Analysis of the Impact of CIMMYT Research on the Australian Wheat Industry

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Abstract
Wheat genetic materials developed from research at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico for developing countries have provided spillover benefits to Australia. Varieties developed from those genetic materials have resulted in yield increases in Australia. CIMMYT's success in developing countries has also reduced the world price for wheat. While the lower prices affect returns in Australia, the increased yields in Australia from the CIMMYT spillovers have provided benefits to Australia averaging A$30 million per year since 1973. If these benefits are to continue in the future, Australia must continue its close relationship with CIMMYT.

Keywords: wheat; research; spillover; CIMMYT; Australia

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Impact of CIMMYT Research on the Australian Wheat Industry

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Acronyms and Abbreviations Used in the Report

A$	Australian dollar
ABARE	Australian Bureau of Agricultural and Resource Economics (Canberra)
ABS	Australian Bureau of Statistics
ACIAR	Australian Centre for International Agricultural Research (Canberra)
AWB	Formerly Australian Wheat Board (now private company AWB Ltd)
AWCC	Australian Winter Cereals Collection (Tamworth)
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Centre
CSIRO	Commonwealth Scientific and Industrial Research Organization
FAO	Food and Agriculture Organisation of the United Nations
GRDC	Grains Research and Development Corporation (Canberra)
DREAM	Dynamic Research Evaluation Model
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
NSW	New South Wales
PBRO	Plant Breeders Rights Office
Qld	Queensland
Rht1, R*ht2*	Reduced height (dwarfing) genes
ROW	Rest of the World (other than Australia)
SA	South Australia
t	tonnes (= 1000 kilograms)
UNDP	United Nations Development Programme
Vic	Victoria
WA	Western Australia

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Several Australian wheat breeders contributed to the survey on the impact of CIMMYT in Australia, and we thank them very much for their contributions. We also want to thank Peter Martin and Michael Mackay for their help with obtaining and understanding variety pedigrees, and in other information on wheat varieties and their origins. John Woolston at CIMMYT also provided valuable assistance in relation to varieties and pedigrees.

We also want to acknowledge the debt that we owe to Tom Nordblom and John Mullen who provided detailed comments on an earlier draft of this report and the valuable insights that resulted.

Executive Summary

The wheat research carried out at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico has led to large increases in wheat yields in many countries throughout the world, particularly through the development and widespread use of semi-dwarf varieties. Even though CIMMYT's breeding program efforts have been directed at developing countries, Australia has received spillover benefits from the program.

Australia has been importing material from CIMMYT since the 1960s. However, few of those imported lines have been suitable for direct release for commercial production in Australia. In most cases, the CIMMYT lines have been used as parent lines in Australian wheat breeding programs, and breeders have combined them with other Australian varieties to develop improved varieties adapted to the Australian environment. Thus the strength of the Australian wheat breeding programs has enabled Australia to obtain the gains provided through germplasm from CIMMYT.

There have been two phases to the impacts of CIMMYT's wheat breeding program on Australia are: (a) Initial introduction and usage of higher-yielding semi-dwarf wheats derived from CIMMYT; and (b) Replacement of the earlier semi-dwarfs by higher-yielding varieties developed through the continuing use of CIMMYT materials in breeding programs. The initial adoption of semi-dwarf wheats led to yield increases that varied between states. Once the semi-dwarfs had been adopted, CIMMYT's research has led to further on-going yield improvements that consolidated and enhanced the yield gains achieved with the semi-dwarfs.

The first semi-dwarf varieties in Australia derived from those introductions were released in 1973. Since that time, breeders have released new and improved varieties regularly in all states incorporating semi-dwarf material originating from CIMMYT. By the end of 2003, 193 varieties had been released in Australia incorporating CIMMYT genetic material, either as direct CIMMYT introductions (3%), Australian varieties using a CIMMYT line as a parent (20%), or Australian varieties with some CIMMYT ancestry in at least one of the parents (77%). Since the 1970s, there has been some limited use of non-CIMMYT semi-dwarfs, but the overwhelming proportion of the wheat area has been sown to varieties based on Australian crosses using parents with CIMMYT ancestry.

In variety trials, the initial CIMMYT-derived semi-dwarf varieties had a yield advantage over other leading varieties. The average yield advantage was greatest in Queensland, NSW and Victoria, and lowest in the drier states of the South Australia and Western Australia. Basing CIMMYT's contribution to those gains on its direct genetic contribution to the parents used in the final cross, the varietal yield increases attributable directly to CIMMYT in 2001 range from 4.1% in Queensland to 0.1% in Western Australia. At its peak in the mid-1980s, the direct contribution of CIMMYT was markedly higher in each state, but the trend has been for an increasing use of second-, third- and subsequent-generation lines from Australia as parents rather than the original CIMMYT semi-dwarfs. As a result, the direct CIMMYT contribution to those gains has declined in the past 15 years or so. At the national level, CIMMYT's contribution to the first phase increases have been as high as 2.5% in 1990, but were only 1.3% in 2001. Thus, although the CIMMYT-derived semi-dwarf wheats led to varietal yield increases as high as 9.2% in Queensland, the majority of those gains (based on contribution to pedigree) were attributable to the Australian breeders and their already-adapted materials, rather than directly to the CIMMYT contribution.

In response to those yield gains, the adoption of the higher-yielding semi-dwarf wheats proceeded rapidly in NSW and Queensland, a little more slowly in Victoria and South Australia, and considerably slower in Western Australia. By the mid-1980s, NSW, Queensland and Victoria all had over 80% of their area sown to CIMMYT-derived wheat varieties. Western Australia was much slower to reach that level of adoption, but by 1997 had reached over 90% of its area sown to CIMMYT semi-dwarfs. At the national level, by 2001 these varieties covered 98% of the area sown to wheat in Australia.

The second phase of CIMMYT's impact in Australia, the post-semi-dwarf phase, began in 1988, by which time semi-dwarfs had been widely adopted in virtually all states. From 1988 to 2001, Australian wheat yields increased rapidly. The contribution of CIMMYT to those gains is estimated on the basis of CIMMYT's contribution to the first-generation pedigree of the varieties grown each year. By 2001, those phase 2 varietal yield gains were estimated at 3.2% nationally, and ranged from 1.6% in South Australia to 6.4% in Queensland.

From both the Phase 1 semi-dwarfs and the Phase 2 post-semi-dwarfs, the varietal yield gains for Australia attributable directly to CIMMYT averaged 4.6% for Australia by 2001. For South Australian and Western Australia, these gains were 2.0% in 2001, while for Queensland (10.5%), NSW (7.9%) and Victoria (7.4%) they were higher.

At the same time as these spillover yield benefits were flowing to Australia, CIMMYT was having a major impact on the world wheat production, especially in developing countries, with substantial productivity gains attributable to CIMMYT. In assessing the impact of CIMMYT, it is clear that the substantial yield gains from CIMMYT in developing countries have led to large supply shifts and a lower price for wheat globally than would have occurred without CIMMYT's research. In this study, world wheat yields are estimated to be 12.2% higher because of CIMMYT's research, and world prices 7.4% lower than if CIMMYT had not achieved those improvements around the world. Those impacts have also affected the benefits that Australia has received from CIMMYT.

Thus, the Australian wheat industry has been affected in two ways by CIMMYT's wheat breeding program. First, via the spillovers of the genetic materials from CIMMYT, Australia's wheat yields have increased by an average of 4.6% in 2001. Second, CIMMYT's global success has resulted in 7.4% lower world prices, including those for Australian wheat. The analysis indicates that the price fall has been greater than the average yield increase, so overall Australian wheat producers have suffered a net reduction in welfare from CIMMYT's activities. The estimated net effects over the period 1965 to 2020 are a reduction in welfare of A$1,239 million for Australian producers from CIMMYT, partly offset by the gains to Australian consumers of A$566 million. The net position for Australia is a net loss of welfare of A$673 million over that period, which is equivalent to A$12 million per year.

These negative impacts of CIMMYT on Australia are the direct outcome of genetic improvement worldwide. By drawing on the potential spillovers from the CIMMYT work aimed at developing countries, Australia has markedly reduced the welfare losses that would have otherwise occurred. The welfare losses for Australia would have been considerably larger (A$2,099 million, or A$38 million per year) without the yield gains from those spillover benefits. Thus, the spillovers have been very valuable to Australia.

The analysis shows that spillovers themselves from CIMMYT to Australia lead to welfare benefits totalling A$1,425 million over the period 1965 to 2020, almost all of which are received by Australian wheat producers. For the period since 1973, when those spillovers were first received in Australia, the net welfare gains for Australia from the CIMMYT spillovers has averaged A$30 million per year. Given that Australia's investment in CIMMYT has averaged close to A$1 million per year, Australia has received a high return on the funds invested in developing, enhancing and capturing those spillovers from CIMMYT. Without this investment, it is likely that Australia would have had less access to CIMMYT materials.

Overall, the yield increases that the CIMMYT wheat breeding program in Mexico has generated around the world have affected Australia by lowering the price for wheat. However, the Australian wheat industry has received extremely valuable spillover yield benefits from CIMMYT to partly counter those price effects. It seems likely that Australian breeders will continue to obtain spillover benefits for some time to come, and efforts to enhance the relationship between CIMMYT and Australia are likely to provide substantial returns for Australia.

1. Introduction

1.1 International Maize and Wheat Improvement Centre

The International Maize and Wheat Improvement Centre (CIMMYT) is an internationally-funded, non-profit, scientific research and training organisation, which has its headquarters in Mexico. CIMMYT works with agricultural research institutions worldwide to improve the productivity and sustainability of maize and wheat systems for poor farmers in developing countries (Evenson and Gollin 2003b). It is one of 16 similar centres supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR comprises over 50 partner countries, international and regional organisations and private foundations. It is co-sponsored by the Food and Agriculture Organisation (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), the United Nations Development Programme (UNDP), and the International Fund for Agricultural Development (IFAD).

Australia is one of the many countries that provide financial support for CIMMYT's research agenda, mainly through part of its foreign aid program. In addition, Australia has many close research links with CIMMYT through special funding provided by the Australian Centre for International Agricultural Research (ACIAR), the Grains Research and Development Corporation (GRDC), and the Cooperative Research Centre for Molecular Plant Breeding.

1.2 Project on CIMMYT's Impact in Australia

CIMMYT's wheat breeding program in Mexico has led to large increases in wheat yields in many developing countries throughout the world, particularly through the development and widespread use of semi-dwarf varieties (for example, see Heisey *et al.* 2002). Even though CIMMYT's breeding program has been directed at developing countries, Australia has received benefits from it (Brennan 1989, Brennan and Fox 1995). By 1994 over 90% of the area sown to wheat in Australia was sown to semi-dwarf varieties. The cost reductions resulting from those yield gains from CIMMYT-derived varieties are estimated to have contributed an average of A$147 million (in 1993-94 values) per year in the period 1974 to 1993 (Brennan and Fox 1995).

More recently, studies of the impact of research at other CGIAR centres such as ICRISAT (Brennan and Bantilan 1999, 2003) and ICARDA (Brennan, Aw-Hassan, Quade and Nordblom 2002; Brennan Aw-Hassan and Nordblom 2003), have assessed the impact on Australian agriculture. Those more recent studies have extended the analysis to include the price impacts of research on both producers and consumers. These have shown the importance of the price effects in assessing not only the total net benefits to Australia, but also in the distribution of those benefits globally. Where these centres have achieved major productivity gains at the global level, the world price is likely to be lower for all producers (including Australia) than if they had not achieved that success.

An analysis of spillover benefits from CIMMYT to Australia in the same context as those of the other CGIAR centres would provide information to assist in determining the appropriate level of investment by Australia in international agricultural research by the CGIAR in the future. Given CIMMYT's success in developing countries, the world price is likely to be lower than it would otherwise have been. Thus, the analysis will assess the value of the spillovers in alleviating the effects of lower world prices.

In addition, wheat research within the CGIAR system in recent years has been integrated between CIMMYT and ICARDA to a large extent. This study presents an opportunity to evaluate the impacts on Australia of all wheat research undertaken by the CGIAR, whether at CIMMYT or ICARDA, without attempting precise attribution to either individual centre.

ACIAR has provided funding for a project (C2002/124) to enable the impact of CIMMYT and its associated work at ICARDA on Australian wheat industry to be assessed. The objectives of the project were:

(a) To update the previous study of the spillover impact of semi-dwarf wheat research at CIMMYT on Australian agricultural productivity;
(b) To extend the analysis to include the impact of post-semi-dwarf spillover impact of CGIAR wheat research (including both CIMMYT and ICARDA) on Australian agriculture;
(c) To incorporate the evaluation of those gains in productivity into an analysis of the overall price impacts of wheat research at the CGIAR centres.

The aim in this report is to outline the analysis undertaken in the project, and to describe the findings of that analysis and their implications for Australia.

1.2 Outline of This Report

In section 2 of this report, the relationship between CIMMYT and Australia is outlined, as is the connection to ICARDA. In section 3, the identification of CIMMYT’s impact on Australia is discussed. In section 4, the impact of CIMMYT’s semi-dwarfs on wheat yields in Australia is analysed, and in the following section the impacts of CIMMYT beyond the semi-dwarfs are examined. The yield increases from CIMMYT varieties are valued in section 6, and in section 7 the contribution of CIMMYT to those gains is estimated. In section 8, an economic analysis of the impact of these increases is undertaken in a market framework, to incorporate price impacts and determine the distribution of those benefits. In section 9, the implications of the results are discussed, and the outcomes of this report are summarised. Appendices are attached with additional data and details of aspects of CIMMYT’s impacts on Australia.

2. CIMMYT and Australia

2.1 Wheat Production in Australia

Wheat production in Australia is mainly in low-rainfall areas, and is almost entirely dryland production. The average growing-season rainfall for all wheat districts across Australia averages approximately 275 mm per year, ranging from 151 mm to 678 mm in the May-October growing season (Hamblin and Kyneur 1993). A large proportion of production takes place on mixed cereal-livestock farms across southern Australia. Production is predominantly for export, with an average of over 80% of production exported annually.

Most varieties grown in Australia are spring wheats, even though they are grown through the winter. Their growth through the winter months is possible because of the relatively mild winters in the Australian wheat-growing areas. In recent years, winter wheats have become more widely grown. Australia has focussed on production of white-grained wheats, and breeders have had to develop white-grained varieties incorporating the desired characteristics, often by adapting characteristics from red wheats overseas.

Data on the area, yield and production for each year from 1972-73 to 2003-04 are shown in Appendix A. The fluctuations over time in the area sown are evident, as is the growth in average yields over the period. However, Australian wheat yields and production are notably variable, so that the annual fluctuations are considerable.

2.2 Australian Wheat Improvement Programs

Until recently, all scientific wheat breeding in Australia was carried out in the public sector. Each State Department of Agriculture established its own breeding program, with other programs operated by the University of Sydney and the Commonwealth Scientific and Industrial Research Organization (CSIRO).

Wheat breeding has long been supported by the levies placed on growers, and the matching Commonwealth Government payments, through the Grains Research and Development Corporation (GRDC) and it predecessors. Thus, farmers were collectively able to fund the public-sector wheat breeding programs. With the introduction of Plant Breeders' Rights in the 1980s, breeders were able to obtain financial returns from the use of their varieties through seed royalties. With the recent introduction of "end-point royalties" on all wheat sold or delivered for sale, the incentives for private breeding programs have changed. Private-sector breeding programs are now able to obtain income from the production of their varieties, and hence to take up breeding on a sound commercial basis. At the same time, public wheat breeding programs have become more commercially oriented and are acting increasingly like private sector breeders. As a result, Australian wheat breeding is now a largely commercially-focused activity, and is taking place increasingly in the private sector.

2.3 Australia's Involvement with CIMMYT

CIMMYT has targeted its research at a wide range of mega-environments across the wheat-producing regions of the developing world. In recent years, progress has been identified in a broad set of those environments (Heisey *et al.* 2002). However, the principal environments in which the main progress has been made are the high-input, irrigated environments. Progress has generally been slower in the drier environments that are typical of Australia.

Australia has been one of CIMMYT's most consistent supporters since the 1970s. Australia has contributed regularly to CIMMYT's core funding over that period, and has also developed a range of project-based funding with CIMMYT. Australian funding organisations that have played a prominent role in those activities include the Australian Centre for International Agricultural Research Centre (ACIAR) and the Grains Research and Development Corporation (GRDC). To illustrate of the breadth of the role of Australian funding at CIMMYT, collaborative projects supported by Australian funding in 2003 are shown in Appendix B.

As a result, there have been a number of successful collaborations between CIMMYT and Australian scientists. In addition, there have been numerous Australian staff employed at CIMMYT since its establishment (CIMMYT 2004). These arrangements have ensured that Australia has been in a strong position to take advantage of any potential spillover benefits that might result from CIMMYT's work.

In addition Australia has a prior connection with some of the early CIMMYT material used as a basis for the initial semi-dwarf wheats that were based on the Norin 10-Brevor cross. Brennan and Fox (1995) provide a detailed description of the early use of CIMMYT material and the development of semi-dwarfs in Australia and those connections to the early CIMMYT materials (such as WW80).

2.4 CIMMYT and ICARDA and Australia

CIMMYT's Wheat Improvement Program has been conducted in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA), and a bread wheat breeder from CIMMYT has been located at ICARDA in past years. In addition, ICARDA's Durum Wheat Improvement Program has been conducted in collaboration with CIMMYT; a CIMMYT Durum Wheat Breeder has been posted at ICARDA headquarters, although other positions in the joint program have been provided by ICARDA. In very recent times, these collaborative arrangements have been re-assessed.

The jointness of the CIMMYT/ICARDA program makes it difficult to determine the value of ICARDA's contribution to materials obtained through CIMMYT. Brennan *et al.* (2003) examined the contribution of ICARDA to the Australian durum wheat industry. In that study, any CIMMYT contribution to that material was not identified separately, and a parallel approach is used in this study. In this study, we have made the simplifying assumption that material distributed by CIMMYT is designated as "CIMMYT material", regardless of any testing and evaluation that has been carried out at ICARDA. This may well understate ICARDA's contribution to that material. However, no bread wheat material has been obtained directly from ICARDA for use in Australia; all genetic materials obtained by Australia have been obtained via CIMMYT.

Thus, in this study no distinction has been made between materials obtained directly from CIMMYT and those with some input from ICARDA. Such simplification is not intended to imply that the benefits from the joint CIMMYT/ICARDA program are all attributable to CIMMYT. Some of the increased productivity for wheat gained by Australia from CIMMYT genetic materials will have included some degree of contribution from the testing and evaluation undertaken at ICARDA. However, those benefits are not identified separately in this study.

2.5 Attribution of Gains to CIMMYT in This Study

Alston and Pardey (2001) have highlighted the significant issues relating to the attribution of research outcomes to particular sources. CIMMYT has to some extent been a clearing-house for wheat genetic resources from around the world, and as a result the countries from which those genetic resources originated have a claim on some of the benefits of CIMMYT's work. For convenience, the benefits of any such genetic materials are attributed in this study (and in similar studies) to CIMMYT, rather than to any country making a prior contribution.

At the same time, the main strength of CIMMYT has been to enhance and further develop genetic materials, rather than to act simply as a clearing-house. The crosses made at CIMMYT have meant that a great deal of CIMMYT material has been changed substantially from the original genetic resources introduced into CIMMYT's germplasm collection. In particular, CIMMYT has: (a) used shuttle breeding to speed up genetic improvement; (b) developed wide adaptation of semi-dwarf materials through testing of segregating material under a wide range of disease pressures; (c) developed crosses between spring and winter wheats; (d) incorporated genetic translocations from rye into wheat; (e) developed durable rust resistance; and (f) developed synthetic wheats developed from wide crosses with wild relatives of wheat. As Alston and Pardey (2001) noted, the attribution difficulties for these developments remain complex, but it is clear that CIMMYT has added considerable value to the genetic material from around the world. In this study, we use the convenient short-hand of labelling the outcomes from that research as "CIMMYT-derived varieties", "CIMMYT varieties" or "CIMMYT materials", without implying that the prior contributions of other countries is unimportant.

3. Identifying CIMMYT's Impact in Australia

3.1 Use of CIMMYT Material in Australian Wheat Breeding Programs

3.1.1 Survey of Australian wheat improvement programs

In early 2004, a survey was conducted of the wheat improvement programs in Australia known to be working on CIMMYT wheat breeding materials. A copy of the survey form is attached in Appendix C. In all, responses were received from nine of the scientists involved, only half the wheat breeders and researchers contacted.

The aim of the survey was to discover the benefits that those involved in the research programs perceived for their programs from CIMMYT, and to identify the key materials involved and the strengths and weaknesses of that material. A further aim was to document which CIMMYT lines were currently being used by Australian breeders.

CIMMYT material is currently being widely used in wheat breeding programs. The breadth of the reliance on CIMMYT as a source of breeding materials and methodologies is relatively consistent in the responses received. The majority of scientists report using breeding material from CIMMYT. The information obtained from the survey is used extensively in identifying the impacts of CIMMYT on Australian breeding programs in the following sections of this report.

The information obtained from the survey is used extensively in identifying the impacts of CIMMYT on Australian breeding programs in the following sections of this report.

3.1.2 Results of survey

The results indicated that CIMMYT material has been widely used in Australian wheat breeding programs. The breadth of the reliance on CIMMYT as a source of breeding materials and methodologies is relatively consistent in the responses received. All bread wheat breeders who responded reported using breeding material from CIMMYT in their programs. The durum breeder reported that his materials have come from ICARDA rather than from CIMMYT, and that the CIMMYT program had provided no benefits to his program.

When asked to report the characteristics in the CIMMYT materials that were of most current interest or benefit in the past to the breeding program, yield potential and rust resistance (particularly the "slow-rusting" genes) were most often mentioned. Increasing diversity, improved grain size, tolerance to abiotic stresses (such as aluminium and drought tolerance) and straw strength were also mentioned. The diseases mentioned included the rusts, yellow leaf spot, Karnal bunt, septoria tritici blotch. While all breeders reported having lines in their program with CIMMYT parentage, and most reported having released cultivars with CIMMYT ancestry or parentage, only about one-third had directly released cultivars developed by CIMMYT.

When asked about the use of CIMMYT materials in research rather than directly in breeding programs, the synthetics and their derivatives and the slow-rusting genes were mentioned by several breeders, as were the lines that related to superior emergence. Breeders generally reported that genetic materials were the only benefits that they saw as coming from CIMMYT, although the screening carried out at CIMMYT was mentioned as being useful by one breeder. Diversity was mentioned as a benefit to research programs from CIMMYT.

While the breeders generally saw CIMMYT as a valuable source of breeding materials, some respondents expressed reservations about the material from CIMMYT. Respondents identified the key limitations to the use of CIMMYT materials as being related to quality, particularly late maturity amylase (LMA) and the 1B/1R gene translocation with its associated sticky dough. Some breeders commented that these difficulties have made them very wary of using CIMMYT lines as parents. Intellectual property was also mentioned as an issue constraining wider use of CIMMYT materials. However, most breeders have released varieties containing CIMMYT material, as it is apparent that there are qualities in these breeding lines that are beneficial to the development of wheat for the Australian wheat industry.

Most breeders reported only sporadic direct contact with CIMMYT, in terms of visits, although e-mail contacts provide some useful means of communication. However, it seems that the majority of Australian wheat breeding programs responding to the survey have relatively little direct contact and linkage to the CIMMYT wheat breeding program, despite the strong impacts that it has had on the Australian wheat industry.

3.2 Nature of CIMMYT Impacts

From the information provided by the Australian breeders, and following Byerlee and Moya (1993) and Byerlee and Traxler (1995), there are two phases to the impacts of CIMMYT's wheat breeding program:

- Initial introduction and usage of semi-dwarf wheats derived from CIMMYT (Phase 1)
- Replacement of the earlier semi-dwarfs by higher-yielding varieties through the continuing use of CIMMYT materials in breeding programs (Phase 2)

The initial adoption of semi-dwarf wheats (Phase 1) led to yield improvements around the world. The level of improvement varied with the production environment, but generally there were significant yield improvements associated with the change from older tall wheats to semi-dwarf wheats. These improvements were linked to the increased harvest index, which was the result of the wheat plant putting more of its growth into grain rather than straw. The semi-dwarfs were associated with reduced lodging, and consequently were able to increase productivity when inputs, including fertiliser and irrigation water, were increased.

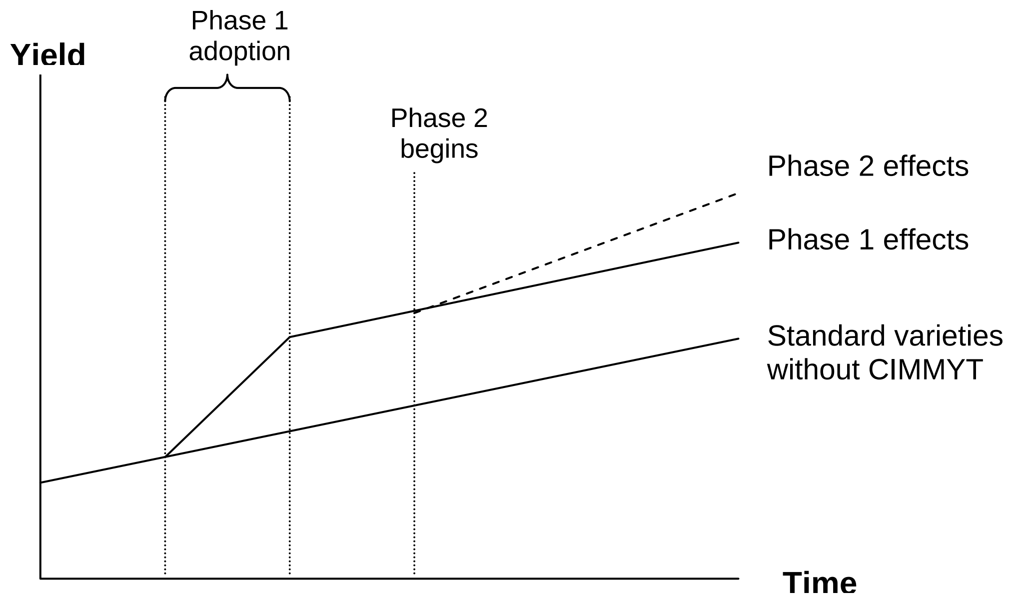
Once the semi-dwarfs had been adopted, CIMMYT's research has led to further yield improvements. Thus, in Phase 2, the yield gains achieved with the use of semi-dwarfs were consolidated and enhanced. CIMMYT's research has continued to contribute to yield gains around the world, even in those regions where semi-dwarfs have long been adopted. It is this second phase that Australia has now reached and is likely to be significant in the future.

Therefore, the analysis is based on the two phases operating together (Figures 3.1 and 3.2). The initial adoption of semi-dwarfs is seen as a permanent upward shift in yields, and as adoption of the semi-dwarfs approaches 100% in each state, these gains are fully realised. Because the germplasm from CIMMYT is the same for each state, the technology for the start of Phase 2 is common to all states. As a result, all states are assumed to have the same starting-year for Phase 2, whether or not Phase 1 has been completed in that state. For the states with rapid adoption of semi-dwarfs, the situation is illustrated in Figure 3.1; Phase 1 is completed before Phase 2 begins. For the states with slower adoption of semi-dwarfs (Figure 3.2), Phase 2 begins before Phase 1 is completed.

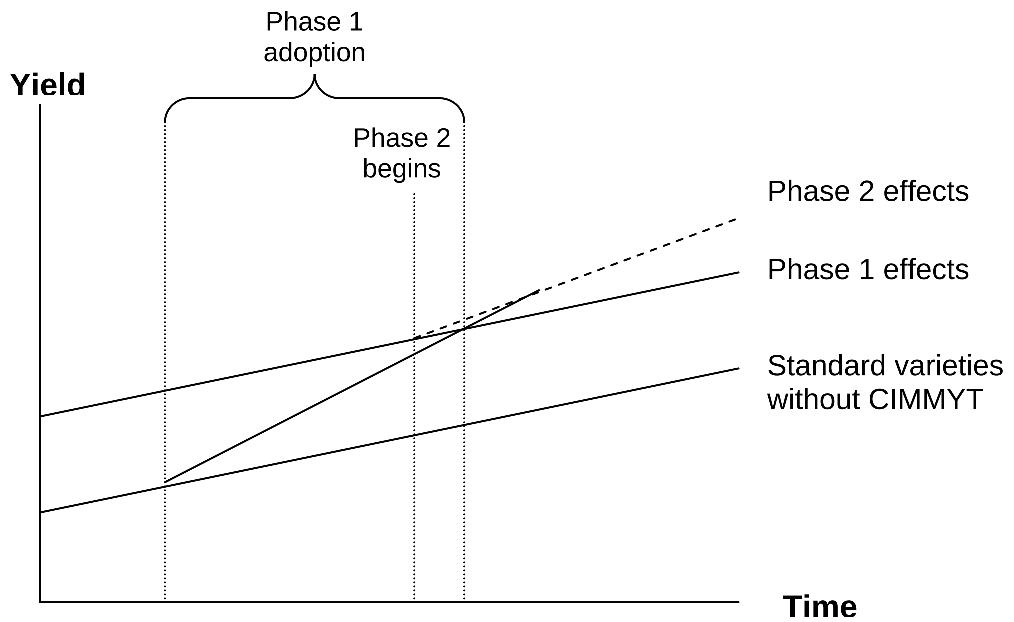
These two phases of impacts in Australia are examined in the following two sections.

Figure 3.1: Effect of CIMMYT Germplasm on Rate of Yield Increase

A: Rapid Adopters in Phase 1



B: Slow Adopters in Phase 1



3.3 Sources of Data

Data have been obtained from a wide range of sources for this analysis. The base data on area, yield and production of Australian wheat, by State, was obtained from the Australian Bureau of Statistics (ABS) and the Australian Bureau of Agricultural and Resource Economics (ABARE). In particular, ABARE (2004a,b) was a valuable source of data. These data are summarised for Australia in Appendix A. Price data were also obtained form ABARE sources.

The data on the share of varieties in the total wheat area were based on several different sources. Up to 1988, the data relate to the percentage area sown to each variety in each state, as collected by the ABS. Since 1989, data have not been available on the *area sown* to different varieties, so it has been necessary to use the available data on the variety shares of the wheat received by the Australian Wheat Board (now AWB Ltd). From 1989 to 1994, data on the share of AWB wheat receivals were obtained. From 1995 onwards, confidential data have been obtained from AWB Ltd on the percentage share of AWB receivals (AWB Ltd, Personal communication) for each state. The latest data available were for 2001 season.

Since deregulation of the domestic wheat market, a large proportion of production has been marketed through channels other than the AWB (Brennan, Martin and Mullen 2004). Given that prior to deregulation in 1989, the Australian Wheat Board controlled the vast majority of wheat marketed in Australia, the data on shares of AWB receivals prior to that time were taken as representative of all production. However, following deregulation, many other marketing channels opened up, and increasing amounts of wheat (particularly specialty types) have been traded through those other channels. Therefore, the extent to which AWB receivals represent all wheat production has decreased in recent years (Brennan, Martin and Mullen 2004), but as no other data are available the AWB data are taken in this analysis to be representative of the entire Australian wheat crop. This is unlikely to affect the results of the analysis of the impacts of CIMMYT on the Australian wheat industry.

The data on the varieties released in Australia and their pedigrees have been mainly derived from information retained at the Australian Winter Cereals Collection (AWCC) (M. Mackay, personal communication). However, in recent years the AWCC has not been able to maintain that data collection, so more recent varietal release data have been based on information available from the Plants Breeders Rights web-site (PBRO 2004).

4. Impact of CIMMYT's Semi-Dwarf Wheats in Australia

4.1 Semi-Dwarf Wheats in Australia

Among varieties of dwarf wheats with very short stature introduced into the United States from Asia in the late 1940s was Norin 10, a Japanese wheat with two dominant genes for dwarfness (*Rht1* and *Rht2*) (Dalrymple 1980). One of the crosses made with those wheats (Norin 10/Brevor) became the foundation of later semi-dwarf[1] varieties developed by CIMMYT in Mexico. Virtually all semi-dwarf wheats used in Australian breeding programs are derived from this cross[2] (Brennan and Fox 1995).

Research has been carried out by CIMMYT in Mexico to develop "high-yielding, widely adapted, semi-dwarf spring-habit bread wheats that were suitable for immediate release *in key developing countries*" (emphasis added) (CIMMYT 1984, p. 11). While they were targeted at developing countries (for example, see Heisey *et al.* 2002), the varieties developed have been grown in many areas apart from the target regions, and spillover benefits to developed countries such as Australia have resulted (Brennan and Fox 1995).

As outlined in Brennan and Fox (1995), the incorporation of the *Rht* genes into commercial varieties has greatly modified the nature of Australian wheats. Earlier Australian wheats had carried the height-reducing genes in the recessive state (*rht1* and *rht2*). Although many varieties were of reduced height, they had low levels of the plant hormone gibberellin, while plants carrying the dominant genes *Rht1* and *Rht2* produce unusually high levels of endogenous gibberellin. Evidence indicates a direct effect of each *Rht* gene on yield *per se*, which can be associated with the high levels of gibberellin (A.T. Pugsley, personal communication). There are other associated beneficial effects, including reduced plant height (which is valuable in controlling crop lodging), increased "harvest index" (the ratio of grain to dry matter in the plant), and synchronous tillering (Syme 1983; A.T. Pugsley, personal communication).

4.2 Release of CIMMYT-Derived Semi-Dwarf Wheat Varieties in Australia

From 1973 to 2003, a total of 216 varieties were released in Australia. Of those, 195 varieties (89%) had at least one CIMMYT line in their pedigree. A list of the CIMMYT-derived varieties is provided in Appendix D. In developing those varieties, the Australian breeders used a range of strategies, including directly releasing a variety developed by CIMMYT, using CIMMYT varieties as a parent in a crossing program, or using CIMMYT-derived lines as parents in the crossing program.

Following Heisey *et al.* (2002), the varieties released were classified as follows:

- CIMMYT cross (made by CIMMYT)
- Australian cross, with at least one CIMMYT parent
- Australian cross, with CIMMYT ancestor in pedigree but no direct CIMMYT parent

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1 For convenience, lines with one *Rht* gene are called "semi-dwarfs".

2 Australia has a prior connection with this material. Brevor was developed from a cross between Brevon and Brevon's parents and Oro. Brevon had two of Farrer's wheats, Federation and Florence, in its pedigree (Dalrymple 1980), and could be considered 50% Australian from its pedigree. Thus, Brevor can be considered 3/8 Australian, and Norin 10/Brevor 3/16 Australian. In addition, the Australian variety Gabo was amongst the varieties used early in the Mexican program, and figured prominently in the pedigree of many lines from Mexico (such as WW80).

- Australian cross, semi-dwarf from source other than CIMMYT
- Australian cross, non-semi dwarf
- Other cross (made by another country's breeders)

The varieties released in Australia since 1973 were classified on this basis, with the results shown in Table 4.1. The initial approach was to release CIMMYT crosses as varieties or to use CIMMYT lines as parents. However, because of the need to adapt the varieties to Australian low-yielding environments, the main strategy has been to use lines with CIMMYT ancestry as parents, and to make the crosses between improved Australian lines/varieties. Therefore the use of CIMMYT in the programs has focussed mainly on the release of varieties with CIMMYT ancestry rather than varieties with direct CIMMYT parentage. Almost two-thirds (137 varieties) of all varieties released since 1973 have been Australian crosses with some CIMMYT ancestry in at least one of the parents, but with no direct CIMMYT parent. Only 3% have been direct CIMMYT introductions, and a further 22% have had at least one CIMMYT parent.

Table 4.1: Origin of Crosses of Australian Varieties Released, 1973-2003
(Numbers of varieties released)

	1973-82	**1983-92**	**1993-02**	**2003**	**Total**
CIMMYT cross	3	2	1	1	**7**
Australian cross: At least one CIMMYT parent	13	11	24	0	**48**
Australian cross: CIMMYT ancestor not parent	13	48	70	6	**137**
Australian cross: Other semi-dwarf	5	3	1	1	**10**
Australian cross: Tall	6	0	2	0	**8**
Other cross/unknown	0	0	5	1	**6**
- Total varieties released	***40***	***64***	***103***	***9***	***216***
% with CIMMYT contribution	*73%*	*95%*	*92%*	*78%*	*89%*
% with direct CIMMYT contribution	*40%*	*20%*	*24%*	*11%*	*25%*

The figures in Table 4.1 reveal a trend away from direct use of CIMMYT lines for release or for use as parents, and an increasing trend towards the release of varieties with CIMMYT in earlier stages of the pedigree. This reflects the value of introducing CIMMYT characteristics to already-adapted Australian varieties rather than introducing new varieties that are less well adapted to the Australian production environments. In addition, there has been a shift away from "other semi-dwarf" varieties and tall varieties, but a recent increase in the number of varieties introduced from other countries.

4.3 Yield Advantages of CIMMYT Semi-Dwarfs in Australia

Semi-dwarf wheats have been found to be high yielding in a wide range of production environments. The yield advantage of CIMMYT's semi-dwarf wheats varies between environments and farming systems. The appropriate yield comparison is not between the semi-dwarfs and the earlier non-CIMMYT wheats, but between semi-dwarfs and the varieties that would have been grown if the semi-dwarfs had not been available.

To assess the yield advantages of CIMMYT semi-dwarf wheats in Australia, Brennan (1986) examined data from the Interstate Wheat Variety Trials in the early years of the testing of semi-dwarfs (1975 to 1982) to compare the yield of the most advanced lines of semi-dwarfs and non-semi-dwarf lines[3]. Thus the overall yield advantage of CIMMYT semi-dwarfs over the other leading lines was estimated for each State (Table 4.2). The advantage of CIMMYT's semi-dwarfs over non-CIMMYT varieties was 7.1%. There was wide variation among States: the advantage was 9.0% or more for New South Wales and Queensland, but only 2.7% for Western Australia.

Table 4.2: Yield Advantage of CIMMYT-Derived Semi-Dwarfs over Non-CIMMYT Lines

State	% advantage
New South Wales	9.0
Victoria	8.1
Queensland	9.2
South Australia	6.1
Western Australia	2.7
Australia	**7.1**

Source: Calculations based on yield comparisons from Interstate Wheat Variety Trials, as described in Brennan and Fox (1995, Appendix C).

These yield advantages were determined on the basis of variety trials where inputs and management were equal. Thus, they measure the extent of the genetic gain from semi-dwarfs, and not the impact on yields when agronomic inputs (such as fertilisers or irrigation) were also increased or where management was improved. There would have been other yield improvements occurring during the period of adoption of the semi-dwarfs, but the gains measured as Phase 1 gains in this study relate specifically to the gains attributable to the varieties themselves.

4.4 Adoption of Semi-Dwarf Varieties

The adoption of semi-dwarf wheats in Australia from the release of the first varieties in 1973 was very rapid (Table 4.3). By 1976, over 1.5 million hectares were sown to semi-dwarfs, over 1.2 million ha of which were CIMMYT-derived semi-dwarfs. By 1990, the area of semi-dwarfs had reached over 8.0 million ha, and in 2001 was over 12.3 million ha.

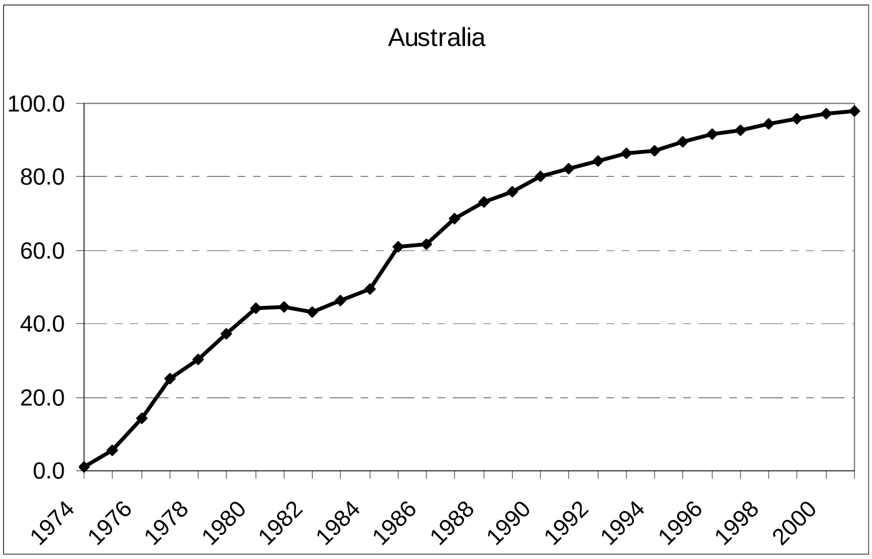
In percentage terms, the area of CIMMYT-derived semi-dwarfs increased to 44% of the total Australian wheat area by 1980, and 80% by 1990. In 2001, they covered 98% of the total Australian wheat area (Figure 4.1).

[3] In more recent years, the Interstate Wheat Variety Trials have been dominated by semi-dwarfs, so that such comparisons could not be made.

Table 4.3: Area Sown to Australian Varieties, by Origin of Cross

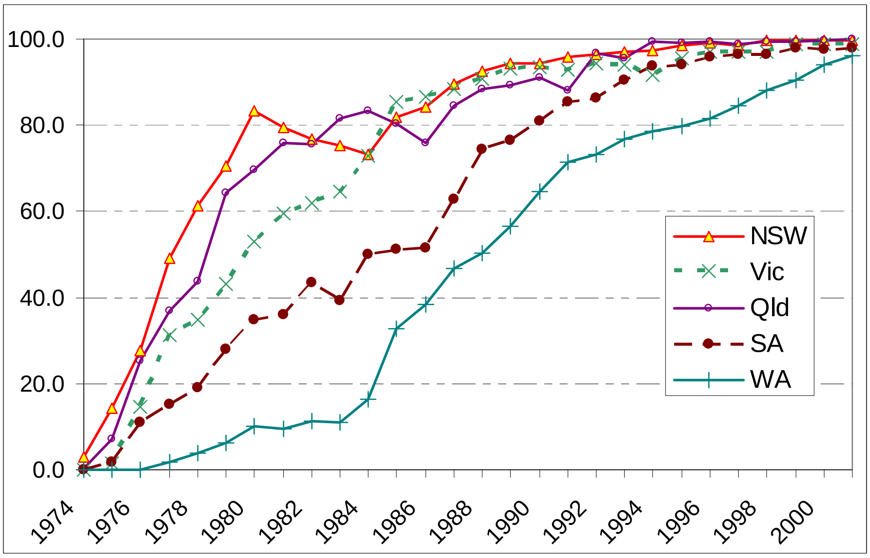
Year	CIMMYT cross	At least one CIMMYT parent	CIMMYT ancestor	Total CIMMYT-derived	Other semi-dwarf	Total semi-dwarf	Tall	Other cross
1974	2	79	0	81	28	109	8,026	0
1975	40	431	0	471	102	573	7,674	0
1976	156	1,106	3	1,265	275	1,540	7,183	0
1977	226	2,271	9	2,506	385	2,891	6,928	0
1978	241	2,754	119	3,114	396	3,510	6,561	0
1979	261	3,354	546	4,161	506	4,668	6,267	0
1980	300	4,016	684	5,000	549	5,549	5,207	0
1981	457	3,442	1,416	5,315	787	6,102	5,391	0
1982	617	2,393	1,974	4,984	770	5,754	5,430	0
1983	963	2,040	2,997	5,999	984	6,983	5,669	0
1984	1,546	1,545	2,882	5,973	1,112	7,084	4,702	0
1985	2,024	2,003	3,134	7,161	1,229	8,391	3,073	0
1986	1,835	2,646	2,472	6,953	1,462	8,415	2,555	0
1987	1,096	2,448	2,690	6,234	1,069	7,303	1,673	0
1988	1,009	2,170	3,337	6,516	944	7,460	1,319	0
1989	1,077	2,057	3,715	6,849	790	7,638	1,211	0
1990	1,278	2,019	4,080	7,377	664	8,041	976	0
1991	759	1,180	3,965	5,904	538	6,443	704	0
1992	1,164	1,740	4,765	7,669	548	8,217	846	0
1993	908	1,655	4,676	7,239	426	7,665	675	0
1994	802	1,485	4,691	6,978	380	7,358	635	0
1995	895	1,788	6,035	8,719	342	9,062	650	1
1996	1,001	2,006	7,392	10,398	358	10,756	564	0
1997	672	1,861	7,125	9,658	315	9,973	429	2
1998	800	1,829	8,314	10,943	275	11,218	338	6
1999	1,071	1,737	9,004	11,812	229	12,041	263	1
2000	1,108	1,730	9,243	12,081	128	12,208	184	1
2001	964	1,592	9,710	12,266	89	12,355	130	0

Figure 4.1: Adoption of CIMMYT-Derived Varieties, Australia



The adoption of semi-dwarf varieties by State is shown Figure 4.2. Detailed State adoption data for CIMMYT-derived varieties are provided in Appendix E. The rapid adoption in NSW and Queensland is evident, as is the initial slow rate of uptake in Western Australia. By 1993, all states except Western Australia had more than 90% of the area planted to CIMMYT-derived semi-dwarfs. Given the recent increases in Western Australia, CIMMYT-derived varieties have now reached over 96% of the wheat area in all States.

Figure 4.2: Adoption of CIMMYT-Derived Varieties, Australian States

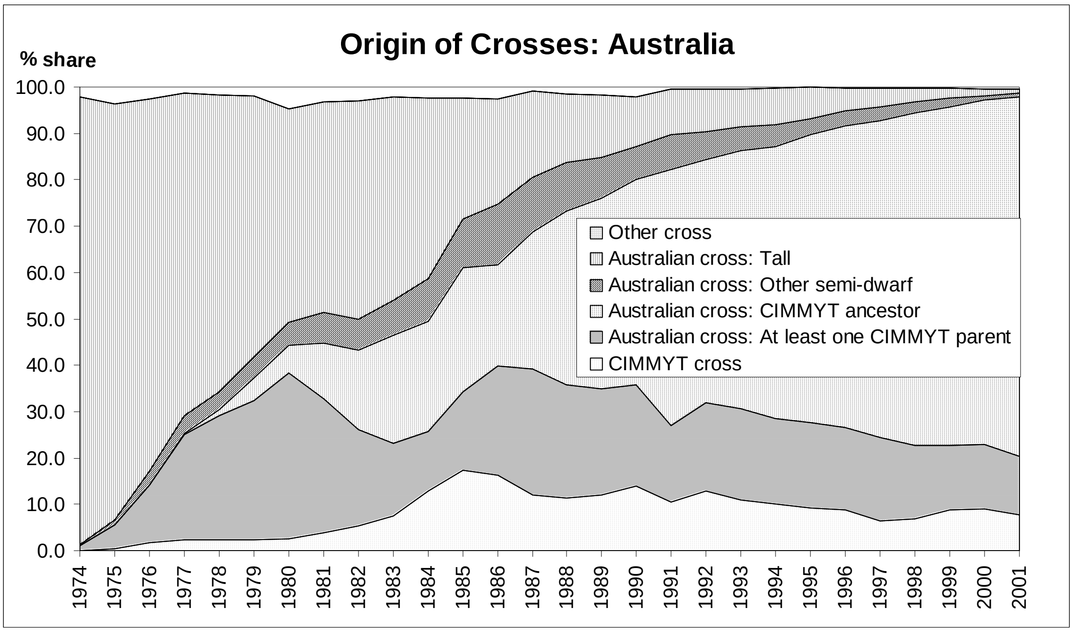


Initially, there was rapid adoption of Condor and Egret, the first two CIMMYT-derived semi-dwarf varieties released. Songlen, the first premium-quality semi-dwarf wheat, was adopted rapidly after its release in 1975. Later releases have tended to be adopted more slowly, with the exception of Banks, Hartog, Vulcan and Reeves (Brennan and Fox 1995). Spear was the leading variety (in terms of area sown) in Australia in the early 1990s. The data on the share of individual varieties is no longer collected by the Australian Bureau of Statistics, and since 1993 has had to be estimated from confidential data on variety receivals provided by AWB Ltd. Thus it is not possible to assess the individual variety shares since that time.

4.5 Adoption of Semi-Dwarfs, by Origin of Cross

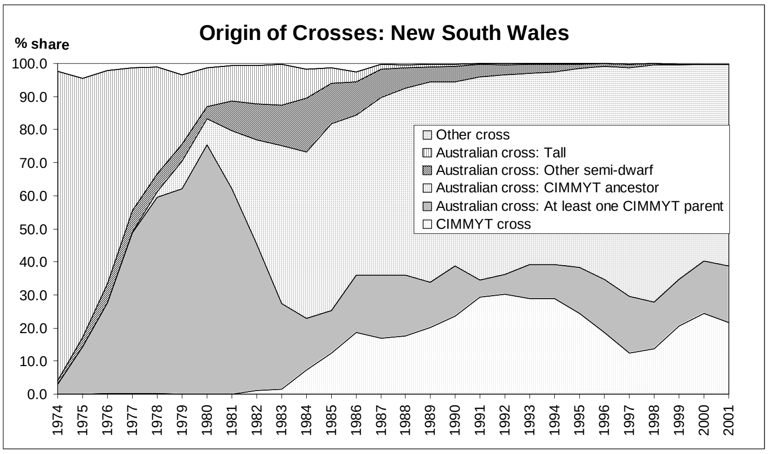
At the Australian level, the area sown to direct CIMMYT crosses has always been less than 20% of the total area, and has declined to 10% in recent years (Figure 4.3). While Australian crosses using at least one CIMMYT parent formed the bulk of the initial semi-dwarf impact, that contribution has declined from its peak in the late 1970s to only around 10% of the total area. While there has been some use over the period of non-CIMMYT semi-dwarfs, the overwhelming proportion of the area has been sown to varieties based on Australian crosses using parents with CIMMYT ancestry.

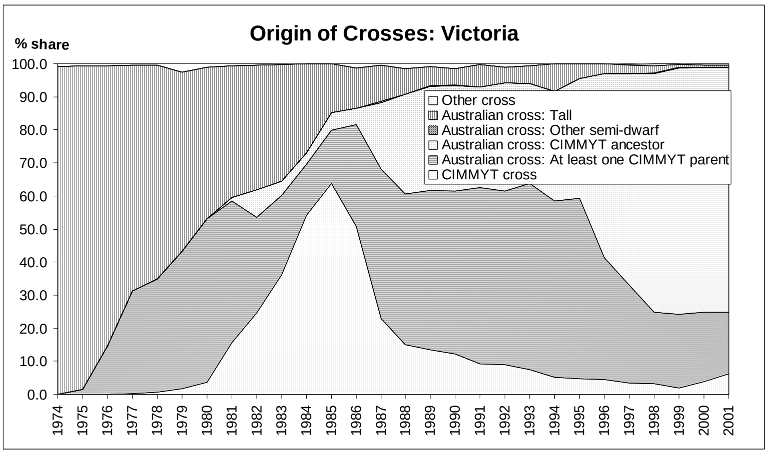
Figure 4.3: Adoption of Semi-Dwarfs, by Origin of Cross, Australia



The adoption of varieties differs between states in the origins of the crosses (Figure 4.4). While NSW has a pattern similar to that at the national level, Victoria has shown a strong reliance on direct CIMMYT introductions and crosses with at least one CIMMYT parent. Queensland has also shown strong use of direct CIMMYT varieties. On the other hand, South Australia and Western Australia have grown few direct CIMMYT introductions or varieties with a direct CIMMYT parent. Those states have relied most strongly on Australian crosses using parents that themselves were not direct CIMMYT introductions. Thus, Figure 4.4 indicates the greater extent to which these two states have had to adapt the CIMMYT material to their lower-rainfall environments before it has had an impact on farms. It is also notable that Victoria has had the lowest reliance on non-CIMMYT semi-dwarfs, while the other states have all used them to some extent.

Figure 4.4: Adoption of Semi-Dwarfs, by Origin of Cross, by State





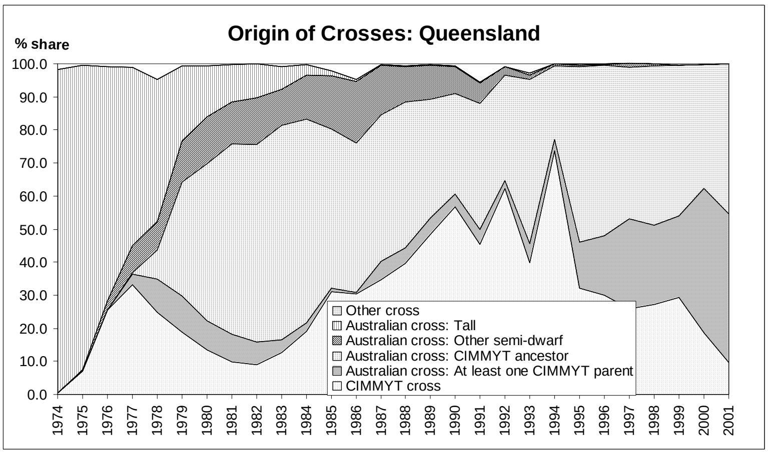
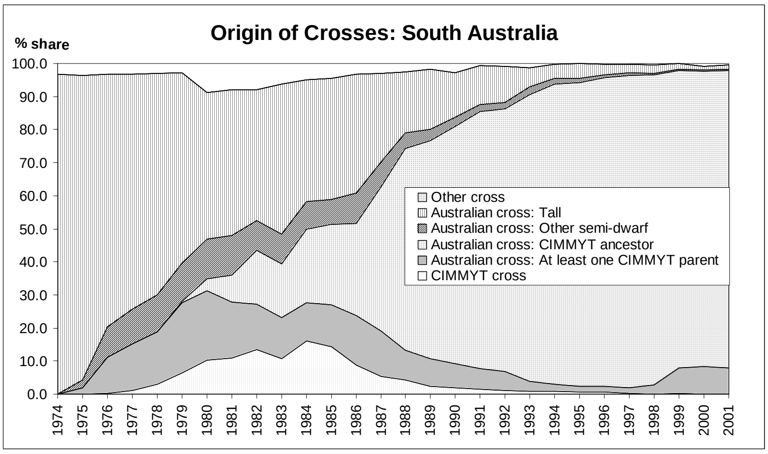
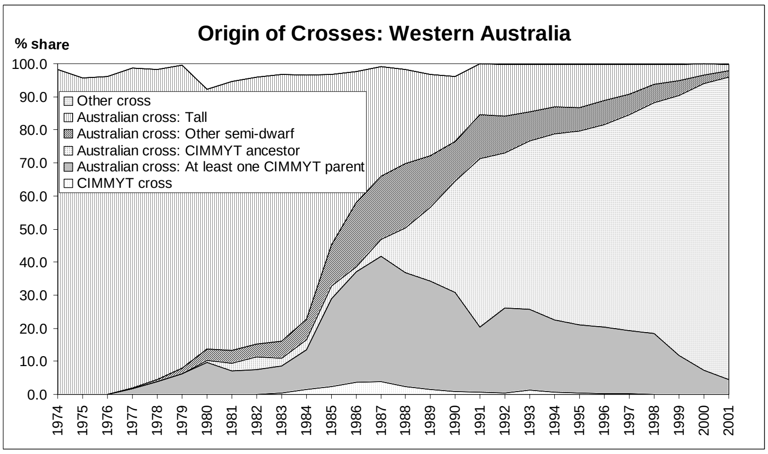


Figure 4.4: Adoption of Semi-Dwarfs by, Origin of Cross, by State (continued)





5. Yield Increases from CIMMYT's Semi-Dwarfs

5.1 Index of Varietal Improvement

Following Brennan and Fox (1995), the value of the yield increases associated with CIMMYT's semi-dwarfs can be calculated using a simplified Index of Varietal Improvement (Silvey 1981, Brennan 1984). This index combines the yields obtained in trials with data on the varieties being grown by farmers, to provide a measure of the genetic contribution that new varieties make to increasing wheat yields.

A modified index of varietal improvement is calculated as follows:

$$I_{it} = 100 + (V_i\, p_{it})/100,$$

where I_{it} is the index in State i in year t; V_i is the yield percentage advantage of CIMMYT-derived varieties in State i; and p_{it} is the proportion of the area sown to CIMMYT-derived varieties in State i in year t. Note that V_i remains constant over time in this analysis. Thus in New South Wales, with a yield advantage of 9.0% (V_i = 9.0) and 70.4% sown to CIMMYT-derived varieties in 1979 (P_{it} = 0.704), the index for 1979 is 106.34. The index has a base value of 100 for years when these varieties were not grown in the State.

5.2 Yield Increases from CIMMYT-Derived Semi-Dwarfs

These indices have been calculated for each State for each year from 1974 to 1993. The increase each year is shown in Appendix Tables F.1 to F.5, and summarised in Table 5.1 The index increases steadily for each State with the increasing adoption of these varieties. The index increased between 1973 and 2001 by 9.0% for New South Wales, 8.0% for Victoria, 9.2% for Queensland, 6.0% for South Australia and 2.6% for Western Australia. The overall increase over this period for Australia was 6.1%.

As described above in Section 4.3, these gains relate to the varietal component of the yield gains from semi-dwarfs. Other gains associated with improved management and higher input levels would also have occurred during the period of adoption of the semi-dwarfs.

5.3 Partitioning of Contributions to Impact of Semi-Dwarfs

5.3.1 Classification of varieties released

The benefits of the CIMMYT-derived semi-dwarf varieties cannot all be attributed to CIMMYT, since many of these varieties have large inputs of germplasm and breeding, evaluation and testing resources from Australian programs. Following Brennan and Fox (1995), we examine the relative contribution of the CIMMYT and Australian programs to these gains. The simplified partitioning of CIMMYT and non-CIMMYT benefits uses the pedigree of each variety and allocates the benefits for each variety according to the origins of its parents. Thus, a variety such as Aroona, which is a direct cross between WW15 and the Australian variety Raven, has 50% of its benefit attributed to CIMMYT. A variety such as Condor, the product of a cross between two CIMMYT lines, is allocated 100% to CIMMYT, even though the crossing, selection, evaluation and testing were all carried out in Australia.

Table 5.1: Increase in Yields from CIMMYT-Derived Semi-Dwarfs, 1973-2001
(% increase from 1973)

Year	NSW	Vic	Qld	SA	WA	Australia
1973	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.3	0.0	0.0	0.0	0.0	0.1
1975	1.3	0.1	0.6	0.1	0.0	0.5
1976	2.5	1.2	2.3	0.7	0.0	1.5
1977	4.4	2.5	3.4	0.9	0.0	2.5
1978	5.5	2.8	4.0	1.2	0.1	3.0
1979	6.3	3.5	5.9	1.7	0.2	3.6
1980	7.5	4.3	6.4	2.1	0.3	3.6
1981	7.2	4.8	7.0	2.2	0.3	4.2
1982	6.9	5.0	6.9	2.6	0.3	2.3
1983	6.8	5.2	7.5	2.4	0.3	4.7
1984	6.6	5.9	7.7	3.1	0.4	4.0
1985	7.4	6.9	7.4	3.1	0.9	5.0
1986	7.6	7.0	7.0	3.1	1.0	4.5
1987	8.1	7.2	7.8	3.8	1.3	5.1
1988	8.3	7.4	8.1	4.5	1.4	5.1
1989	8.5	7.5	8.2	4.7	1.5	5.2
1990	8.5	7.6	8.4	4.9	1.7	5.4
1991	8.6	7.5	8.1	5.2	1.9	4.7
1992	8.7	7.6	8.9	5.3	2.0	5.3
1993	8.7	7.6	8.8	5.5	2.1	5.4
1994	8.8	7.4	9.1	5.7	2.1	4.0
1995	8.9	7.7	9.1	5.7	2.2	5.4
1996	8.9	7.9	9.2	5.8	2.2	6.2
1997	8.9	7.9	9.1	5.9	2.3	5.7
1998	9.0	7.9	9.1	5.9	2.4	5.9
1999	9.0	8.0	9.2	6.0	2.4	6.1
2000	9.0	8.0	9.2	6.0	2.5	6.4
2001	9.0	8.0	9.2	6.0	2.6	6.1

A distinction has been made between the “first generation” and full pedigrees. In the “first generation”, the origin of the direct parent lines is used. In the full pedigree, rather than the origin of the parent lines, the contribution of CIMMYT to those lines is used. In the first generation, a variety such as Osprey (a cross between Condor and WW33B) used two Australian lines as parents and is considered wholly Australian. In the full pedigree, the fact that Condor and WW33B were 100% CIMMYT lines denotes Osprey as 100% CIMMYT. In this analysis, only the first generation parentage is taken into account in partitioning the contribution made to the CIMMYT material by Australian varieties, although the full pedigree is used to determine whether or not a variety is “CIMMYT-derived”.

Such an attribution is arbitrary, and can be no more than indicative. It is likely to understate the contribution of Australian breeders to the development of many varieties, given the extent of testing and evaluation involved, and overstate their contribution to others where the entire genetic background comes from CIMMYT. Nevertheless, calculations have been carried out on this basis to provide an indication of the contribution of CIMMYT to the impact of CIMMYT-derived varieties in Australia.

The percentage contribution of CIMMYT to each variety's pedigree, calculated in the first generation, ranges from 0% in varieties such as Cook, Banks and Osprey to 100% for varieties such as Condor, Oxley, Millewa and Hartog. In the full pedigree, the contribution of CIMMYT is equal to or greater than that in the first generation. The contribution is greater than zero in every variety in the full pedigree with some CIMMYT material in their background.

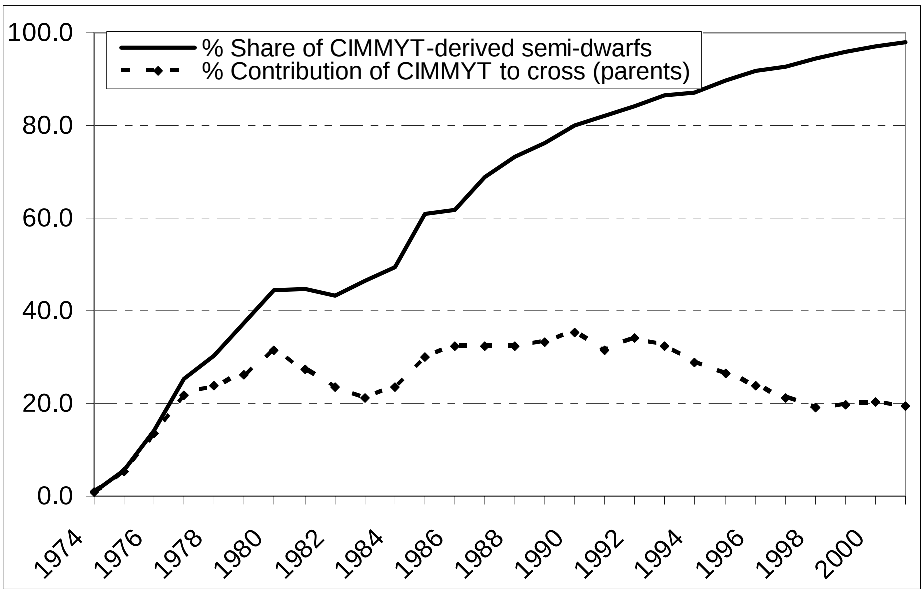
5.3.2 CIMMYT's contribution to parents

The contribution of CIMMYT to the impact of CIMMYT-derived varieties, based on parents, was carried out for each year since 1973. The measure of the contribution of CIMMYT in the first generation, W_t, is calculated as follows:

$$W_t = \sum_i (x_i\, p_{it}),$$

where x_i is the proportional direct contribution of CIMMYT to the pedigree of variety i, and p_{it} is the percentage of the area sown to variety i in year t. Compared with the increasing importance of CIMMYT-derived varieties in Australia shown in Figure 4.1, the actual CIMMYT contribution in the first generation at the national level peaked at 35% in 1990 and has declined since that time to approximately 20% (see dotted curve in Figure 5.1).

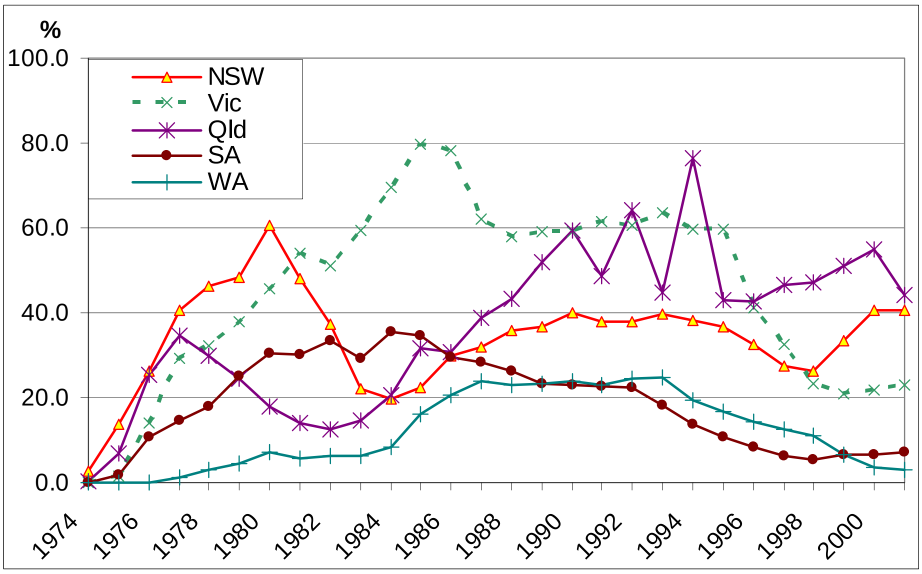
Figure 5.1: Contribution of CIMMYT to Gains from CIMMYT-Derived Varieties[a]



a: Based on origin of parents used in cross.

The overall pattern of CIMMYT contribution varies considerably in each state (Figure 5.2). NSW and Victoria both reached peaks above 60% in the 1980s, and have declined since. Queensland reached its peak of almost 80% direct CIMMYT contribution in the 1990s. In contrast, both SA and WA have had lesser reliance on direct CIMMYT inputs, with peaks of no more than 35% and levels of less than 10% direct CIMMYT contribution in recent years.

Figure 5.2: Contribution of CIMMYT to Gains from Semi-Dwarfs, by State[a]



a: Based on origin of parents used in cross.

Thus the yield increases identified in Table 5.1 and Appendix Tables F.1 to F.5 are those from the semi-dwarf wheats. When adjusted by the CIMMYT contributions illustrated in Figure 5.2, the resultant yield increases that are attributable directly to CIMMYT are shown in Table 5.2. For NSW, CIMMYT's contribution increased to 3.6% in 2001, 4.1% in Queensland, 1.8% in Victoria, 0.4% in South Australia and 0.1% in Western Australia. These, then are the yield increases due directly to CIMMYT, and are used in the analysis of CIMMYT's impact.

Table 5.2: Yield Increases from Semi-Dwarfs Attributable to CIMMYT
(% increases due to CIMMYT)

Year	NSW	Vic	Qld	SA	WA	Australia
1973	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.2	0.0	0.0	0.0	0.0	0.1
1975	1.2	0.1	0.6	0.1	0.0	0.4
1976	2.4	1.1	2.3	0.7	0.0	1.0
1977	3.7	2.4	3.2	0.9	0.0	1.5
1978	4.2	2.6	2.8	1.1	0.1	1.7
1979	4.4	3.1	2.3	1.5	0.1	1.9
1980	5.5	3.7	1.7	1.8	0.2	2.2
1981	4.3	4.4	1.3	1.8	0.2	2.0
1982	3.4	4.1	1.1	2.0	0.2	1.7
1983	2.0	4.8	1.3	1.8	0.2	1.5
1984	1.8	5.6	1.9	2.2	0.2	1.7
1985	2.0	6.5	2.9	2.1	0.4	2.1
1986	2.7	6.3	2.8	1.8	0.6	2.3
1987	2.9	5.0	3.6	1.7	0.6	2.3
1988	3.2	4.7	4.0	1.6	0.6	2.3
1989	3.3	4.8	4.8	1.4	0.6	2.4
1990	3.6	4.8	5.5	1.4	0.6	2.5
1991	3.4	5.0	4.5	1.4	0.6	2.2
1992	3.4	4.9	5.9	1.4	0.7	2.4
1993	3.6	5.2	4.1	1.1	0.7	2.3
1994	3.4	4.8	7.0	0.8	0.5	2.1
1995	3.3	4.8	4.0	0.6	0.5	1.9
1996	2.9	3.3	3.9	0.5	0.4	1.7
1997	2.5	2.6	4.3	0.4	0.4	1.5
1998	2.3	1.9	4.4	0.3	0.3	1.4
1999	3.0	1.7	4.7	0.4	0.2	1.4
2000	3.6	1.8	5.1	0.4	0.1	1.4
2001	3.5	1.8	4.1	0.4	0.1	1.3

6. Post-Semi-Dwarf Impacts of CIMMYT on Australia

6.1 Period to Full Adoption of Semi-Dwarfs

The first phase varies in timing for each of the states. The first semi-dwarfs were released in 1973, and began production in 1974 in NSW, and Queensland. Other states were slower to start adoption, with Victoria and South Australia beginning in 1975, and Western Australia beginning in 1977 (see previous section). Once adoption started, it proceeded rapidly in the eastern states, and more steadily in South Australia and Western Australia. It took Victoria thirteen years (until 1988) for 90% of the area to be sown to CIMMYT-derived wheat varieties[4], while in NSW it took 14 years (also 1988) (Table 6.1). In Queensland, that level of adoption was reached in 1990, but it was not until 1993 (South Australia) and 1999 (Western Australia) before CIMMYT-derived semi-dwarfs in the other states reached 90% of the area sown.

Table 6.1: Timing of Semi-Dwarf Improvements

	NSW	Vic	Qld	SA	WA
Start of adoption of CIMMYT semi-dwarfs	1974	1975	1974	1975	1977
Years to 90% adoption of semi-dwarfs	14	13	16	18	22
Year reached 90% adoption of semi-dwarfs	1988	1988	1990	1993	1999

6.2 Post-Semi-Dwarf Impacts

The second phase occurs where the original semi-dwarfs were being replaced by improved semi-dwarfs with higher productivity. Because the germplasm from CIMMYT was the same for each state, the technology available for Phase 2 is common to all states. As a result, all states are assumed to have the same starting year for Phase 2, whether or not Phase 1 has been completed in that state. For example, data on adoption of the individual varieties (Brennan and Fox 1995, Table 3) indicates that by the early 1980s the key original varieties Condor, Egret and Songlen were being replaced by Banks, Millewa, Aroona and Hartog, with Spear, Vulcan and Janz following shortly afterwards. Given that this process took some years to be fully effected, and that the first states (Victoria and NSW) reached 90% adoption of CIMMYT-derived varieties in 1998, Phase 2 is assumed to begin in 1988 in all states.

The CIMMYT technologies involved in the post-semi-dwarf period (Phase 2) have generally related to improved diseases resistance, particularly rust resistance, improved tolerance to abiotic stresses such as soil acidity, and other more general improvements in yield potential since the development of the initial semi-dwarfs. Globally, improvements in Phase 2 have also been related to the agronomic benefits of the rye gene introduced in the 1B/1R translocation, in the Veery type wheats. These wheats have been little used in Australia because of their associated “sticky dough” problems.

Future CIMMYT technologies identified by breeders in the survey (section 3.1 above) include the further improvement of rust resistance, particularly the slow-rusting genes, the synthetic wheats derived from *Triticum tauschii*, improved wheat quality, and genetic markers for a

[4] For this analysis, 90% adoption was considered as a proxy for “full” adoption, given the difficulty of complete adoption on all the area sown.

range of characteristics. The continuing use of these developments within the Australian wheat breeding programs is likely to see the continuation of Phase 2 increases in yields in Australia in the future.

After 1988, the use of CIMMYT materials also increased the rate of improvement, so that yield increased further. Thus, by the time that states such as South Australia reached "full" adoption of the semi-dwarfs, it had not merely achieved the yield improvement found with semi-dwarfs (Table 4.2), but had obtained higher yield increases available in the improved varieties based on the higher-yielding materials coming from CIMMYT from the 1980s onwards. The extent of those further increases from Phase 2 is more difficult to determine from the available data.

From 1983 to 2001, Australian wheat yields increased by an average of 1.86% per year. Brennan and Bialowas (2001) found that approximately 50% of yield increases in NSW could be attributable to varieties, and 50% to other farm management factors, so we have taken the variety contribution to that increase as 50%, or 0.93% per year. This is the varietal increase that has taken place nationally in the period in which CIMMYT's Phase 2 has been operating. CIMMYT's share of those increases can be determined by its contribution to the varieties (see Section 5.3 above). Thus, if CIMMYT contributed 30% to the varieties in one state in a particular year, it is taken as contributing 30% of the 0.93% gain in yield in that year, on top of the gains from the Phase 1 increase in yield level from the initial adoption of semi-dwarfs.

Those annual estimates of the yield increases attributable to Phase 2 gains from CIMMYT in each state from 1988 are shown in Table 6.2. For those states where the CIMMYT's share in the CIMMYT-derived wheats was greatest, the post-semi-dwarf impacts were also greatest. By 2001, Queensland and Victoria had both received yield gains from CIMMYT in excess of 5%, with NSW at 4.4%. South Australia and Western Australia had both received 2.0% or less by 2001 through post-semi-dwarf yield gains. On average, the yield gains were 3.2% for Australia by 2001, on top of the gains from the semi-dwarfs.

Table 6.2: Yield Increases Attributable to CIMMYT from Post-Semi-Dwarfs Gains
(% increases due to CIMMYT)

Year	NSW	Vic	Qld	SA	WA	Australia
1988	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.3	0.5	0.5	0.2	0.2	0.3
1990	0.7	1.1	1.0	0.4	0.4	0.6
1991	1.1	1.7	1.5	0.6	0.7	0.9
1992	1.4	2.2	2.1	0.8	0.9	1.2
1993	1.8	2.8	2.5	1.0	1.1	1.5
1994	2.2	3.4	3.2	1.1	1.3	1.8
1995	2.5	4.0	3.7	1.2	1.5	2.1
1996	2.8	4.4	4.1	1.3	1.6	2.3
1997	3.1	4.7	4.5	1.4	1.7	2.5
1998	3.3	4.9	5.0	1.4	1.8	2.7
1999	3.6	5.1	5.5	1.5	1.9	2.9
2000	4.0	5.3	6.0	1.6	1.9	3.1
2001	4.4	5.6	6.4	1.6	2.0	3.2

When these Phase 2 gains are added to the semi-dwarf (Phase 1) gains from CIMMYT shown in Table 5.2, the overall yield impact of CIMMYT can be determined (Table 6.3). The gains are greatest in Queensland, and lowest in South Australia. Overall, the contribution of CIMMYT to yield gains in Australia, including both Phase 1 and Phase 2 increases, was 4.6% in 2001.

Table 6.3: Total Yield Increases Attributable to CIMMYT from Phases 1 and 2
(% increases due to CIMMYT)

Year	NSW	Vic	Qld	SA	WA	Australia
1973	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.2	0.0	0.0	0.0	0.0	0.1
1975	1.2	0.1	0.6	0.1	0.0	0.4
1976	2.4	1.1	2.3	0.7	0.0	1.0
1977	3.7	2.4	3.2	0.9	0.0	1.5
1978	4.2	2.6	2.8	1.1	0.1	1.7
1979	4.4	3.1	2.3	1.5	0.1	1.9
1980	5.5	3.7	1.7	1.8	0.2	2.2
1981	4.3	4.4	1.3	1.8	0.2	2.0
1982	3.4	4.1	1.1	2.0	0.2	1.7
1983	2.0	4.8	1.3	1.8	0.2	1.5
1984	1.8	5.6	1.9	2.2	0.2	1.7
1985	2.0	6.5	2.9	2.1	0.4	2.1
1986	2.7	6.3	2.8	1.8	0.6	2.3
1987	2.9	5.0	3.6	1.7	0.6	2.3
1988	3.2	4.7	4.0	1.6	0.6	2.3
1989	3.6	5.3	5.3	1.6	0.8	2.7
1990	4.3	5.9	6.5	1.8	1.1	3.1
1991	4.5	6.7	6.0	2.0	1.3	3.2
1992	4.8	7.1	8.0	2.2	1.5	3.7
1993	5.4	8.0	6.6	2.1	1.8	3.8
1994	5.6	8.2	10.3	2.0	1.8	3.9
1995	5.8	8.8	7.6	1.9	1.9	4.0
1996	5.7	7.7	8.0	1.8	2.0	4.0
1997	5.5	7.3	8.8	1.8	2.1	4.0
1998	5.7	6.8	9.3	1.8	2.1	4.1
1999	6.6	6.8	10.2	1.9	2.1	4.3
2000	7.6	7.1	11.1	2.0	2.0	4.5
2001	7.9	7.4	10.5	2.0	2.0	4.6

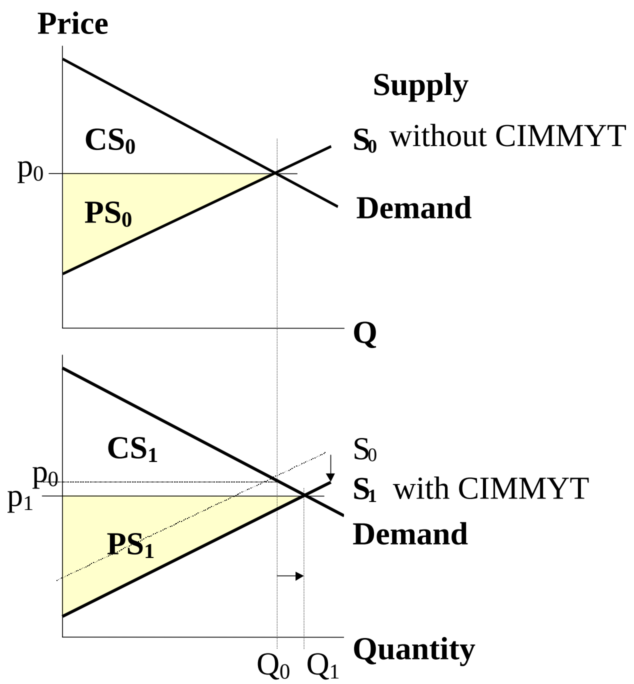
7. Economic Analysis of Impacts

7.1 Economic Analysis of Productivity Increases

A genetic improvement in yield means an increase in productivity, in the sense that there is higher output for each level of input. In economic terms, the yield-increasing effects of a new variety result in a shift of the supply curve (Lindner and Jarrett 1978; Norton and Davis 1981; Edwards and Freebairn 1984). As in Brennan and Bantilan (1999), the increase in productivity is defined as a parallel vertical (downward) shift in the supply curve through a lowering of the production costs per tonne (Edwards and Freebairn 1984). Assuming that new varieties do not interact with changes in other inputs (see Brennan and Fox 1995), the economic benefits can be estimated directly from these cost reductions.

The benefits that are measured are changes in the "Producer surplus" and the "Consumer surplus", which are measures of the economic welfare of each of the two industry groups. The analysis aims to measure the difference between the producer and consumer surpluses with the CIMMYT contribution and the surpluses that would apply if there were no impact from CIMMYT. This is illustrated in Figure 7.1, where the situation *without* CIMMYT is shown with producer surplus = PS_0, and consumer surplus = CS_0, and the situation *with* CIMMYT is shown with producer surplus = PS_1, and consumer surplus = CS_1. The change in producer surplus is the difference between PS_1 and PS_0, while the change in consumer surplus is the difference between CS_1 and CS_0.

Figure 7.1: Changes in Producer and Consumer Surpluses



Change in producer surplus = $\mathbf{PS_1 - PS_0}$

Change in consumer surplus = $\mathbf{CS_1 - CS_0}$

7.2 Framework for Analysis of Spillover Impacts

The benefits of agricultural research are directly affected by the productivity changes that occur. In addition, the net benefits of agricultural research in a tradeable commodity in a particular region are influenced by the spillover of the effects of that research to other producing regions with which the target region competes for a share of the world market. Edwards and Freebairn (1984) showed that the greater the extent to which the research innovations are adopted in other competing regions, the lower the producer benefits for the target region. Davis *et al.* (1987) further developed the incorporation of spillover effects into an analytical framework for the evaluation of research.

The shifts in world supply attributed to research emanating from CIMMYT are likely to have an impact on the world price for the relevant crops (Evenson and Rosegrant 2003). It is likely, therefore, that the increased supply resulting from the increased productivity in developing countries obtained through CIMMYT material has affected the prices received for Australia's wheat production, so that the net gains to Australian producers indicated by this analysis are lower than if the assumption of perfect elasticity (as in Brennan and Fox 1995) had been maintained. As a result, these price effects are likely to reduce the benefits for Australian producers of those crops, while at the same time producing benefits for Australian consumers (Brennan and Bantilan 1999; Brennan *et al.* 2003).

While a large proportion of production in some of the crops analysed is not traded, the simplifying assumption of a single world price applying to all production is a practical means of allowing us to assess the impacts on Australia, which is the main objective of the study.

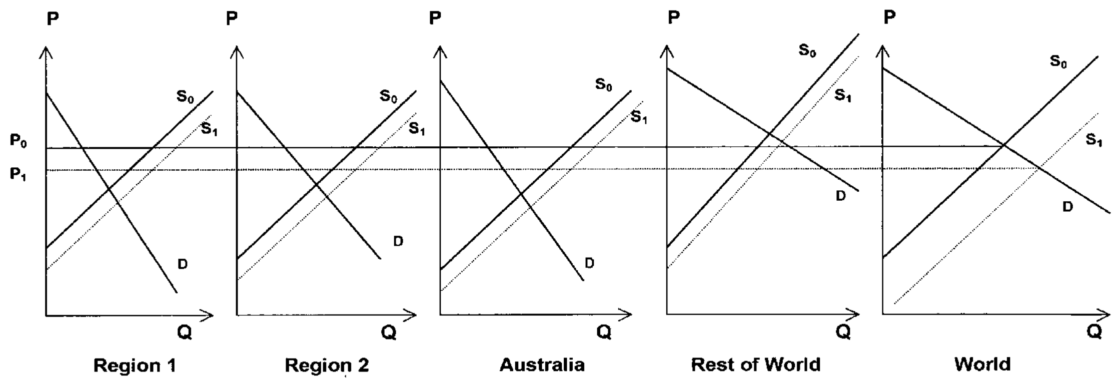
The framework used in this analysis is based on Edwards and Freebairn (1984). The world market for wheat is disaggregated into two major component regions, namely Australia and the Rest of the World (ROW). Australia is further sub-divided into five wheat-producing states.

The following assumptions are made for the analysis of the impact of spillovers in Australia:

(a) Elasticities of demand and supply are the same throughout Australia;
(b) All countries other than Australia are grouped into the Rest of the World;
(c) The total production costs per tonne equal the equilibrium price (see Brennan *et al.* 2002);
(d) All supply and demand curves are linear, and
(e) All shifts in supply are defined as parallel vertical shifts (i.e., cost reductions).

The framework used is illustrated in Figure 7.2, where P is price and Q is the quantity supplied or demanded. CIMMYT research leads to a shift in supply curves for each region from S_0 to S_1. Direct shifts are obtained in the Rest of the World (the "target" region for that research), with spillovers impacting on Australia. For simplicity in this analysis, the impacts on developed countries other than Australia are incorporated with the Rest of the World.

Figure 7.2: Spillover Framework Used in Analysis



The shifts in supply in the Rest of the World and regions within Australia lead to a shift in the aggregate supply curve for the World. The shift in the world supply leads to a price fall from P_0 to P_1, given that there has been no change in the demand curve. The lower price feeds back to each region, so that each region faces a changed equilibrium price as well as the shift in the supply curve. The resultant welfare gains are measured as changes in producer and consumer surpluses for each of the regions (as illustrated in Figure 7.1). Regions that do not obtain a supply shift still face the price effect of the supply shifts in the other regions, and can have a change in producer or consumer surplus.

One of the consequences of a static analysis such as this one is that a number of simplifications are made. One such simplification is the lack of dynamic aspects such as second-round impacts on demand or supply of other commodities as a result of an increase in yields, and therefore income. As in Brennan *et al.* (2002), a further simplification is that demand is assumed to remain static. Consequently, an increase in productivity leading to a downward shift of the supply curve means that the price falls. However, it is likely that in the time period used in this analysis, increases in world population and income are likely to lead to an upward or outward shift in the demand curve, so that the price may not actually fall over the period of the analysis. Nevertheless, ignoring the demand-changing factors has little impact on the outcome of the analysis, since the welfare analysis measures the difference between the with- and the without-CIMMYT scenarios. Therefore, the results would be similar whether the demand curve shifts out over time or not.

In reporting the results, figures for the Rest of the World are provided in this report for completeness, but they do not reflect the impact on individual countries. As the focus of this report is on Australia, all other countries are grouped together in the analysis. In some countries, there will be impacts significantly different from the overall aggregate for the Rest of the World, so the results of this study should not imply any particular impact for countries other than Australia.

7.3 DREAM Evaluation Model

The analysis outlined above was carried out using the DREAM (Dynamic Research Evaluation Model) evaluation model (Alston *et al.* 1995, Appendix A5.1.2). The model has been developed by the International Food Policy Research Institute (IFPRI)[5], and is becoming the standard for economic analysis of ACIAR projects. It provides a useful and reliable means of analysing the economic impact of research.

For each of the crops, the data were used in DREAM, run as a horizontal multi-market to provide analysis of the spillovers from CIMMYT to Australia (and in states within Australia). Parameters used in the analysis were:

(a) Linear adoption;
(b) The estimated supply shift was entered as having 100% probability of success;
(c) Benefits were measured for the period from 1965 to 2020;
(d) Two groups were used, namely Australia and the Rest of the World, with Australia being subdivided into five states (Queensland, New South Wales, Victoria, South Australia and Western Australia);
(e) Disadoption was assumed to occur immediately at 2021 (so that no benefits were measured beyond that time).

7.4 Data Used in the Empirical Analysis

In estimates of supply shifts, the technological impact of CIMMYT is expressed as a percentage yield gain. Following GRDC (1992) and the way in which the Alston *et al.* (1995) formulae have been incorporated into the DREAM analytical model, the simplifying assumption adopted here is that the world price represents an equilibrium at which the total cost of production equals the price. On the basis of that assumption, we use the world price as a proxy for the total costs per tonne without the CIMMYT technology. Increases in yield due to CIMMYT lead to a reduction in costs, which measures the downward shift in the supply curve (for further discussion see Brennan *et al.* 2002).

The data used for the empirical analysis were derived from a number of sources. The data on area, yield and production in Australia for wheat in recent years are shown in Appendix A (ABARE, 2004a,b). World area, yield, production and trade data were obtained from FAO statistics (FAO 2004). The prices used in the analysis were also obtained from ABARE. Average prices are taken as A$216 per tonne, based on the average unit value of production in the three years to 2002-03.

The supply and demand elasticities used in the analysis were derived from elasticities obtained from ACIAR (Table 7.1).

Table 7.1: Elasticities[a] of Supply and Demand Used in Analysis

	Supply elasticity	Demand elasticity
Australia	0.25	-0.20
Rest of World	0.30	-0.20

a: Elasticity = $(\Delta Q/Q)/(\Delta P/P)$

Source: ACIAR spillover model (D. Templeton, personal communication).

[5] The model and its documentation is publicly available from IFPRI on www.ifpri.org/dream/

7.5 Analysis of CIMMYT's Impact on Australian Wheat Industry

7.5.1 Yield increases in Australia attributable to CIMMYT

The yield increases attributable directly to CIMMYT (Table 6.3), from both Phases 1 and 2, are used in the analysis of CIMMYT's impact.

While not measured or valued in this analysis, a substantial contribution has been made by the Australian breeders in addition to those measured here as attributable to CIMMYT. As indicated earlier, CIMMYT materials have only rarely been directly released for Australian farmers, and have generally needed incorporation into Australian germplasm before being useful in Australia. Thus, the role of Australian breeders in assessing the value of the materials from CIMMYT and incorporating the desirable characteristics into improved varieties for Australian farmers has been substantial.

7.5.2 Yield increases in the Rest of the World attributable to CIMMYT

Estimation of the extent to which CIMMYT's research has affected wheat productivity in the rest of the world (*i.e.*, all but Australia) is difficult. There have been many studies, including Byerlee and Moya (1993), Byerlee and Traxler (1995) and Heisey *et al.* (2002), which have addressed this issue, culminating with the very detailed work described in Evenson and Gollin (2003a). However, even within each of those studies, there is no clearly defined estimate published that can be readily utilised.

Instead, an estimate had to be developed from the information provided in those papers, as follows (Table 7.2):

- Heisey *et al.* (2002) suggest that CIMMYT has led to yield increases in developing countries between 0.2 and 0.4 t/ha. We use their mid-point estimate, 0.3 t/ha. Given that wheat yields in those countries averaged 1.33 t/ha in 1965-67, the assumed increase in production in yield in developing countries is 22.6% over the period 1965 to 1997.
- Following the work of Pardey *et al.* (1996) and Thomas (1996), the impact on some developed countries has been significant, while it is unclear how much CIMMYT has had an influence on yields in Europe or much of the former Soviet Union in the period up to the late 1990s. We assume a 3.0% from CIMMYT increase for all countries other than developing countries and Australia for the period 1965 to 1997.
- Using average world wheat production data for 1995-97, the weighted average yield increase for the Rest of the World (that is, all but Australia) is 12.5%.
- These increases were assumed to be increasing at a regular linear rate between 1965 and 2001.

Table 7.2: Global Impact of CIMMYT on Wheat, 1965-2001

Region	**Production 1995-97 (m.t.)**	**Yield increase from CIMMYT (%)**
Developing countries	271.6	22.6%
Other countries without Australia	291.9	3.0%
"Rest of World"	***563.4***	***12.5%***
Australia[a]	24.8	4.6%
World total	**584.2**	**12.2%**

a Weighted average yield increase, from Table 6.3.

7.5.3 "Counterfactual" baseline for measurement of benefits

The key element of the measurement of benefits from CIMMYT is to define the "counterfactual", or the "without-research" scenario. In this case, we are measuring the impacts of Australian spillovers. With or without Australia's involvement in CIMMYT and spillovers from CIMMYT to Australia, CIMMYT wheats would have increased production the rest of the world, particularly the developing countries. Therefore, the large price effects likely to result from CIMMYT's success in that task would have been felt by Australian producers in any case. Given that Australia has been able to capture some spillover benefits, those effects have been mitigated. The analysis addresses the issue of how much those benefits have been.

In this analysis, we are not addressing directly the value to Australia of CIMMYT's existence, but are focussing on the value of the spillovers from CIMMYT. That broader question addressed more directly in Evenson and Rosegrant (2003) for the entire CGIAR system. However, an estimate of the impact of CIMMYT itself on Australia is a by-product of the analysis undertaken, and the results are presented in the next section.

7.5.4 Welfare effects of spillovers from CIMMYT's wheat research

Initially, the analysis was run for the current situation in which CIMMYT provides benefits to the Rest of the World and the observed spillovers to Australia. In that situation, the substantial gains from CIMMYT in developing countries lead to large supply shifts, and a fall in price from the initial A$216.00 to A$200.10. That fall (7.4%) in price results in loss of producer surplus of A$1,239 million over the period 1965 to 2020, which are partly offset by gains of A$566 million for Australian consumers (Table 7.3). Thus, while the Rest of the World has net gains (shared by both producers and consumers) of A$132 billion over that period, Australia suffers a net loss of welfare of A$673 million from the successful work of CIMMYT.

Table 7.3: Welfare Impacts of Spillovers from CIMMYT to Australia, 1965 - 2020
(Present Value, 2003 Australian dollars)

	Producer surplus *(A$ million)*	**Consumer surplus** *(A$ million)*	**Total welfare** *(A$ million)*	**Price** *(A$/t)*
CIMMYT spillover benefits to Australia				
Australia	-1,239	566	-673	
Rest of World	53,661	78,340	132,001	
- Total	52,422	78,906	131,328	200.10
No spillover benefits to Australia				
Australia	-2,659	560	-2,099	
Rest of World	54,375	77,606	131,982	
- Total	51,717	78,167	129,883	200.30
Net gains from spillovers to Australia				
Australia	1,420	5	1,425	
Rest of World	-714	734	20	
- Total	706	739	1,445	-0.20

When the analysis was re-run excluding the observed spillovers to Australia, the world price falls is slightly less (7.3%). The results indicate that Australian producers would be considerably larger net losers of welfare from CIMMYT (A$2,659 million), with gains to Australian consumers of A$560 million. The position for Australia if there were no spillovers from CIMMYT is a net loss of welfare of A$2,099 million over the period 1965 to 2020.

Thus the results of the analysis (Table 7.3) show that spillovers from CIMMYT to Australia lead to welfare benefits totalling A$1,425 million over the period 1965 to 2020. As shown in Brennan, Aw-Hassan and Nordblom (2003) for ICARDA, the spillovers also enhance the benefits to the rest of the World, through inducing a further price fall of A$0.20 per tonne. That price fall leads to a transfer of welfare from the rest of World producers to Rest of the World consumers, and increases overall welfare by A$20 million. Global benefits of the spillovers (including those to Australia) are estimated at A$1,445 million over the period.

Of the net gain in welfare of A$1,425 million, almost all is received by Australian wheat producers. For the period since 1973, when those spillovers were first received in Australia, the net welfare gains for Australia from the CIMMYT spillovers have averaged A$30 million per year (Table 7.4). Without spillovers, CIMMYT would have reduced Australia's welfare by A$45 million per year over that time, while the spillovers mean that there is a net reduction of only A$14 million per year for Australia.

Table 7.4: Average Annual Welfare Benefits for Australia, 1973 - 2020
(Average Present Value per year, 2003 Australian dollars)

	Producer surplus *(A$ million)*	**Consumer surplus** *(A$ million)*	**Total welfare** *(A$ million)*
With spillover benefits to Australia	-26.4	12.0	-14.3
Without spillover benefits to Australia	-56.6	11.9	-44.6
Net gains from spillovers to Australia	**30.2**	**0.1**	**30.3**

Given that Australia's investment in CIMMYT has been close to A$1 million per year on average, the net returns to Australia from the benefits (including all the price impacts) of funds invested in developing, enhancing and capturing those spillovers have been high. At the same time, the net benefits to the Rest of the World have also been enhanced, though only marginally.

7.5.5 Sensitivity of Results to Changes in Parameter Values
These results are sensitive to the assumptions made in the analysis. To examine the extent to which the chosen values for the parameters of the analysis have an impact on the findings of the study, the sensitivity of the results (measured as the aggregate gains for Australia) was examined (Table 7.5). Each selected parameter was varied by ±20% and the effect on the gains for Australia estimated. For elasticities, a test was made of considerably smaller (50% reduction) and larger elasticities (a five-fold increase in magnitude to represent possible longer-term elasticity estimates).

Across the range chosen for the possible values of the main parameters, none change the overall result that Australia obtains a significant net gain of welfare from the impact of the spillovers from CIMMYT's work. The estimated aggregate impacts for Australia vary with the wheat price used and (inversely) with the discount rate, though less than proportionately to the change in parameter value. The benefits are proportional to the cost reductions (yield gains) in Australia. In addition, because the yield changes in the Rest of the World impact on the price, the impacts for Australia are also sensitive to the value for those yield gains. Australian welfare impacts are insensitive to a variation in the elasticity of demand and supply in Australia, though similar changes in the elasticity of demand and supply for the Rest of the World lead to greater changes in the aggregate Australian welfare. In particular, Australian benefits are sensitive to changes in the elasticity of supply for the rest of the World.

Table 7.5: Sensitivity of Results to Changes in Parameters[a]

Parameter	**Value**	**Net gains to Australia** *(A$ million)*
Cost reduction in Australia by 2001	3.7%	1,139
	4.6%	1,425
	5.5%	1,712
Cost reduction in ROW by 2001	10.0%	1,846
	12.5%	1,425
	15.0%	1,006
Price (A$/tonne)	$173	1,559
	$216	1,425
	$259	1,291
Elasticity of demand ROW	-0.10	899
	-0.20	1,425
	-1.00	1,462
Elasticity of demand Australia	-0.10	1,421
	-0.20	1,425
	-1.00	1,461
Elasticity of supply ROW	0.15	2,038
	0.30	1,425
	1.50	387
Elasticity of supply Australia	0.13	1,414
	0.25	1,425
	1.25	1,511
Discount rate (% per annum)	4.0%	1,273
	5.0%	1,425
	6.0%	1,540

a: Selected parameter values varied by -20% and +20% from values used in estimates, except elasticities varied by -50% and +400%.

8. Discussion of Results and Implications

8.1 Value of CIMMYT Spillovers to Australia

The results of the yield improvement analysis indicate that there have been two phases to the yield increases obtained in Australia as spillovers from the CIMMYT wheat improvement programs. In the first phase relating to the adoption of the semi-dwarf wheats, varietal yields increased in each state, though at varying levels. Basing CIMMYT's contribution to those gains on its direct genetic contribution to the parents used in the final cross, the yield increases attributable directly to CIMMYT in 2001 range from 4.1% in Queensland to 0.1% in Western Australia. At their peak in the mid-1980s, the direct contribution of CIMMYT was markedly higher in each state, but the trend has been for an increasing use of second-, third- and subsequent-generation lines from Australia as parents rather than the original CIMMYT semi-dwarfs. As a result, the direct CIMMYT contribution to those varietal gains has declined in the past 15 years or so. At the national level, CIMMYT's contribution to the first phase increases have been as high as 2.5% in 1990, but were only 1.3% in 2001. Thus, although the CIMMYT-derived semi-dwarf wheats led to varietal yield increases as high as 9.2% in Queensland, the majority of those gains (based on contribution to pedigree) were attributable to the Australian breeders and their already-adapted materials, rather than directly to the CIMMYT contribution.

At the same time, since 1988, CIMMYT has also been contributing to post-semi-dwarf yield gains (Phase 2), which have grown steadily throughout the period since 1988. By 2001, those phase 2 varietal yield gains were estimated at 3.2% nationally, and ranged from 1.6% in South Australia to 6.4% in Queensland.

From both the Phase 1 semi-dwarfs and the Phase 2 post-semi-dwarfs, the yield gains for Australia attributable directly to CIMMYT averaged 4.6% for Australia. For South Australian and Western Australia, these gains were 2.0% in 2001, while for Queensland (10.5%), NSW (7.9%) and Victoria (7.4%) they were more significant. Further gains associated with improved management and higher input levels would also have occurred during this period.

At the same time as these spillover yield benefits were flowing to Australia, CIMMYT was having a major impact on the world wheat production, delivering substantial productivity gains, especially in developing countries. In assessing the impact of CIMMYT, it is clear that the substantial yield gains from CIMMYT in developing countries have led to large supply shifts and a lower price for wheat globally than would have occurred without CIMMYT's research. In this study, world wheat yields are estimated to be 12.2% higher because of CIMMYT's research, and world prices 7.4% lower than if CIMMYT had not achieved those improvements around the world. Those impacts have also affected the benefits that Australia has received from CIMMYT.

Thus, Australia has been affected in two ways by CIMMYT's wheat breeding program. First, via the spillovers of the genetic materials from CIMMYT, Australia's wheat yields have increased by an average of 4.6% in 2001. Second, at the same time CIMMYT's global success has resulted in 7.4% lower world prices, including those for Australian wheat. The analysis indicates that the price fall has been greater than the average yield increase, so overall Australian wheat producers have suffered a reduction in welfare from CIMMYT's activities. The estimated net effects over the period 1965 to 2020 are a reduction in welfare of A$1,239 million for Australian producers from CIMMYT, partly offset by the gains to

Australian consumers of A$566 million. The net position for Australia is a net loss of welfare of A$673 million over that period. That is equivalent to approximately A$12 million per year.

While the overall impact of CIMMYT on Australia has been negative, those impacts are essentially the outcome of genetic improvement worldwide. By drawing on the potential spillovers from the CIMMYT successful work aimed at developing countries, Australia has markedly reduced the welfare losses that would have otherwise occurred. The welfare losses for Australia would have been considerably larger (A$2,099 million, or A$38 million per year) without the yield gains from those spillover benefits.

The analysis shows that spillovers from CIMMYT to Australia lead to welfare benefits totalling A$1,425 million over the period 1965 to 2020. As previously shown in Brennan, Aw-Hassan and Nordblom (2003) for ICARDA, the spillovers to Australia also enhance the benefits to the rest of the World, through inducing a price fall of A$0.20 per tonne. That price fall leads to a transfer of welfare from the rest of World producers to Rest of the World consumers, and increases overall welfare by A$20 million. Global benefits of the spillovers to Australia are estimated at A$1,445 million over the period 1965 to 2020.

Almost all of the benefits of the spillovers from CIMMYT to Australia are received by Australian wheat producers. For the period since 1973, when those spillovers were first received in Australia, the net welfare gains for Australia from the CIMMYT spillovers has averaged A$30 million per year. Given that Australia’s investment in CIMMYT has averaged close to A$1 million per year, Australia has received a high return on the funds invested in developing, enhancing and capturing those spillovers from CIMMYT. Without this investment, it is likely that Australia would have had less access to CIMMYT materials.

8.2 Impacts on Wheat Diversity in Australia

An important issue related to the adoption of semi-dwarf wheats has been whether that has had an impact on the genetic diversity of wheat grown by farmers. Brennan and Fox (1995, 1997) found that for Australia as a whole there had been little change in weighted diversity over the period 1973 to 1993, although there was a small improvement after the mid-1980s. Given the range of environments across the states, the weighted diversity reflects the fact that different genetic materials are better suited in the different states.

However, Brennan and Fox (1995, 1997) also found evidence of varying impacts on weighted diversity for different States during that time. For New South Wales and Queensland, the introduction of semi-dwarfs was associated with a reduction in the weighted diversity. For Victoria, the initial adoption of semi-dwarfs resulted in an increase in weighted diversity, but after 1983 diversity fell by almost 50% to relatively low levels. For South Australia and Western Australia, the pattern was reversed, with both States relying heavily on a small number of varieties in the early 1970s. As semi-dwarf varieties were introduced, the weighted diversity increased markedly, dating from the mid-1970s in South Australia and mid-1980s for Western Australia. As a result, both of these states had significantly increased diversity through the adoption of semi-dwarfs. This appears to reflect a movement to more specific adaptation, away from broader adaptation based on single varieties.

In this study, the resources and data were not available to enable the same measures of coefficients of parentage and coefficient of diversity to be calculated as in Brennan and Fox, given the confidentiality of some of the data. However, there is no evidence to suggest that there have been major changes in the coefficients of diversity in the period since 1993 compared to the earlier period analysed by Brennan and Fox. For example, in a study of wheat varieties in 8 shires in New South Wales, Brennan and Bialowas (2001) found that the genetic diversity of varieties grown in the south of the state fell significantly during the 1990s, but that in the northern parts of the state it had increased. Overall, the average genetic diversity (measured by the weighted coefficient of diversity) across all 8 shires was similar in the 1990s to that in the 1970s.

8.3 Implications of Results

It is clear that Australia has received a significant dividend from the efforts in Australia to develop and enhance the spillovers from CIMMYT. While CIMMYT's success in other countries has resulted in price reductions and a consequent loss of welfare for Australian producers, the benefits obtained from the spillovers have mitigated those effects to a substantial extent. Given that CIMMYT's global impact will be similar whether or not Australia supports the work at CIMMYT, the most appropriate strategy (from the point of view of economic benefits) for Australia is to continue to fund research at CIMMYT, particularly research that can develop and enhance spillovers to Australia. The extent of the research connections between Australia and CIMMYT that are demonstrated in Appendix B indicate that those efforts are already well established. Clearly, for Australia to maximise its welfare in the presence of a successful international agricultural research centre such as CIMMYT, the greater the collaborative and funding ties and the greater the extent of research cooperation, then the greater the spillover benefits that will flow to Australia.

From CIMMYT's point of view, increased spillovers to Australia have not been associated with any trade-off in terms of benefits to developing countries. Indeed, the spillovers to Australia have resulted in marginal increases in the benefits flowing to the Rest of the World, through a shift in welfare from producers to consumers. As discussed in Brennan *et al.* (2003), where increasing supplies of cheaper food are a priority for food security, such spillovers should be encouraged. Where increasing production and the welfare of the farmers producing such crops in developing countries is considered more important than cheaper food, the spillovers to countries such as Australia can be seen as a slight negative for CIMMYT. Thus, while in aggregate terms the spillovers represent a win-win situation for both Australia and the Rest of the World, whether the small shift in welfare gains from the producers in the Rest of the World to the consumers is seen as desirable by the CIMMYT is not clear.

In all studies such as this, there are significant issues relating to attribution of research outcomes (Alston and Pardey, 2001). In thus study, we have not evaluated whether CIMMYT's existence can be justified, but rather we have evaluated the impact of materials that have emanated from CIMMYT. There has been no attempt to attribute to particular prior sources the gains that have come through CIMMYT. Thus, the gains attributable to the genetic materials from CIMMYT in this study may in fact have been derived from other countries or research programs around the world, and may have had a relatively small input from CIMMYT itself.

As Brennan *et al.* (2003) found for ICARDA, the results of this study also provide clear support for the role of national agricultural research systems such as that in Australia, as international research would not be able to replace nationally-funded research. Very few CIMMYT wheat varieties have been released without further development and breeding in

Australia. The incorporation of genetic material from CIMMYT into Australian varieties has been carried out through nationally-funded research, which has been necessary to capture the potential benefits available from the CIMMYT genetic materials.

In conclusion, the Australian wheat industry has received extremely valuable spillover yield benefits from the CIMMYT wheat breeding program in Mexico. It seems likely that Australian breeders will continue to obtain spillover benefits for some time to come, and efforts to enhance the relationship between CIMMYT and Australia are likely to provide substantial returns for Australia.

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Appendix A: Area, Yield and Production Data for Australian Wheat

Year	Area	Production	Yield	Gross value of production	Unit value of production
	('000 ha)	*('000 t)*	*(t/ha)*	*(A$ m)*	*(A$/t)*
1972-73	7,603	6,590	0.87	357	54
1973-74	8,949	11,987	1.34	1312	109
1974-75	8,308	11,357	1.37	1256	111
1975-76	8,555	11,982	1.40	1249	104
1976-77	8,956	11,810	1.32	1051	89
1977-78	9,955	9,370	0.94	935	100
1978-79	10,249	18,090	1.77	2296	127
1979-80	11,153	16,188	1.45	2478	153
1980-81	11,283	10,856	0.96	1684	155
1981-82	11,885	16,360	1.38	2600	159
1982-83	11,520	8,876	0.77	1566	176
1983-84	12,931	22,016	1.70	3606	164
1984-85	12,078	18,666	1.55	3203	172
1985-86	11,738	16,167	1.38	2694	167
1986-87	11,261	16,780	1.49	2462	147
1987-88	9,063	12,369	1.36	2016	163
1988-89	8,903	14,060	1.58	2976	212
1989-90	9,004	14,214	1.58	2775	195
1990-91	9,218	15,066	1.63	1988	132
1991-92	7,183	10,577	1.47	2097	198
1992-93	9,101	16,184	1.78	2894	179
1993-94	8,383	16,479	1.97	2723	165
1994-95	8,003	8,903	1.11	2127	239
1995-96	9,721	16,504	1.70	4305	261
1996-97	11,336	23,701	2.09	4878	206
1997-98	10,422	19,417	1.86	3716	191
1998-99	11,583	22,108	1.91	4011	181
1999-00	12,338	25,012	2.03	4833	193
2000-01	12,440	22,190	1.78	5131	231
2001-02	12,526	23,960	1.91	6278	262
2002-03	11,045	10,058	0.91	2675	266
2003-04	12,400	24,920	2.01	5582	224

Source: Australian Bureau of Agricultural and Resource Economics (2004a,b) and previous issues

Appendix B: Australian Funding for CIMMYT, 2002-03

Project	**Funding received from**			**Total**
	AusAID	**RDC**	**Other**	
	($'000)	*($'000)*	*($'000)*	*($'000)*
Australian Cereal Rust Control Program	-	366	-	366
Exploitation of the Genetic Resources of Synthetic Wheats	-	250	-	250
Strategic framework to model CIMMYT Wheat Breeding Program	-	154	-	154
Protecting the Australian Wheat Industry from Karnal Bunt	-	180	-	180
Molecular Markers for Wheat Product Quality and Disease Resistance	-	85	-	85
Enhanced Evaluation of CIMMYT Germplasm in Australia	-	181	-	181
Stress Tolerant Wheat and Maize for Afghanistan	650	-	-	650
Chinese Wheat Quality Project	-	24	-	24
CRC Molecular Plant Breeding	-	-	473	473
Training in Soil Borne Diseases of Cereals	-	18	-	18
Application of Novel Physiological And Germplasm Strategies	156	-	-	156
Review of the RWC for the Indo-Gangetic Plains	10	-	-	10
Seeds of Life – East Timor Project	23	-	-	23
Smallholder Maize Systems in South Africa	328	-	-	328
Total	**1,167**	**1,257**	**473**	**2,897**
- Proportion of total funds	*40%*	*43%*	*16%*	*100%*

Appendix C: Survey of Australian Wheat Breeding Programs

Survey of Impact of CIMMYT on Australian Wheat Industry

1. Links with CIMMYT

1.1 Has CIMMYT provided genetic materials or other outputs of value to you in your breeding and/or research over recent years?

2. Use of CIMMYT Materials in Breeding

2.1 Are you using or testing CIMMYT lines or lines based on CIMMYT materials in your program? If YES, what characteristics of those materials are of most interest to you?

2.2 Are there CIMMYT parent lines or lines based on CIMMYT materials among your current breeding lines? If YES, please identify the CIMMYT materials, and provide details of the stage of the lines.

2.3 Have you or your organisation released cultivars that were developed by CIMMYT? If so, please provide details.

2.4 Have you or your organisation released cultivars that have CIMMYT materials in their pedigrees? If so, please provide details.

2.5 What do you believe CIMMYT has provided to your breeding program in the past and is likely to provide in the future?

3. Use of CIMMYT Materials in Research

3.1 Are you using CIMMYT genetic materials in your current research that are not part of a breeding program? If YES, please identify the CIMMYT materials the nature of the research.

3.2 If you are using CIMMYT materials, what characteristics of those materials are of most interest to you?

3.3 Are there CIMMYT outputs other than genetic materials that you have used or are using (eg, analytical techniques, screening methods, etc)? If so, please specify.

3.4 What do you believe CIMMYT has provided to your research program in the past and is likely to provide in the future?

4. Other Comments

4.1 Do you have regular contact with CIMMYT, such as regular visits? If so, please specify.

4.2 Any other comments on the impact of CIMMYT in Australia?

Appendix D: CIMMYT-Derived Varieties Released by Australian Breeding Programs, 1973-2003

Variety	Year released
Condor	1973
Egret	1973
Oxley	1974
Jabiru	1975
Songlen	1975
Timson	1975
Warimba	1976
Cook	1977
Durati (D)	1977
Shortim	1977
Warigal	1978
Avocet	1979
Banks	1979
Jacup	1979
Miling	1979
Millewa	1979
Bindawarra	1980
Hybrid Titan	1980
Aroona	1981
Bodallin	1981
Canna	1981
Eradu	1981
Sunkota	1981
Flinders	1982
Hartog	1982
Hyden	1982
Kamilaroi (D)	1982
Matong	1982
Suneca	1982
Bass	1983
King	1983
Osprey	1983
Quarrion	1983
Sunstar	1983
Torres	1983
Bayonet	1984
Cocamba	1984
Corella	1984
Cranbrook	1984
Dagger	1984
Meering	1984
Skua	1984
Spear	1984
Sundor	1984
Wyuna	1984
Blade	1985
Kulin	1985
Machete	1985
Mokoan	1985
Rosella	1985

Variety	Year released
Vasco	1985
Vulcan	1985
Diaz	1986
Grebe	1986
Hybrid Comet	1986
Lowan	1986
Schomburgk	1986
Sunco	1986
Dollarbird	1987
Hybrid Meteor	1987
Kiata	1987
Minto	1987
Moray	1987
Owlet	1987
Sunbird	1987
Yallaroi (D)	1987
Kelalac	1988
Miskle	1988
Molineux	1988
Sunfield	1988
Tatiara	1988
Wilgoyne	1988
Janz	1989
Lark	1989
Perouse	1989
Reeves	1989
Cunningham	1990
Lillimur	1990
Shrike	1990
Sunbri	1990
Angas	1991
Batavia	1991
Excalibur	1991
Lawson	1991
Yarralinka	1991
Cadoux	1992
Hybrid Pulsar	1992
Katunga	1992
Sunmist	1992
Sunstate	1992
Amery	1993
Beulah	1993
Darter	1993
Goroke	1993
Houtman	1993
Ouyen	1993
Pelsart	1993
Rowan	1993
Stiletto	1993
Stretton	1993

Appendix D (Continued): CIMMYT-Derived Varieties Released by Australian Breeding Programs, 1973-2003

Variety	Year released
Swift	1993
Tasman	1993
Trident	1993
Vectis	1993
Wollaroi (D)	1993
BT Schomburgk	1994
Cascades	1994
Currawong	1994
Sunland	1994
Sunvale	1994
Tammin	1994
Tern	1994
Triller	1994
Warbler	1994
Hybrid Apollo	1995
Hybrid Gemini	1995
Hybrid Mercury	1995
Leichardt	1995
Sunbrook	1995
Arnhem	1996
Carnamah	1996
Cunderdin	1996
Gordon	1996
Kalannie	1996
Paterson	1996
Perenjori	1996
Petrel	1996
Silverstar	1996
Sunlin	1996
Tailorbird	1996
Yanac	1996
Barunga	1997
Bowie	1997
Buckley	1997
Chough	1997
Diamondbird	1997
Frame	1997
Krichauff	1997
Snipe	1997
Arrino	1998
Baxter	1998
Brookton	1998
Calingiri	1998
Chara	1998
Goldmark	1998
Kennedy	1998
Mawson	1998

Variety	Year released
Nyabing	1998
Tamaroi (D)	1998
Westonia	1998
Whistler	1998
Worrakatta	1998
Ajana	1999
Brennan	1999
Giles	1999
Mitre	1999
Tennant	1999
Yitpi	1999
Babbler	2000
Camm	2000
Dennis	2000
H45	2000
Lang	2000
Mira	2000
Mulgara	2000
Pardalote	2000
Petrie	2000
Strzelecki	2000
Sunpict	2000
Thornbill	2000
Bowerbird	2001
Kalgarin	2001
Kukri	2001
QALBis	2001
Wylah	2001
Anlace	2002
Braewood	2002
Clearfield WHT JNZ	2002
Clearfield WHT STL	2002
Drysdale	2002
EGA Bonnie Rock	2002
EGA Wedgetail	2002
Koelbird	2002
Lorikeet	2002
MacKellar	2002
Rudd	2002
Sunsoft 98	2002
Annuello	2003
EGA Hume	2003
Ellison	2003
Pugsley	2003
QAL2000	2003
Rubric	2003
Wyalkatchem	2003

Appendix E: Adoption of CIMMYT-Derived Varieties, by State

(% area sown)

	NSW	Vic	Qld	SA	WA	Australia
1974	3.0	0.0	0.4	0.0	0.0	1.0
1975	14.3	1.5	7.0	1.9	0.0	5.5
1976	27.7	14.6	25.4	11.1	0.0	14.1
1977	49.1	31.2	36.8	15.3	1.7	25.2
1978	61.2	34.9	43.7	18.9	3.8	30.4
1979	70.4	43.3	64.2	28.1	6.2	37.3
1980	83.3	53.1	69.8	34.9	10.2	44.3
1981	79.6	59.5	75.8	35.9	9.5	44.7
1982	76.8	61.8	75.5	43.4	11.3	43.3
1983	75.2	64.5	81.4	39.3	10.9	46.4
1984	73.2	73.0	83.3	50.0	16.5	49.5
1985	81.8	85.3	80.4	51.3	32.7	61.0
1986	84.3	86.5	75.9	51.5	38.5	61.7
1987	89.7	88.3	84.5	62.7	46.8	68.8
1988	92.6	90.8	88.4	74.3	50.4	73.2
1989	94.4	93.2	89.2	76.6	56.6	76.1
1990	94.4	93.4	91.1	81.0	64.5	80.0
1991	96.0	92.9	88.0	85.5	71.4	82.2
1992	96.5	94.2	96.7	86.4	73.1	84.3
1993	97.0	94.1	95.4	90.5	76.7	86.3
1994	97.3	91.7	99.4	93.8	78.7	87.2
1995	98.5	95.5	99.2	94.1	79.7	89.7
1996	99.1	97.1	99.5	95.8	81.6	91.7
1997	98.6	97.1	98.9	96.5	84.6	92.7
1998	99.7	97.1	99.4	96.5	88.2	94.5
1999	99.7	98.7	99.5	97.8	90.4	95.7
2000	99.7	98.9	99.7	97.6	94.1	97.1
2001	99.7	98.9	99.9	97.9	96.0	97.9

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Number

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