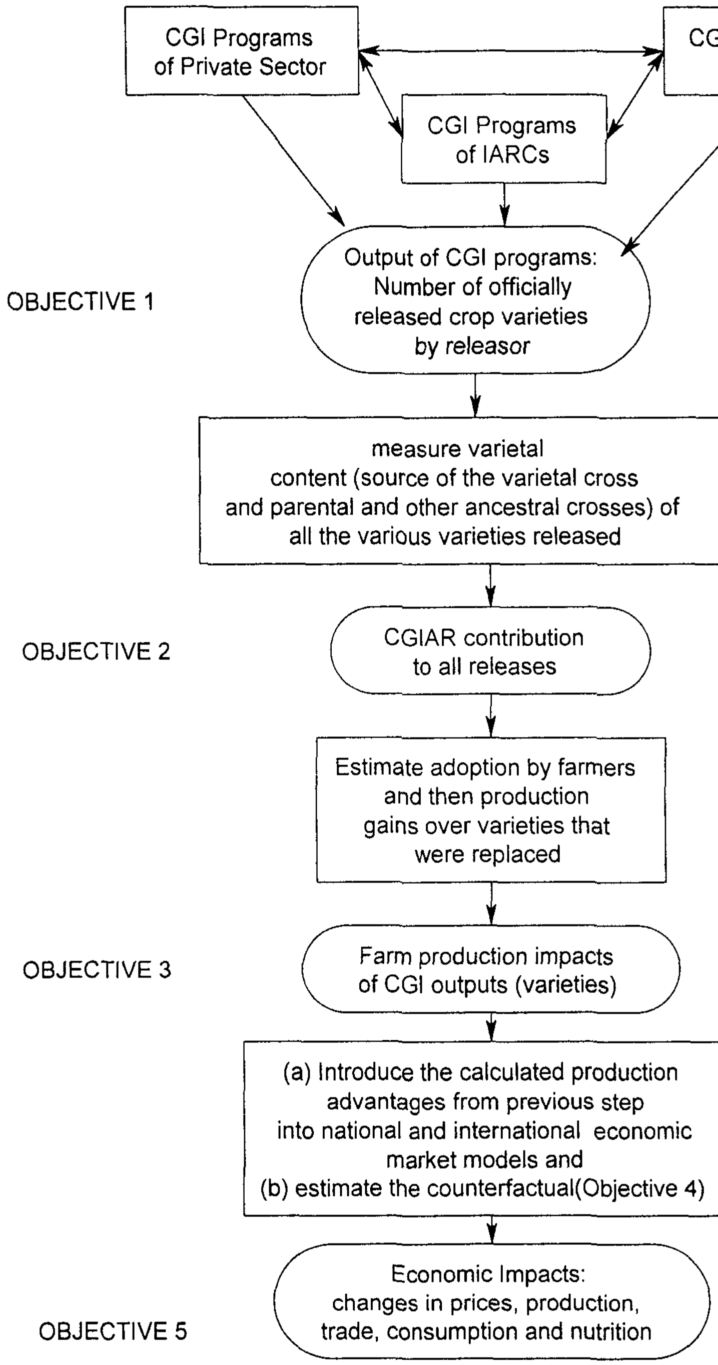
In his paper, Professor Evenson concludes that: "Consumers benefit most and poor consumers benefit most of all from agricultural research. Farmers are consumers too and for the world's smallest farm producers the total producer and consumer gains are large. The provisional findings provide support for the proposition that IARC investments have had impacts in all of the study crops. These impacts have been large, partly because of high "leverage" through IARC-NARS joint production. The placing of crop germplasm improvement at the core of IARC programs appears to have very strong justification.

SPIA congratulates Professor Evenson and his colleagues for the important results and insights that they are bringing forth on the impacts of crop germplasm improvement work in the CGIAR. The full reports of the commodity and the country case studies will be available by the end of summer 2000, in time for ICW. The final results of this broad set of assessment activities will be published in various forms and provide significant information for use by the Group, centers, TAC and the broader community interested in the value and impacts of agricultural research.

Hans Gregersen
Chair, SPIA

17 May 2000

Figure 1: OVERALL FLOW OF THE CROP GENETIC IMPROVEMENT (CGI) ASSESSMENT



CROP GENETIC IMPROVEMENT AND AGRICULTURAL DEVELOPMENT

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I. Introduction

The Consultative Group for International Agricultural Research (CGIAR) established the system of International Agricultural Research Centers (IARCs) with two broad objectives in mind. The first was to bring more research scientists to work on developing technology for the agriculture sector in developing countries. The second was to provide support for the National Agricultural Research Systems (NARS) in developing countries. The design of the IARCs with a commodity or crop focus called for their location in one or more of the major ecosystem regions in developing countries for the crop of concern. The design also incorporated crop genetic improvement (CGI) as the "core" element, both for the development of new technology and for the strengthening of NARS programs. The mechanics for NARS strengthening through CGI included a) developing, maintaining and evaluating basic crop germplasm collections (genebanks); b) facilitating the exchange and use of germplasm collection materials between IARCs, NARS programs and private seed firms; c) breeding crop varieties that can serve as releasable varieties and/or as advanced breeding lines to NARS breeding programs (and private seed firms); and d) providing evaluations and information exchange to support the exchange and use of genetic resources by NARS breeders (and private seed firms).

The popular press noted that important technological developments in the form of "high yielding varieties (HYVs)" were achieved in both rice and wheat in the mid 1960s and that these HYVs ushered in a "green revolution" beginning in the late 1960s and extending into the 1970s. The popular press largely credited these HYVs to IARC research programs (i.e., to IRRI and CIMMYT), with relatively little or no attention to the contribution of NARS. The popular press also left the impression that somehow the green revolution of the late 1960s also "solved" the fundamental population-food problem without noting that the population increases in developing countries in the 1980s and 1990s exceeded the increases of earlier decades (and of the first half of the 20th century as well).

A more complete examination of the contribution of CGI to agricultural development requires attention to all of the crops in the IARC system and to all experience to date. It also requires an evaluation of the merit of the design strategy of the IARCs. Did the focus on CGI achieve development objectives? Did the IARCs support NARS and induce an expansion of NARS programs? Have rates of CGI production changed over time, i.e., are diminishing returns setting in as available "pools" of potential varieties are "exhausted"?

This paper reports a synthesis of findings from an evaluation of CGI programs that addresses the questions posed above. The study was commissioned by the Impact Assessment and Evaluation Group (IAEG) of the CGIAR (now SPIA/TAC). The evaluation covers most IARC crops and it covers the periods since the establishment of IARC programs to date. (The crops covered are wheat, rice, maize, sorghum, pearl millet, barley, lentils, beans, cassava, and potatoes. (See Appendix A for Study Details)

The objectives of the IAEG evaluations were five in number and were applied to each CGI program evaluated. This synthesis paper will follow the format of the objectives and will provide comparisons and synthesis across CGI programs.

Study Objective 1

To document the output of CGI programs for IARCs, NARS and private firms, where output is measured in terms of number of officially released crop varieties. This documentation is to include all periods and all regions in developing countries where the crop is important.

Study Objective 2

To evaluate the IARC contributions to CGI output. This evaluation calls for varietal content measures identifying the source of the varietal cross and parental and other ancestral crosses. It also requires statistical estimation of breeding production functions where germplasm (parental material) is explicitly treated as a factor of production.

Study Objective 3

To evaluate the farm production impact of CGI products (varieties). This requires evidence on the adoption of varieties by farmers and on the production or productivity advantage of improved varieties over the varieties that they replaced. It also requires consistency between estimates of production advantage at the experimental plot, farm plot and the aggregate (District) production levels.

Study Objective 4

To evaluate the IARC program effects on NARS and private sector investments in CGI programs. This objective directly addresses the question of the "strengthening" design element in IARC programs.

Study Objective 5

To evaluate the economic consequences of CGI programs. This requires incorporation of the production advantage estimates from study Objective 4 into market (both national and international) models enabling the calculation of changes in equilibrium prices, production, international trade, consumption and nutrition.

II. Summaries by Crop: Study Objectives 1-3

Figures 1-10 provide summaries of annual rates of varietal production for the 1970s, 1980s and 1990s by crop and major production region. For varietal releases, indicators of releases based on an IARC cross (IX), on a NARS cross with one or more IARC-crossed ancestors (IA) and on a NARS cross without IARC ancestors are given. The figures also provide indicators of farmer adoption of varieties. For 1970, 1980 and 1990, proportions of "modern HYVs" and "traditional" varieties in farmers' fields are reported. For 1998, proportions of HYVs based on IARC crosses, NARS crosses with IARC ancestors and on NARS crosses without IARC ancestors are given.

1. Rice (Figure 1)

Rice varietal production is reported for three major regions, each served by a different IARC. Significant differences in varietal production by region attest to the fact that rice is planted in a broad range of climate and soil conditions. Rice ecosystems can be classified as upland, rain-fed (paddy), irrigated (paddy), and deep-water (paddy). The fact that three IARCs (IRRI in Asia, CIAT in Latin America and WARDA in Africa) contributed to CGI attests to the inherent limitation of an IARC to serve NARS stockholders in diverse ecosystems.

The oldest of the IARCs, IRRI, is associated with the "green revolution" in rice production. The pattern of varietal releases in Asia shows that the varietal release rates per year were highest in the 1980s and have declined somewhat in the 1990s reflecting possible "exhaustion" of the search process underlying varietal discovery. It is important to note that virtually none of the released varieties in Asia or other regions were suited to deep-water ecosystems and very few to upland ecosystems in Asia. Upland rice varietal improvement was achieved in a NARS program (EMBRAPA) in Brazil and by WARDA in Africa.

The varietal releases in Asia were virtually all suited to irrigated and favorable rain-fed conditions. Scholars have noted that the "first generation" of rice HYVs in Asia were suited to irrigated rice production and that these varieties were rapidly adopted on 20 percent or so of the irrigated area in Asia. Later generations of varieties added landrace based traits; host plant disease resistance, insect resistance and stress tolerance. The incorporation of these traits enabled the expansion of HYV areas by 1998 to more than 90 percent of irrigated area in Asia. (Evenson, 1998)

The first generation HYVs from IRRI were actually not adopted in Latin America. The CIAT program, however, effectively modified the Asian HYVs to Latin American conditions. The "CICA" varieties from CIAT were then incorporated into varieties suited to irrigated rice conditions in Brazil and other Latin American countries. The CIAT program did not develop upland rice varieties, but the EMBRAPA program did achieve success in developing improved upland rices in Brazil.

African ecosystem conditions were also not suited to simple transfer of Asian HYVs (either directly or indirectly) to Africa. WARDA, thus faced both administrative and ecosystem challenges in developing varieties. The administrative challenges were not met until WARDA was established in Côte D'Ivoire. The ecosystem challenges are now being met with recent releases of both upland and irrigated varieties.

The IARC content indicators show both direct IARC impacts in the form of IARC crosses and indirect or "germplasmic" IARC impacts on varietal production in the form of "joint products," i.e., NARS bred varieties with IARC ancestors (mostly parents). The Asian rice pattern shows "maturity" of the IARC-NARS relationship in that direct impacts have been largely replaced by germplasmic indirect IARC impacts.

Adoption data show steady increases in modern variety adoption with adoption beginning later in Africa. The international component of modern varieties in 1998 was at least as high in the adoption data as in the release data in all regions.

2. Wheat (Figure 2)

Wheat is the second of the green revolution crops. The ecosystem range for wheat is not as diverse as for rice. It encompasses both spring and winter wheats and both Durum and Bread wheat qualities. Figure 2 shows that CIMMYT (and its predecessor program in Mexico) had larger direct (IARC cross) contributions in varietal releases in all regions than was the case for rice. Indirect (IARC ancestry) contributions are also high. This is in part because NARS programs are somewhat less advanced for wheat than is the case for rice.

Regional differences are apparent. Release rates peaked in the 1980s in West Asia and Africa. The decline in annual releases in Latin America may reflect some "exhaustion" of potential, but it should be noted that varietal production rates remain high.

The adoption data show that modern wheat varieties were adopted earliest in Asia and had reached high levels in both Asia and Latin America by 1997. As with rice, the proportion of modern wheat varieties adopted by farmers with IARC content is higher than the comparable proportion in varietal releases. Comparisons by time period show that steady replacement of traditional varieties by modern varieties is taking place. As with rice, the landrace complexity and trait complexity of modern varieties has steadily increased over time.

3. Maize (Figure 3)

Maize is the third most important crop in economic value in developing countries. Figure 3 shows that maize varietal production rates for public sector varieties rose in the 1980s and have continued to be high during the 1990s in both Latin America and Africa. IARC content measures indicate that CIMMYT (Latin America) and IITA (Africa) have made significant contributions to varietal production in both regions.

Data for private sector varietal production indicate that hybrid varieties (almost all private sector varieties are hybrid varieties) have become more important relative to open pollinated varieties. These data also show that IARC direct and indirect contributions to the private sector have been high. In effect, public sector IARC and NARS programs established the foundations on which private sector varietal development was built. When the private seed industry is competitive, public sector IARC-NARS contributions benefit farmers and consumers in much the same way that benefits are realized in crops where private sector programs do not exist.

Adoption data for 1998 show that modern variety adoption rates remain lower than is the case for rice and wheat. This is in part due to the widespread use of traditional varieties valued for taste qualities.

4. Sorghum and Pearl Millet (Figures 4 and 5)

Sorghum varietal release data show growth in rates of production over time with high NARS contributions in India. Varietal production in Africa is more recent and was initiated by the ICRISAT program in Africa.

Adoption rates for modern sorghum varieties are highest in Asia. IARC content in adopted varieties is similar to IARC content in releases.

Pearl Millet varietal production rates are also increasing in Asia. In Africa, development is more recent in origin. Adoption rates for modern pearl millet varieties are relatively high.

For both sorghum and pearl millet, private sector hybrid seed production is growing rapidly. As with maize, the IARC-NARS breeding programs have contributed to this development.

5. Barley and Lentils (Figures 6 and 7)

The ICARDA programs for barley and lentils are among the more recently established IARC programs. Both programs have been productive in the 1980s. Both have high IARC contribution to varietal production. Modern variety adoption is recent and more rapid for barley. IARC content varieties are important in the field.

6. Beans (Figure 8)

Varietal production in beans has been growing steadily with releases in Latin America and Africa. IARC contribution to varietal release has been high. Modern variety adoption has been limited in both Latin America and Asia. IARC content varieties account for most modern variety adoption.

Beans represent a major challenge to plant breeders. Because of taste factors, high diversity in traditional varieties exists. In Latin America, rapid CGI in other crops tended to crowd beans onto marginal lands. This trend is now being reversed with the development of modern varieties.

7. Cassava (Figure 9)

Cassava varietal improvement has also represented a major challenge to breeders. The programs at IITA and CIAT have stimulated varietal production, most of which is IARC based. While releases have been higher in Africa, adoption rates have been higher in Latin America.

8. Potatoes (Figure 10)

Potato production in developing countries has also had a diverse base of traditional varieties. Research programs have in many cases stressed seed production technology. A number of NARS programs have been in place for long periods. Figure 10 shows that varietal production has been constant in the 1980s and 1990s in Latin America and rising in Asia and Africa. The IARC (CIP) contributions to varietal productions are growing in all three regions and dominate varietal production in Africa.

Modern varietal adoption in 1998 was high in Latin America and Africa with IARC content varieties accounting for significant production.

III. IARC Contributions: Direct and Indirect (Study Objectives 2 and 3)

IARC contributions to CGI can be divided into direct contributions, where the cross and subsequent selection leading to a released variety is undertaken in the IARC program, and indirect contributions, where IARC programs provide CGI "germplasm" to NARS. This germplasm can be in the form of "landraces" evaluated by the IARC and distributed to NARS programs, or "advanced breeding lines" made available for NARS crossing purpose The germplasm components include varieties directly produced by IARC programs (Note that IARC programs also receive germplasm from NARS programs)

The direct contributions of IARCs can be measured from "source indexes" indicating the proportion of CGI products released in a given country that were crossed and selected in an IARC program The indirect contribution of IARCs can be inferred from source indexes indicating the proportion of varietal parents and other ancestors that were crossed and selected in IARC programs (and in other NARS programs) The indirect NARS contributions to IARC programs could similarly be inferred from IARC variable source indexes The indirect contribution of IARC germplasm to NARS programs can also be estimated in a breeding production specification (see below)

Table 1 reports a summary of the varietal release data for all crops in the study (and covered in Figures 1-10) This summary shows that varietal production rates increased from 93 per year in the 1965-70 period to over 300 per year in the 1990s These data also show that the preparations of direct IARC products has remained roughly constant at 33 percent of all releases

Indirect germplasmic effects can be inferred from the number of NARS releases based on IARC parents and other ancestors These indexes show that in recent years 20 percent of NARS varieties were based on IARC-crossed parents and 15 percent on other IARC-crossed ancestors

These indirect indexes do not actually measure the true germplasmic effect of IARCs To measure this effect, a statistical estimation of a breeding function for NARS programs must be estimated This estimation requires a statistical specification based on a theory of plant breeding and a "testing" of that specification against alternative specifications

Table 1: Varietal Releases: All Crops 1965-1998

Annual Releases	1965-70	1971-75	1976-80	1981-85	1986-90	1991-95	1996-98
All Varieties	93	132	189	244	304	342	301
IARC-Crossed	31	42	55	77	92	136	98
IARC-Parents	18	26	43	52	55	66	69
IARC-Ancestors	3	8	15	19	31	47	47
NARS-ahla	41	56	75	96	126	93	87
NARS-Total	62	90	134	167	212	206	203

This also requires specification of a meaningful IARC germplasm variable

Not all germplasm produced by an IARC program is of equal value to all NARS programs. The proportion of germplasm relevant to a given NARS program depends on the differences in soil and climate conditions in the NARS region and in the IARC location and on the efforts of the IARC program to actually "target" germplasm for the NARS program. One indicator of the relevance of IARC germplasm is the release (and adoption) of IARC-crossed varieties by the NARS program. Since most IARC germplasm contributions are through IARC-based parent and other ancestral material, the cumulated number of IARC-crossed varieties released by the NARS and achieving significant adoption in the country is taken as the measure of IARC germplasm.

In Appendix B, a formal varietal discovery model that has been used in agricultural invention and CGI analysis is developed. The two major concepts in the model are:

1. that plant breeding search, under conditions where germplasm and methods are fixed or constant, is subject to diminishing returns;
2. an increase in germplasm (made available through IARC programs or through other NARS programs has a positive effect on the productivity of national breeding activity.

Appendix B reports tests of the theoretical model specification against an alternative specification. These tests show the theoretical specification to be the preferred specification for each crop analyzed. Coefficient estimates are also reported in Evenson 2000. For the estimated coefficients for all crops pooled, the statistically significant coefficients imply the following:

1. That NARS breeding activity is subject to diminishing returns. From 1965 to 1980, NARS breeding were approximately doubled in size. This would have produced an increase in NARS varietal production of approximately 60%. Actual NARS varietal production approximately doubled, however, from the 1970s to the 1990s.
2. That the IARC germplasm effect made NARS more productive by approximately 30%. Thus, the combined effect of the increase in NARS breeding effect and the IARC germplasm effect produced an approximate doubling of NARS varietal production. The IARC germplasm effect approximately offset the diminishing returns effect. (Note that in Table 1 IARC parents were present in 33% of NARS varieties and other IARC ancestors in 22% of NARS varieties; the IARC germplasm indicator thus overstates the real IARC germplasm effect.)

IV. IARC Program Impacts on NARS and Private Sector Investment (Study Objective 4)

The evidence for direct and indirect IARC CGI contributions does not answer the question as to whether IARC programs had positive or negative impacts on NARS CGI investments. The direct IARC effects would generally be expected to have a negative "crowding out" effect on NARS investment because the directly produced IARC varieties are substitutes for NARS varieties. The indirect germplasmic effects, on the other hand, should have a positive effect on NARS investments because they seem to make NARS scientists more productive. IARC programs can have broader germplasmic effects than those embodied in crop germplasm and most IARC programs have attempted to achieve these effects. For most crop programs, some form of contact between NARS scientists and IARC scientists in almost all countries and fields of research have been developed.

To estimate the net effect of IARC programs on NARS investments, an investment specification is required. This specification is developed in Appendix C. It relates the number of scientist man years of CGI effort in the NARS program to:

- The IARC germplasm variable used in the germplasm analysis. This variable reflects both the direct and indirect effects of IARC programs.
- The area planted to the crop in the NARS country. This variable measures the economic potential for CGI activities.
- Population density (i.e., the rural population per hectare of arable land) in the NARS country. This variable captures the expression of political concern for population growth effects.
- Gross domestic product in US dollars per capita. This variable measures the income effect on the demand for NARS scientists.
- The interaction of the area planted and the IARC germplasmic variable. This interaction variable is designed to test for IARC effects and country size. A positive coefficient on this variable indicates that the IARC effect is larger for countries with larger areas planted.

Appendix C summarizes investment data in NARS and IARC programs and reports estimates of the investment analysis. The investment analysis showed the following:

- That area planted to a crop stimulates more investment in NARS CGI programs.
- That higher population density stimulates more NARS CGI investment.
- That higher per capita income stimulates more NARS CGI investment.
- That IARC germplasm stimulates more NARS CGI investment, and that this effect is larger the larger is area planted to the crop. For NARS serving small areas, this stimulus causes less than 10% more NARS investment. For NARS with large areas, this IARC stimulus is over 20%; on averages, IARC germplasm stimulated 15 percent more NARS CGI investment.

V. Estimating Production Impacts of Improved Varieties

If improved crop varieties are to have a production impact they must first be adopted by farmers. If IARC content is important, IARC content varieties must be adopted by farmers. Varietal adoption data are depicted in Figures 1-10. These data show that modern varieties have been adopted for all study crops, although at different rates. These data also show that IARC-content varieties are considered by farmers to be as valuable as, or more valuable than, non-IARC-content improved varieties.

Estimation of production impacts, given adoption data, was approached in two ways. First, IARC collaborators prepared syntheses of IARC studies addressing this issue. Second, three country studies in the study addressed this issue. Table 2 reports estimates based on the country studies. The country studies commissioned as part of this evaluation study addressed two important problems that have not been effectively addressed in prior studies. The first problem is the specification of both varietal and non-varietal research contributions. The second problem is the treatment of adoption as being based on farmer decisions and investment in agricultural research and extension.

The first problem requires the development of variables in a statistical specification measuring varietal and non-varietal "service flows". Past studies have used a "percent modern varieties" variable based on past investments or research with time lag and depreciation weights and spatial spill-in weights (See Evenson, 1999, for a review). This variable is used to represent research services. The coefficient on this variable (holding constant the varietal services variable) is then interpreted as representing non-varietal contributions. This practice is subject to the problem that varietal improvement may not be well measured by the percent modern varieties variable. It is possible that the continuous flow of new varieties produces improved productivity without changing the percent modern variety variable. Recently released modern varieties replace earlier modern varieties and this can have a significant productivity effect.

To remedy this, the country studies attempted to develop "varietal turnover" variables. The varietal turnover measure is defined as the sum of positive varietal acreage share changes from one period to the next. The problem of endogeneity of adopted area is dealt with by treating the percent modern variety or variable turnover as an endogenous variable.

In the Indian study the endogenous variables are the four dependent variables, Area, % HYV, % IRR (Irrigation) and Yield. Exogenous variables include research variables (public and private), extension, markets, prices and climate and soil variables. The India study used district data for the 1959-94 period to estimate the model. The Brazil study estimated a similar model (without the irrigation variable). For China, it was possible to estimate a crop total factor productivity (TFP) equation, reducing the China model to 2 equations for TFP and varietal turnover.

Table 2: Estimates of Productivity Contributions (Δ Production/ha in Tonnes).

Crop	Proportions of Varieties Based on								
	India Study 100% MV Adoption			Brazil Study Varietal Turnover 1990-96			China Study Varietal Turnover		
	Δ Prod/ha	& Increase	Annual TPF Change	Δ Prod/ha	& Increase	Annual TPF Change	Δ Prod/ha	& Increase	Annual TPF Change
Rice	0.62	40.00	0.90	0.50	20.00	1.60	1.62	29.00	2.00
Wheat	1.21	55.00	1.70	Ns	Ns		0.74	24.00	1.90
Maize	0.98	65.00	1.30	0.41	20.00	2.00			
Sorghum	1.38	100.00	1.00						
Pearl Millet	0.38								
Beans						0.90			
Potatoes				Ns	Ns				

From the estimated coefficients in these models one can calculate the increased production per hectare that is associated with a change in varieties planted. Table 2 reports the estimated increase in production per hectare for a complete replacement of traditional varieties by modern varieties in the India study. These estimates range from 40% for rice to 100% for sorghum.

The second set of estimates is for the varietal turnover variable for Brazil and China. The reported estimates are for a 100% varietal turnover. In Brazil varietal turnover for rice and maize was roughly 250% over the 1970-1996 period. For China it was similar. Thus the two sets of estimates are consistent in their implications.

When the estimates in Table 2 are combined with the varietal turnover and modern varieties adoption levels, the annual varietal improvement in productivity gains noted in Table 2 are obtained. These range from 1% per year to 2% per year. Actual productivity rate gains range from over 2% for rice, wheat and maize to 1½% or so for other crops. It appears then that varietal gains account for approximately half to three quarters of real productivity gains in these crops.

Statistical estimates of yield and area equations using international data also confirm the role of varietal impacts estimated in a pooled regression indicated that the contribution of non-CGI NARS research was realized primarily in interaction with CGI research.

For purposes of calculating the contribution of IARC CGI programs it is necessary to construct a production "counterfactual". This means estimating varietal production under two scenarios, one with IARC CGI programs, one without. Then estimates of varietal impact on production can be used to simulate the change in productivity, i.e., the change in production that would have occurred if factors of production in crop production except the crop genetic factor remained unchanged (see below for a more general economic calculation).

The counterfactual scenario without IARC CGI programs has three parts:

1. NARS CGI programs would lose the IARC Indirect germplasm effect.
2. NARC CGI programs would lose the IARC investment stimulus effect.
3. IARC CGI direct varietal production would be lost.

Part a, the indirect germplasm effect was estimated (Appendix B) as a 30% reduction in NARS varietal production.

Part b was estimated to be 15% in the investment study (Appendix C). This reduces NARS varietal production by an additional 7%.

Direct IARC varietal production was approximately 30% for all CGI programs. However, substantial substitutability might exist between NARS and IARC programs. The loss of the IARC varieties might be partially compensated by more NARS varieties. If NARS would not release more varieties in the absence of IARC programs, parts a, b and c sum to more than 60%. Forty percent as many varieties would be produced in a scenario without IARC programs. If NARS would produce more varieties in the absence of competing IARCs, the reduction in varietal production might be 45 percent. (This conservative scenario will be used for further calculations.)

This scenario for reduced CGI production can be translated into productivity growth terms with reference to Table 2. The actual rates of CGI produced approximately 1.2% productivity growth per year. Growth accounting studies (discussed in Appendix D) show that for rice in Asia, the combined impact of CGI and non-CGI research, extension, markets and infrastructure was roughly 1.9% per year. The reduced CGI scenario calls for reducing this by .5%. (This is probably a low estimate of the input of CGI reduction because other sources of productivity growth also depend on CGI impacts.)

VI. Estimating Economic Effects (Study Objective 5)

How does the calculation made in the previous section translate into economic terms? Basic economic logic indicates that with lower rates of productivity growth, farm production costs will be higher and lower quantities of crops will be produced in developing countries. This would result in higher prices, not just in one country but in all or most countries because IARC investment affects many countries and because most crop markets are globalized with increased trade.

Thus, to calculate economic impacts an international or global equilibrium market model is required. Fortunately, such a model is available from the International Food Policy Research Institute (the IFPRI-IMPACT model). This model calculates equilibrium prices, production and consumption quantities, trade and welfare effects measured in terms of malnourished children. (See Evenson, 2000, for details of the model.) It is possible with this model to compare cases where this varietal component is reduced by 45% to simulate the "counterfactual" case where IARC investments had not been made. These simulations are summarized in Table 3.

First consider the price effects. These are expressed relative to the base case simulation and thus compare the difference between equilibrium prices cumulated over a 25-year period under the counterfactual case. This shows that wheat prices would have been 34% higher under the counterfactual than they actually were. The price counterfactuals differ by commodity, because both supply and demand conditions vary.

The trade implications of the counterfactual are that food imports in developing countries would increase by 9% or so. This reflects the differential advantage that the counterfactual confers to developed countries relative to developing countries.

There are two groups that would be harmed by this counterfactual simulations. The first is the environmentalist community. The simulations show that area planted to crops would be significantly higher if IARC investments had not been made. This would create more pressure on biodiversity habitats and on fragile land problems, particularly as these would be marginal lands in many cases.

The second group, consumers, would experience the greatest harm in the counterfactuals from the price rises. This harm is done to consumers in both developed and developing countries. Furthermore, this harm is greatest among the poorer groups in each economy because the poor spend a higher fraction of their income on food. In addition, this harm is also greatest in poor economies because most food is consumed in non-processed form (often on the farm where it is produced), thus the price effect is greater than in an economy where the farm value of food is low relative to the consumer value (i.e., where high levels of processing takes place).

Two points regarding this simulation should be made. The first is that the counterfactual has a reverse side. The investments in IARC germplasm improvement have produced lower food prices and massive gains to consumers. These gains can be seen in Table 3 where effects on the percent of children who are malnourished are simulated. Because of IARC programs, between 1.5 and 2% fewer children in developing countries are malnourished than would have been the case without IARC CGI investments. For India this is 3% and this literally translates into millions of children.

The second point is that the finding that consumers are the largest beneficiaries of IARC program consistent with economic logic and with a large number of empirical studies. Consumers do benefit most and poor consumers benefit most of all from agricultural research. Farmers are consumers too and for the world's smallest farm producers the total producer and consumer gains are large. The provisional findings provide support for the proposition that IARC investments have had impacts in all of the study crops. These impacts have been large, partly because of high "leverage" through IARC-NARS joint production. The placing of crop germplasm improvement at the core of IARC programs appears to have very strong justification.

Table 3. IFPRI-IMPACT Simulation
(Percentage Differences Relative to Base Case 1970-1995)

	COUNTERFACTUAL CASE
Equilibrium Prices	
Wheat	34
Maize	29
Rice	41
Other Grains	29
Root Crops	27
Trade – Import + Export	
Wheat	-20
Maize	-5
Rice	-8
Other Grains	10
Root Crops	-40
Total Grains Developed Countries	5
Total Grains Developing Countries	-5
Area Planted Developing Countries	
Wheat	4
Maize	2
Rice	5
Other Grains	4
Root Crops	6
Changes in % Malnourished Children (Age 0-6)	
Africa	1.0
WANA	1.2
India	3.0
China	1.4
Latin America	0.9
Developing Countries	2.2

APPENDIX A

The IAEG Crop Germplasm Impacts Study

The Impact Assessment and Evaluation Group (IAEG) of the Consultative Group for International Agricultural Research (CGIAR) is undertaking a study of crop germplasm impacts. This study covers ten crops for which both International Agricultural Research Center (IARC) and National Agricultural Research System (NARS) germplasm improvement programs have been in place in recent decades. Germplasm improvement is defined to include plant breeding activities including selection and field testing and pre-breeding activities including the collection, management and distribution of genetic resources, and the evaluation of genetic resources for potential plant breeding value. This evaluation thus encompasses genetic resource collection activities of both IARCs and NARS and the international nursery programs of IARCs as well as plant breeding programs.

This report is a provisional draft of the Centers-Wide report of the project. The final report will be available in September 2000.

Coverage-Collaborators.

The crops covered by the study and the associated IARC collaborators are:

Rice-Asia - IRRI (M. Hossain, D. Gollin)
Rice-Latin America - CIAT (N. Johnson, D. Pachico)
Rice-Africa - WARDA (T. Dalton)
Wheat - CIMMYT (P. Heisey, P. Pingali)
Maize-Latin America - CIMMYT (M. Morris)
Maize-South and West Africa - IITA (V. Manyong)
Sorghum - ICRISAT (C. Bantilan, U. Deb)
Pearl Millet - ICRISAT (C. Bantilan, U. Deb)
Barley – ICARDA (A. Aw-Hassan)
Beans - CIAT (N. Johnson, D. Pachicho)
Lentils - ICARDA (A. Aw-Hassan)
Potato - CIP (T. Walker)

In addition three country studies have been commissioned:

- India (J. McKinsey, Bryant College, P. Kumar, IARI)
- Brazil (A. F. Avila - EMBRAPA)
- China (J. Huang, R. Hu – CAAS, S. Rozelle - UC Davis)

Each IARC collaborator has undertaken basic data collection and analysis, and study reports will be forthcoming from each.

APPENDIX B
Varietal Discovery

The cumulative distribution of the largest value of *x(z)* from a sample of size *(n)* is the 'order statistic' (Evenson and Kislev, 1975):

$$H_n(\mathrm{z}) = [\, 1 - e^{-\lambda(z-\theta)}]^{\,n} \qquad \text{(B1)}$$

And the probability density function for *(z)* is:

$$h_n(\mathrm{z}) = \lambda n[1 - e^{-\lambda(z-\theta)}]^{n-1}\, e^{-\lambda(z-\theta)} \qquad \text{(B2)}$$

The expected value and variance of $h_n(z)$ are:

(B3) and (B4)

Evenson and Kislev discuss the applicability of equations (B3) and (B4) to plant breeding research. Equation (B3) can be derived from a uniform distribution and this is a very general expression for a broad range of functions *f(x)*. Basically (B3) can be thought of as the breeding production function with a very simple marginal product:

(B5)

When a measure of the units over which *(z)* applies is available (e.g. production in a specific ecosystem), V, the value of the marginal product can be computed and set equal to the marginal cost of search to solve for optimal *n*:

(B6)

Figure 1 depicts f(x) and $E_n(z)$ for two traits for a single period and shows the optimum level of search, n_i^x.

This model implies that equation (B3) predicts varietal releases, given existing germplasm. This germplasm to a given NARS program may be made available by on IARC program or by other NARS programs. The extension of (B3) to incorporate changes in germplasm is straightforwarded. Germplasm in the form of improved breeding materials could shift the mean ($\theta + 1/\lambda$) of the search distribution or it variance ($1/\lambda^2$) or both, enabling a richer field of search in a given NARS. This implies the following functional form for a NARS varietal release relationship:

$$VR_{it} = \alpha + b_1\, CCR_{it} + b_2 \ln(Sc_{it}) + b_3 \ln(SC_{it})^{*}\, CCR \qquad \text{(B7)}$$

Note that the variable measuring germplasm, CCR_{it} enters the equation in a linear form and interacts linearly with the logarithmic NARS search variable, SC_{it}. The contribution of IARC programs to NARS releases can be estimated with international data on varietal releases and on IARC germplasm contributions to NARS programs. Table B1 reports estimates of specifications for five study commodity and for pooled commodities.

The functional form in (A7) may be tested against a more general functional form (B8).

$$\ln(V_N) = a'' + b''\ln(sc) + c''\ln(CCR) \qquad \text{(B8)}$$

Since (B8) is a very general (Cobb-Douglas) form also allowing for diminishing returns but is not consistent with the discovery model, this is a strong test of the discovery model.

Table B1 reports estimates of specification (B7) for 5 study crops and for pooled crops with crop fixed effects. Observations are for NARS programs for three period, the 1970s, 1980s and 1990s. For each crop, all NARS programs of significance are included in the analysis.

Table B1 reports the adjusted R-squared statistics for specification (B7) above and the alternative specification (B8). In all estimates the data fit specification (B7) better and in all cases a statistical test showed this to be statistically significant (at the 5 percent level). This provides quite strong evidence for the discovery specification.

All coefficient estimates are of the expected sign and magnitude. The positive or statistically significant coefficient on the variable ln(SC) x CCR indicates that there is a strong IARC indirect germplasm effect on NARS programs. IARC germplasm makes NARS breeders (scientists) more productive. The negative coefficients for CCR indirect or "threshold" for the germplasm effect. For small amounts of IARC germplasm little effect is observed. As germplasm accumulates, its effect on NARS productivity is substantial.

The "net" productivity of NARS scientists depends on the coefficients for both the ln(sc) and the ln(sc) and the ln(sc) x CCR variable. This is positive and statistically significant.

The pooled estimate indicates that the 50 percent increase in CCR variable – roughly the increase of the 1990s over the 1980s – contributed a 25 percent increase in varietal production. This IARC germplasm effect thus roughly offsets the diminishing returns effect for NARS breeding programs, enabling varietal production.

APPENDIX C

The evidence for direct and indirect IARC CGI contributions does not answer the question as to whether IARC programs had positive or negative impacts on NARS CGI investments. The direct IARC effects would generally be expected to have a negative "crowding out" effect on NARS investment because the directly produced IARC varieties are substitutes for NARS varieties. The indirect germplasmic effects, on the other hand, should have a positive effect on NARS investments because they seem to make NARS scientists more productive. IARC programs can have broader germplasmic effects than those embodied in crop germplasm and most IARC programs have attempted to achieve these effects. For most crop programs, some form of contact between NARS scientists and IARC scientists in almost all countries and fields of research have been developed.

To test the net effect of IARC programs on NARS investments an investment specification is required. The specification estimated was:

(C1) $\ln(SC) = a + b(CCR) + c\ln(HA) + d\ln(HA) \times CCR + e\ln(PoPDEN) + f\ln(GDP/POP)$
where:

SC is the number of scientists man years of CGI effect in the NARS program. This is a real variable, not a financial variable.

CCR is the IARC germplasm variable used in the indirect effect analysis. It actually reflects both the direct and indirect effects of IARC programs.

HA is the area planted to the crop in the NARS country. It is expected that this measures the economic potential for CGI activities.

PoPDEN is the population density (i.e., the rural population per hectare of arable land) in the NARS country. This variable captures the expression of political concern for population growth effects.

GDP/P is gross domestic product in US dollars per capita. It is designed to capture the income effect on the demand for NARS scientists.

ln(HA) x CCR is the interaction of ln(HA) and the IARC germplasmic variable. This variable is designed to test for IARC effects and country size. A positive coefficient on this variable indicates that the IARC effect is larger for countries with larger areas planted.

Table C1 summarizes investment data in NARS and IARC programs. The study produced estimates of numbers of senior scientists engaged in CGI for 1997-1998. Data for the number of scientists in IARC programs by period were also obtained in the study. The research intensity data were based on estimates of "CGI shares" of all NARS scientists by commodity. These shares were obtained from publication shares in the FAO data. Shares of publications by country were obtained for each commodity CGI program, as well as soil science, agronomy and social science research programs.

Data on expenditures indicate that the IARC proportion of total IARC-NARS expenditures ranges from to 10 to 20 percent.

Table C1: CGI Research Intensities (Scientist/000 ha) NARS 1970-1990, (Scientists 1992), Expenditures and Scientists, IARC Program

	Wheat	Rice	Maize	Beans	Potatoes
Asia					
1970	0.102	0.016		0.076	0.54
1980	0.154	0.038		0.173	0.73
1990	0.176	0.062		0.086	1.09
1997 (Scientists)	(997)	(374)			(706)
Latin America					
1970	0.048	0.062	0.022	0.039	0.079
1980	0.067	0.103	0.041	0.062	0.161
1990	0.105	0.171	0.061	0.083	0.269
1997 (Scientists) (Private)	(167)	(97)	(809) (2089)	(41)	(204)
Sub-Saharan Africa					
1970	0.261			0.070	1.10
1980	0.224			0.061	1.02
1990	0.620			0.082	1.04
1997 (Scientists) (Private)	(104)	(106)	(105) (630)	(36)	(40)
West Asia-North Africa					
1970	0.028				
1980	0.045				
1990	0.099				
1997 (Scientists)	(439)				
IARC Expenditures					
1970	8.0		5.0	2.0	
1980	9.2		9.0	47.0	
1990	9.1		9.0	26.0	
1997	10.2		10.6		
IARC Scientists					
1970	17	4	12	2	
1980	30	17	32	17	
1990	36	50	28	26	
1997	34	40	29	19	
IARC Expenditure Shares	.12	.10	.15	.20	.10

Table C2: Estimates: NARS CGI Investments
Dependent Variable: ln(SC) by period: 1965, 1978, 1985 (t ratios in parentheses)

	Wheat	Rice	Maize	Beans	Potatoes	Pooled
Observations	84	81	51	66	33	315
R-Squared (Adj)	0.403	0.383	0.568	0.505	0.275	0.439
Constant	-2.521 (0.90)	-4.892 (2.26)	-9.424 (2.53)	-2.461 (0.73)	-5.396 (1.10)	-3.875 (2.98)
Ln(CCR)	0.048 (0.29)	0.262 (2.29)	-0.124 (1.07)	-0.092 (0.58)	-0.354 (1.44)	0.109 (1.84)
Ln(HA)	0.180 (6.85)	0.112 (3.98)	0.0057 (1.63)	0.0040 (1.18)	0.103 (2.30)	0.114 (7.76)
Ln(HA)*CCR	0.014 (2.07)	0.0034 (1.93)	0.0018 (1.42)	0.0049 (1.19)	0.007 (0.72)	0.0018 (3.42)
Ln(Pop Den)	0.794 (3.74)	0.360 (1.54)	-0.013 (0.06)	0.157 (0.57)	1.000 (2.40)	0.506 (4.62)
Ln(GDP/P)	0.015 (0.06)	0.619 (3.66)	1.500 (4.42)	0.480 (1.82)	0.344 (0.98)	0.423 (3.87)
D 65-75	-0.641 (1.47)	0.598 (1.26)	0.143 (0.25)	-0.668 (0.95)	-14.30 (1.35)	-0.069 (0.27)
D 76-85	-0.219 (0.62)	0.308 (0.79)	0.216 (0.56)	-0.216 (0.44)	-0.720 (0.95)	0.017 (0.08)
D Beans						-0.732 (2.82)
D Maize						-0.090 (2.75)
D Potatoes						-0.605 (1.59)
D Rice						0.031 (1.13)

Table C2 reports estimates of NARS investment functions by commodity and for pooled commodities. The estimates in Table C2 should be interpreted as national (NARS) demand functions. The dependent variable is the number of CGI scientists in each commodity program. Observations are for countries for three periods. The explanatory variables are:

- ln(HA): hectares of land planted to the crop.
- ln(CCR): cumulated IARC crossed released in the country.
- ln(HA)*CCR: the interaction of ln(HA) and CCR.
- ln(Pop Den): rural population density in the country (rural population/all agricultural land).
- ln(GDP/P): GDP per capita in the country.

Period and commodity dummy variable are included as appropriate.

The estimated model is incomplete in that the price of scientists is not included in the specification. To some extent, the GDP/P variable is capturing both a positive income effect on the demand for scientists and a negative price effect. The net effect is positive.

The HA variable is the major demand variable. The ln(HA)*CCR variable and the ln(CCR) variable test the IARC germplasm effect. The coefficient estimates for the ln(CCR) variable are generally not significant, although for the pooled estimates the level of statistical significance is modest. The major impact of IARCs on NARS programs is picked up by the ln(HH)*CCR term indicating that IARC programs do stimulate NARS investments and that this stimulus increases with ln(HA). Small NARS receive little stimulus. Large NARS receive considerable stimulus. (Note alternative specification using quadratic and cubed HA terms showed similar results). For the average HA level, this stimulus effect was roughly 19 percent in the 1990s. This can be considered to be a large IARC impact.

Finally, we may note that population density stimulates NARS CGI investments. This is a "Boserup" effect, indicating that population pressure does stimulate a response to the perceived "Malthusian" diminishing returns associated with increased labor use per unit of land. This response estimate is quite significant in the pooled data, indicating that a population increase of ten percent stimulates five percent more investment. This is of the some magnitude as the income effect. (In fact, a population increase of ten percent under Malthusian conditions would cause an income decline proportional to the labor share, so the Boserup effect actually is larger than the Malthusian effect).

APPENDIX D

Economic Imports

To calculate economic impacts an international or global equilibrium market model is required. Fortunately, such a model is available from the International Food Policy Research Institute (The IFPRI-IMPACT model). This model calculates equilibrium prices, production and consumption quantities, trade and welfare effects measured in terms of malnourished children.

The productivity improvements in the IFPRI-IMPACT model include contributions from a number of sources as shown in Table D1 for the South Asian base case for rice for 1965-1995.

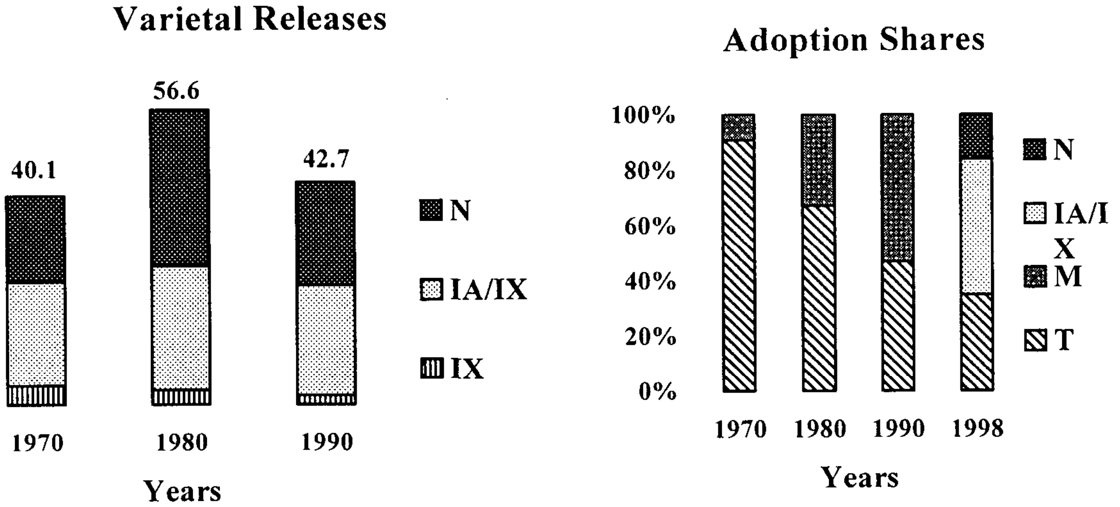
This case attributes 1.237 percent growth to public research, of this 1.02 percent is due to varietal improvement. (This agrees with the calculations in the countries table.) It is then possible to compare cases where this varietal component is reduced by 45 percent to simulate the "counterfactual" case where IARC investments had not been made.

Table D1. The South Asia Rice Non-price Productivity Terms (Expressed in Annual Percentage Change).

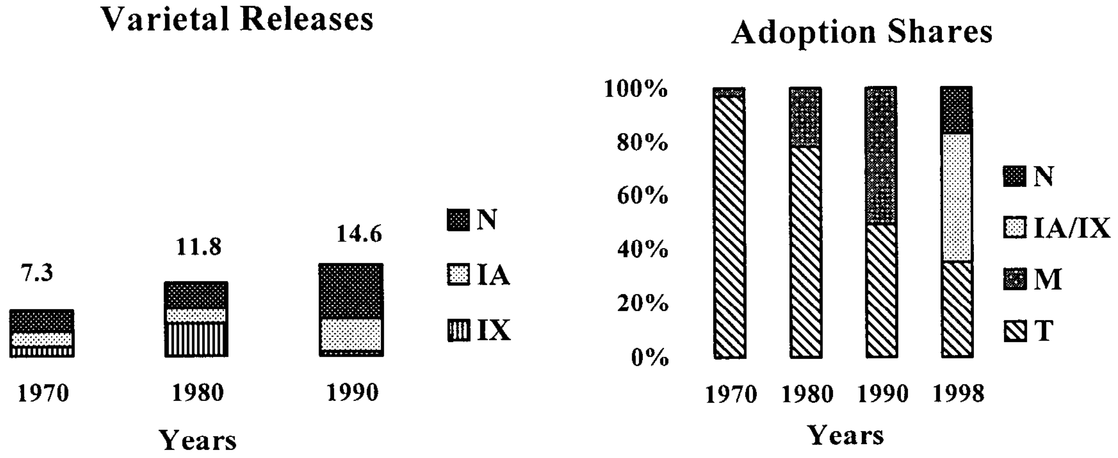
1	Public Research	
	A. Management	0.216
	B. Conventional breeding	0.763
	C. Wide-crossing, hybrids	0.100
	D. Biotechnology	0.158
	Total Public Research	1.237
2	Extension-Schooling	0.470
3	Private research	0.100
4	Markets-Infrastructure	0.150
	Total Base Case	1.957

Figure 1. Varietal Releases and Adoption Shares: Rice.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

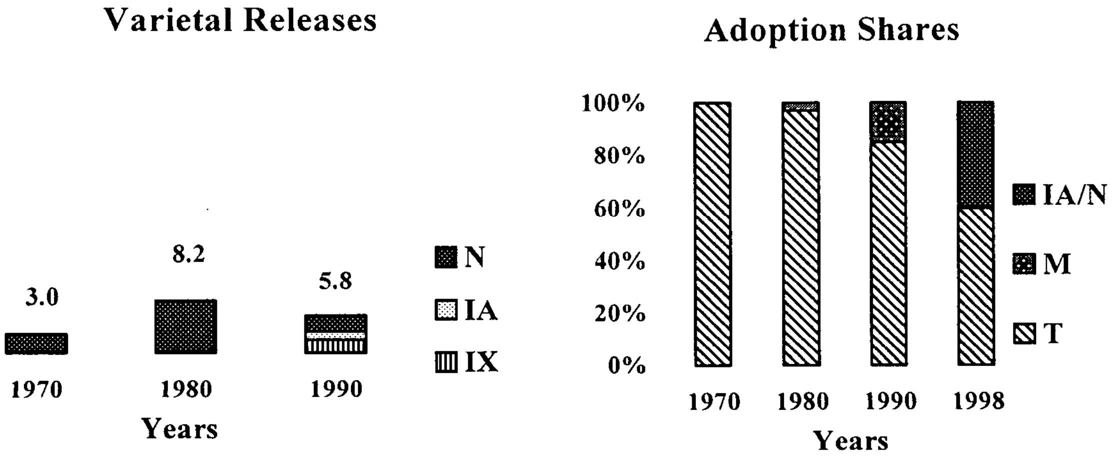
Asia



Latin America



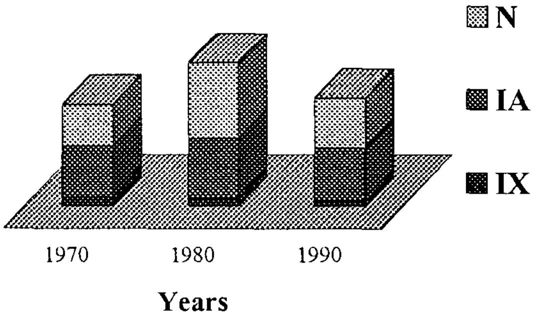
Africa



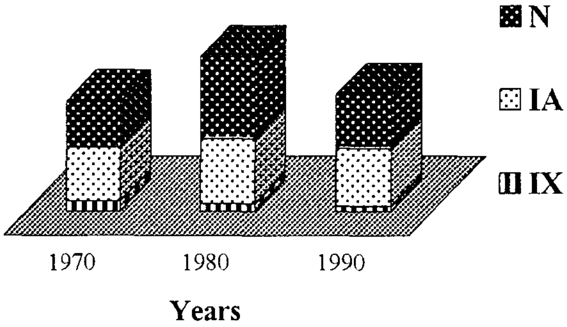
Rice

Asia

Varietal Releases

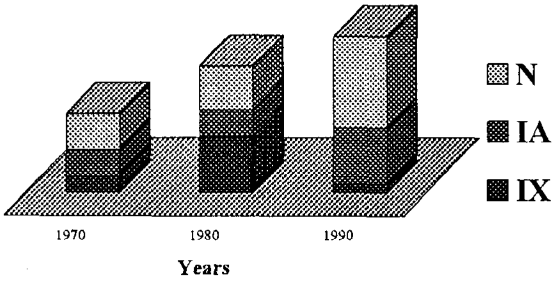


Varietal Releases

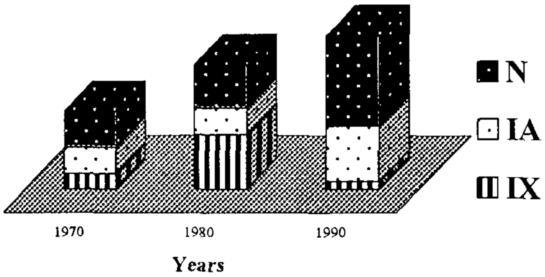


Latin America

Varietal Releases

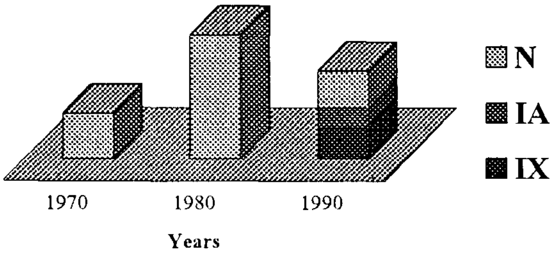


Varietal Releases



Africa

Varietal Releases



Varietal Releases

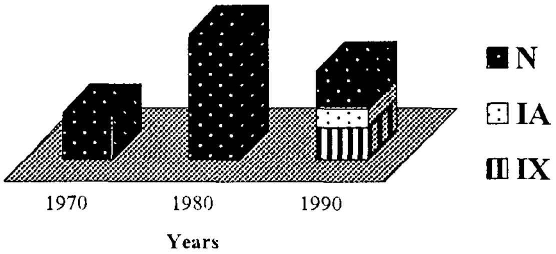
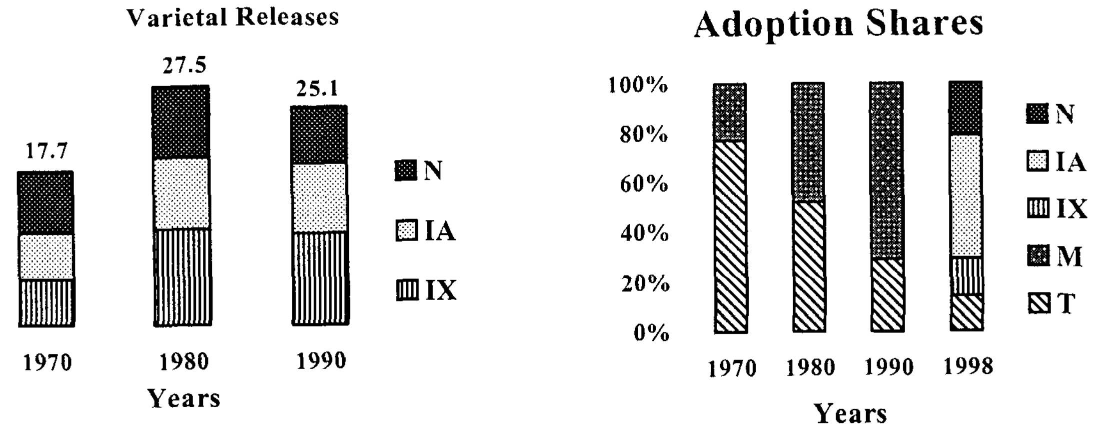
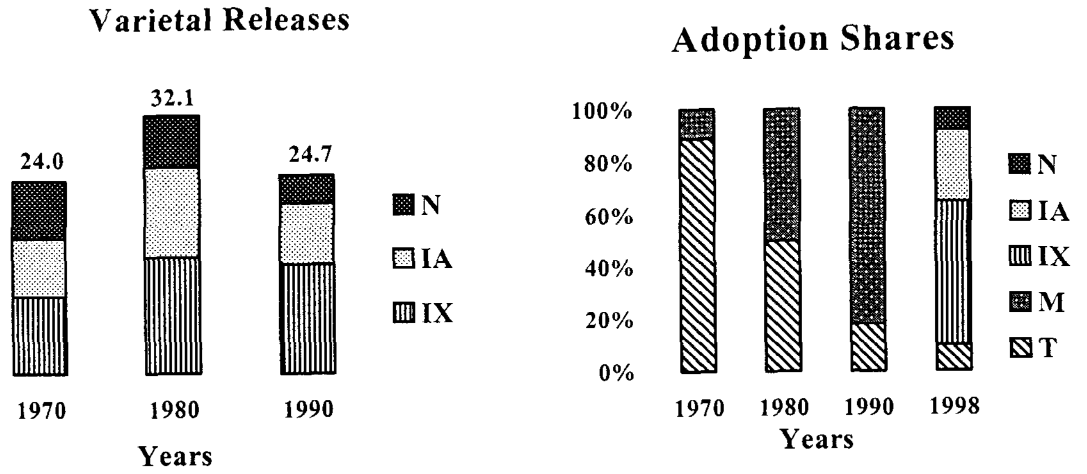


Figure 2. Varietal Releases and adoption Shares: Wheat.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

Asia



Latin America



WANA

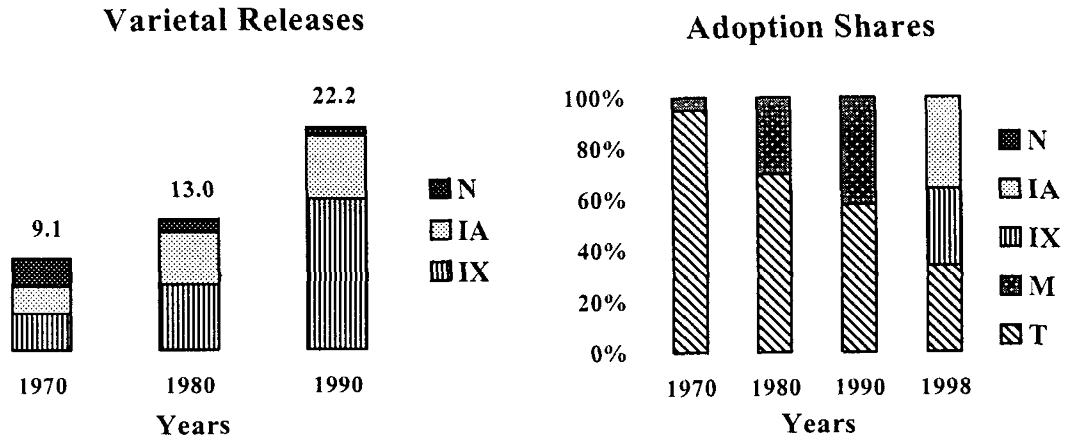
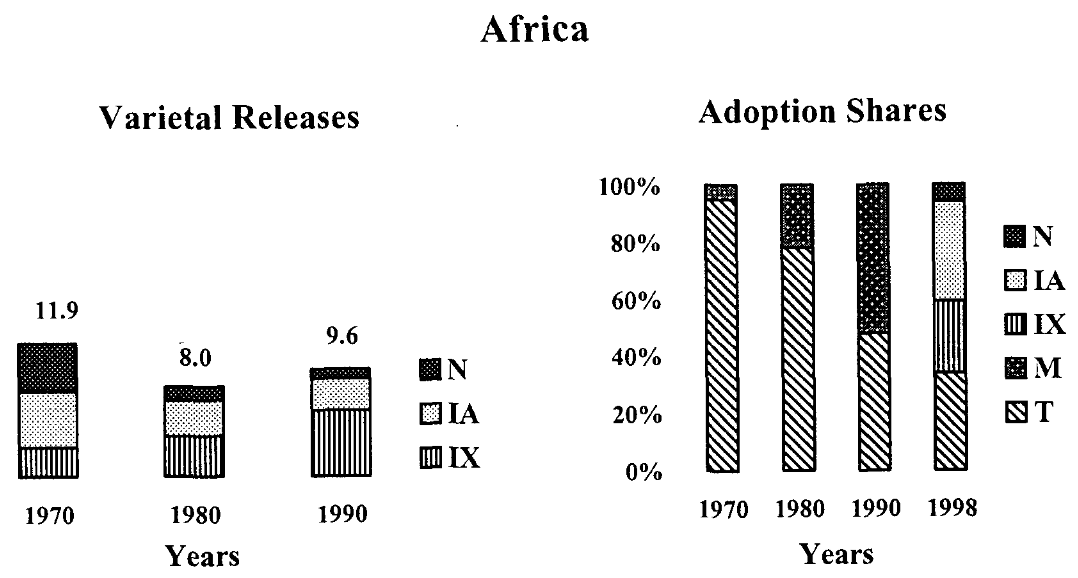


Figure 2. Varietal Releases and Adoption Shares: Wheat.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).



Africa

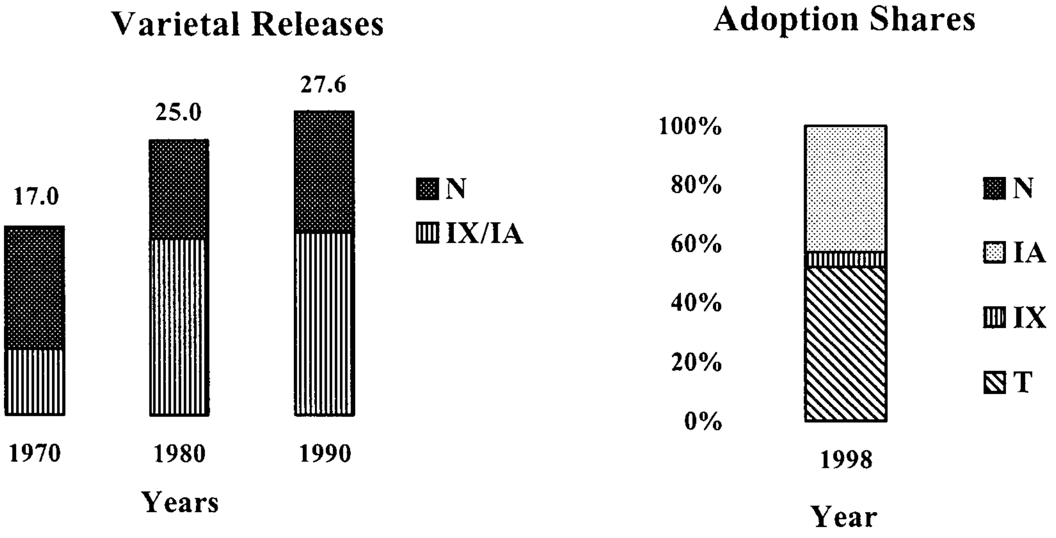
Varietal Releases

Adoption Shares

Figure 3. Varietal Releases and adoption Shares: Maize.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

Latin America

Public Maize


Varietal Releases

Adoption Shares

Private Maize

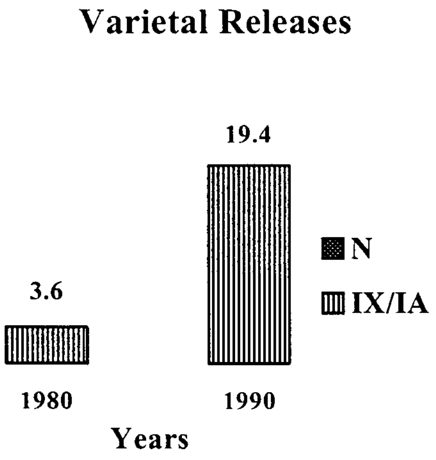
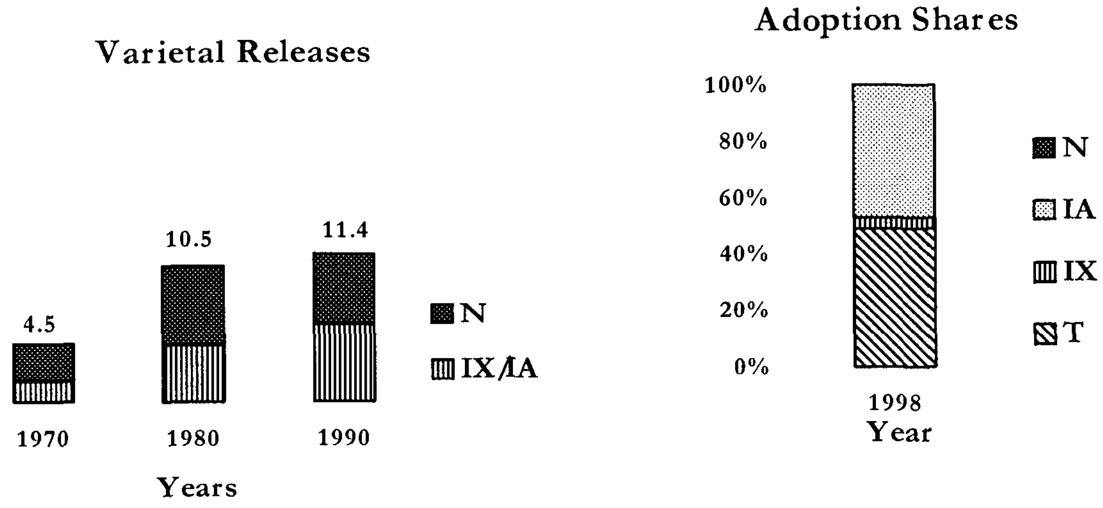

Varietal Releases

Figure 3. Varietal Releases and adoption Shares: Maize.

(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

Africa

Public Maize



Private Maize

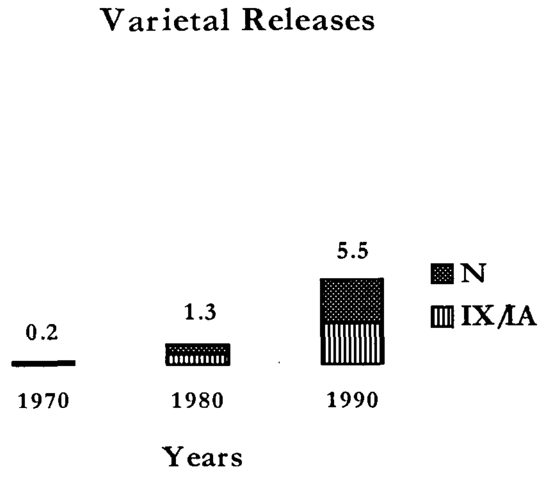
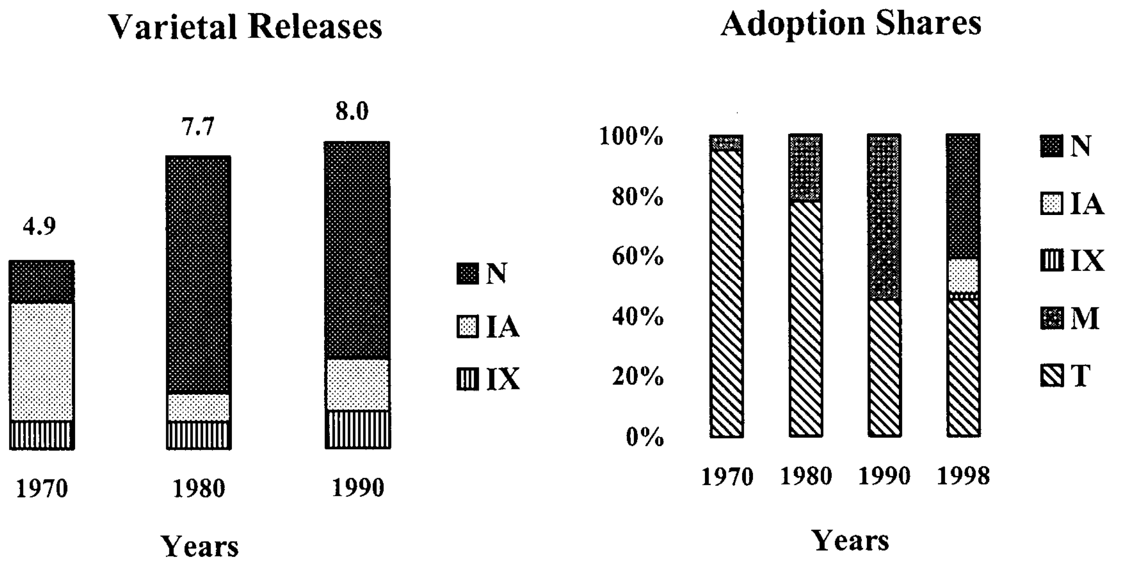


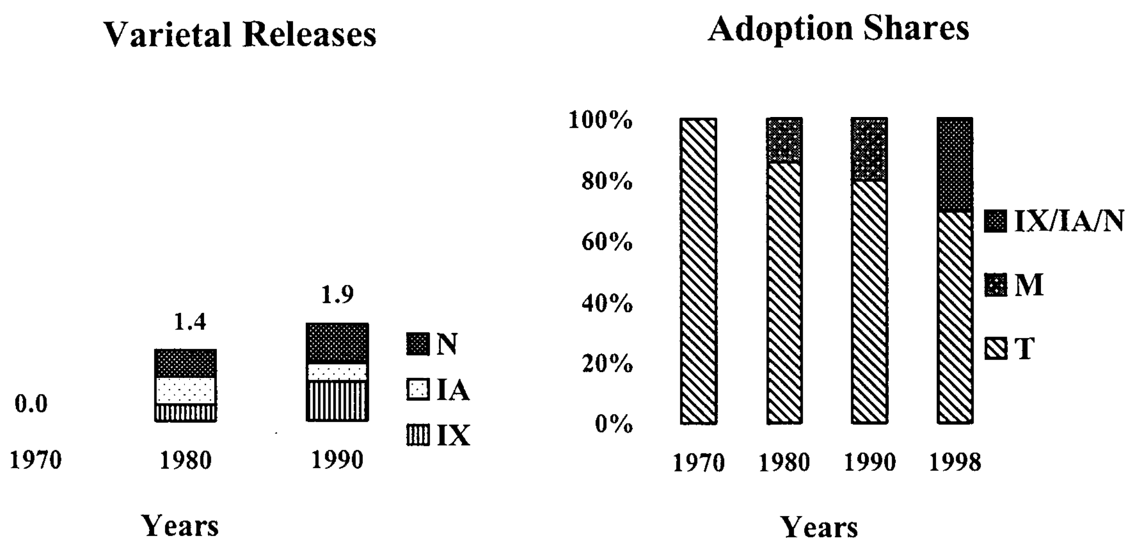
Figure 4. Varietal Releases and adoption Shares: Sorghum.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

Asia


Varietal Releases

Adoption Shares

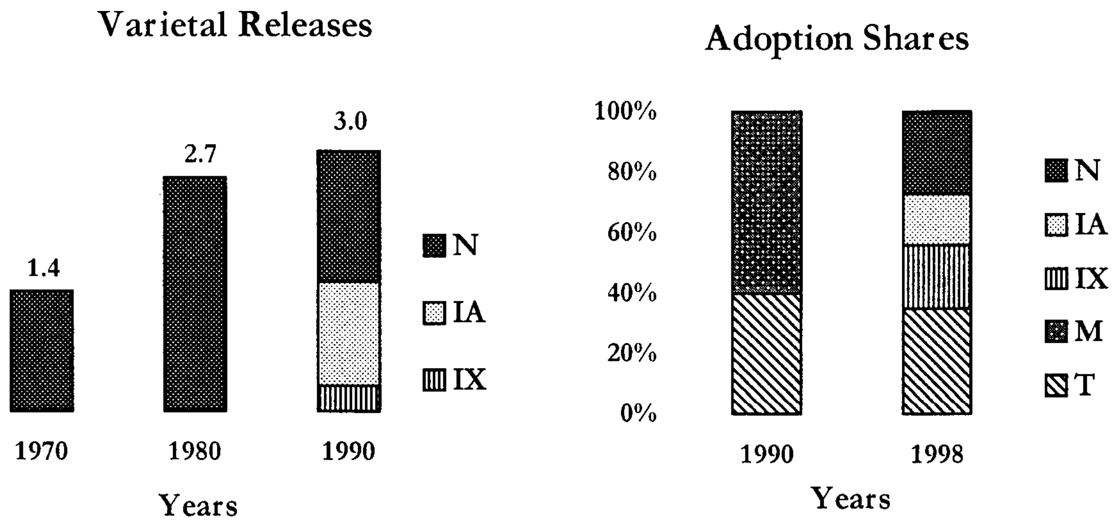
Africa


Varietal Releases

Adoption Shares

Figure 5. Varietal Releases and adoption Shares: Pearl Millet.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

Asia



Africa

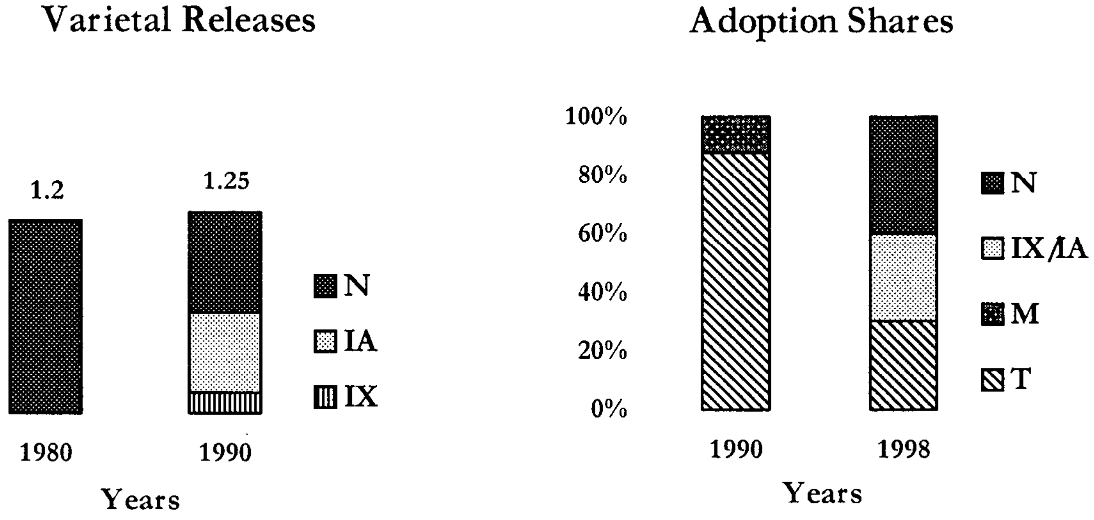
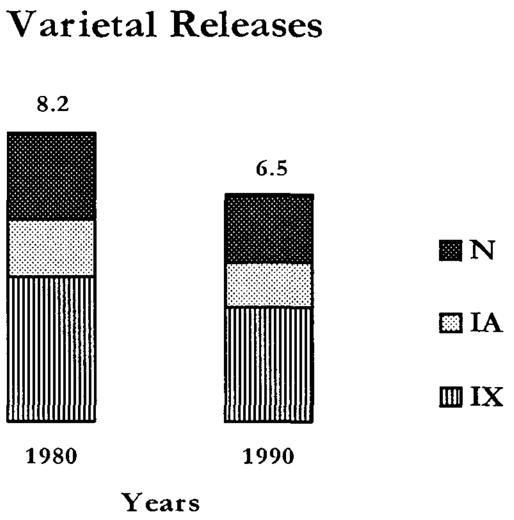


Figure 6. Varietal Releases and adoption Shares: Barley.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

WANA



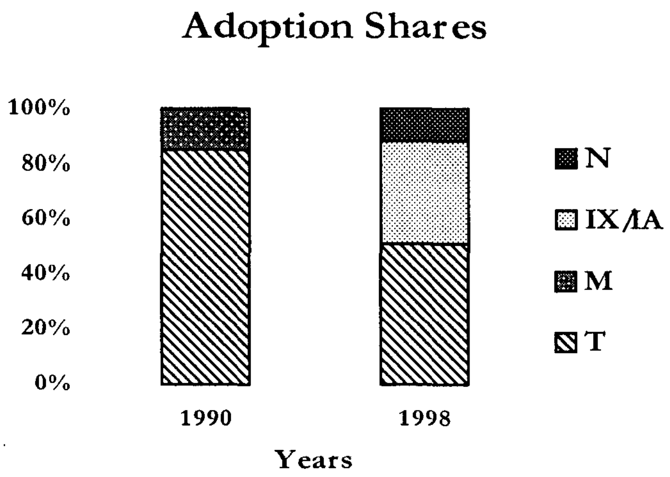
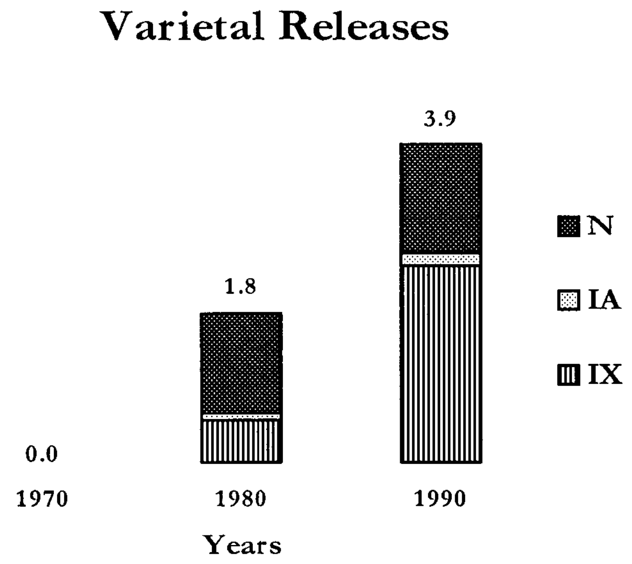


Figure 7. Varietal Releases and adoption Shares: Lentils.

(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).



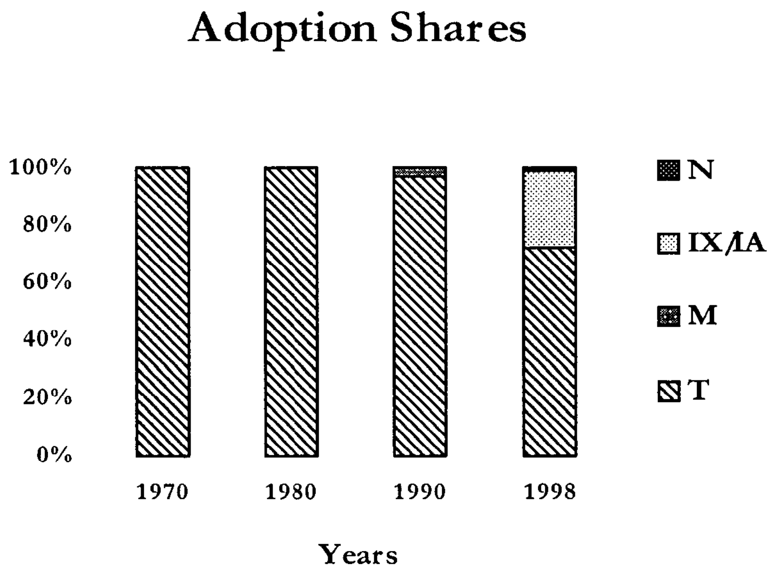


Figure 8. Varietal Releases and adoption Shares: Beans.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

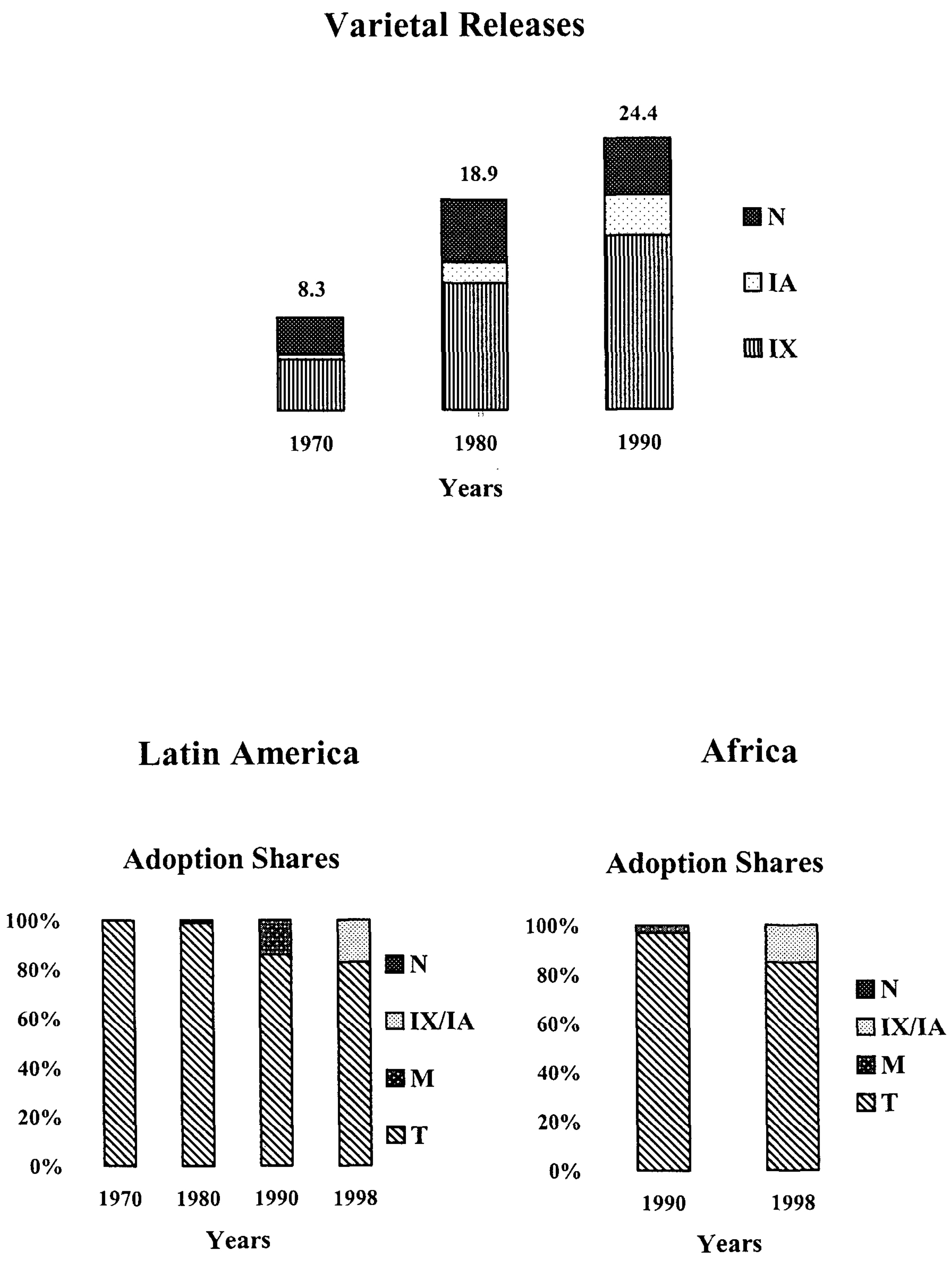
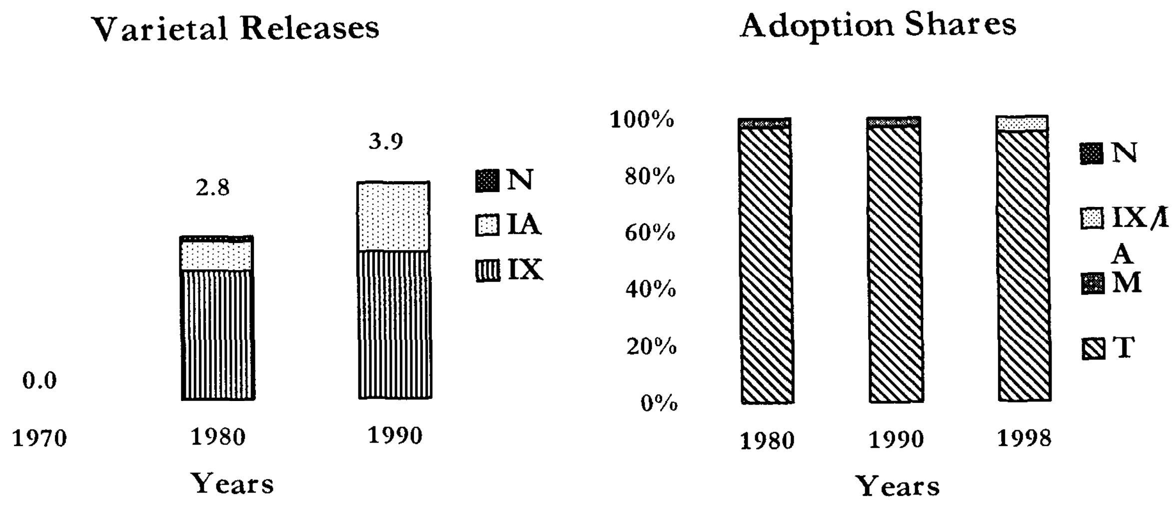


Figure 9. Varietal Releases and adoption Shares: Cassava.

(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

Latin America



Africa

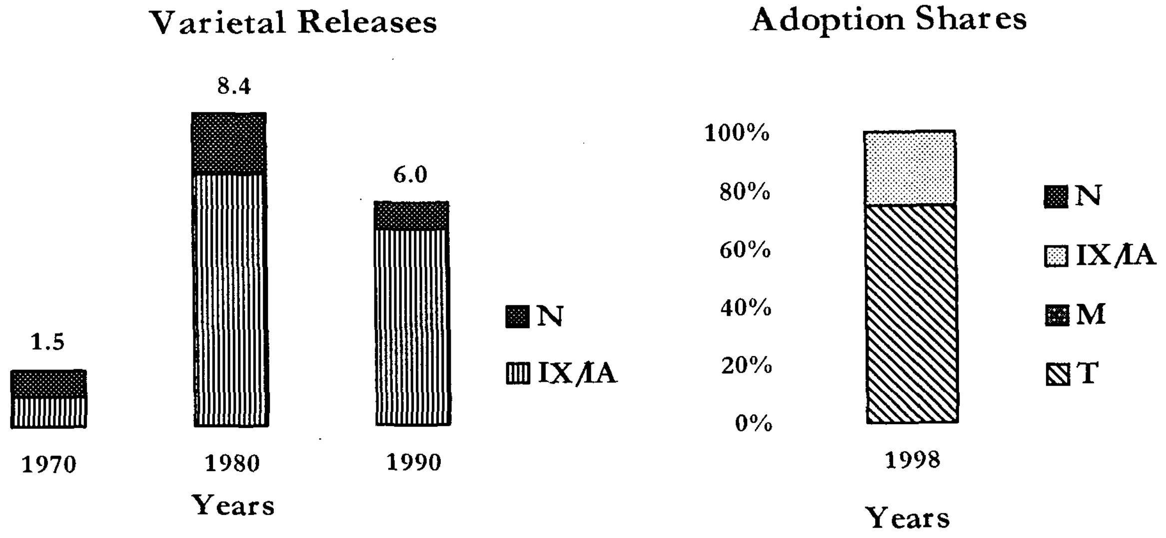
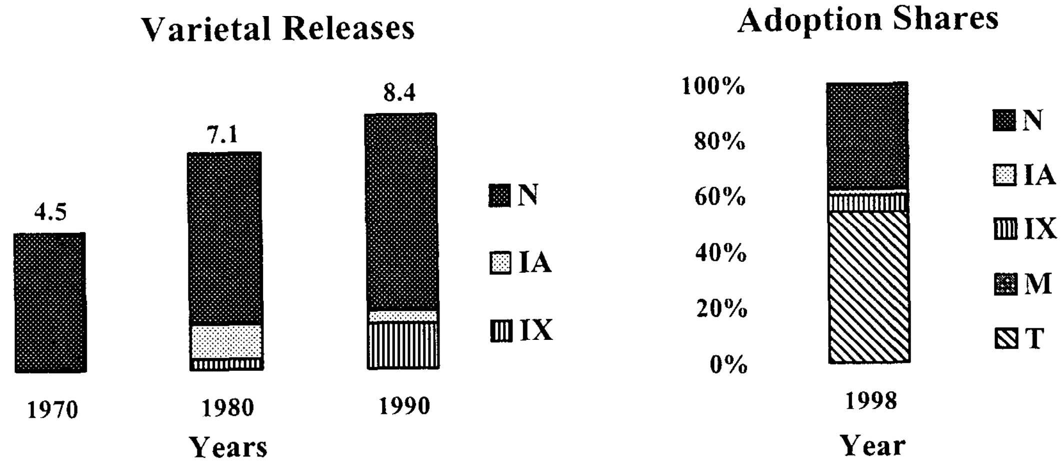
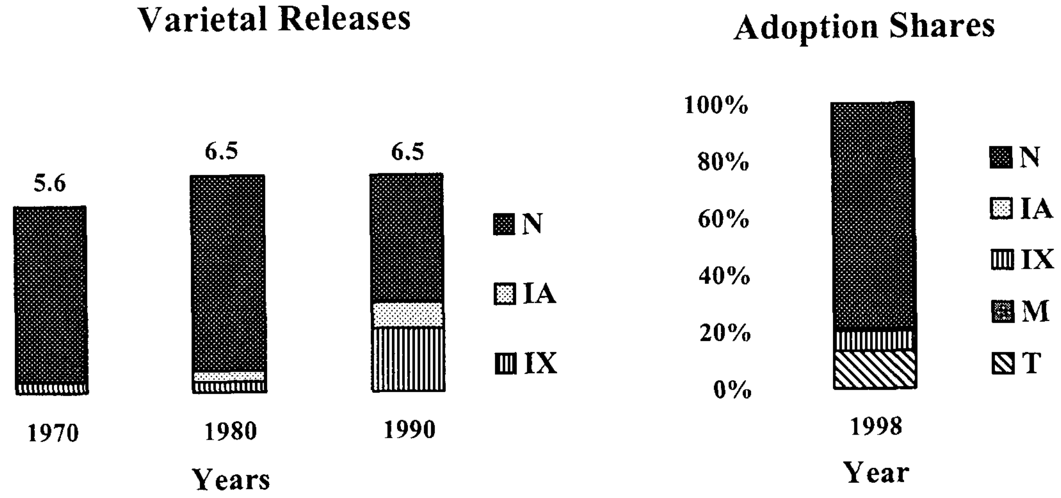


Figure 10. Varietal Releases and adoption Shares: Potatoes.
(T = Traditional Variety; M = Modern Varieties; IX = IARC Crosses; IA = NARS Crosses - IARC Ancestors; N = NARS Crosses – NARS Ancestors).

Asia



Latin America



Africa