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Impact of Wheat Varieties from CIMMYT on Australian Wheat Production

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Department of Agriculture New South Wales

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ABSTRACT

Australia has been importing semi-dwarf material from the wheat breeding program at CIMMYT (and its precursor, the Rockefeller Foundation) in Mexico, since the early 1960s. Although few varieties from CIMMYT have been released directly in Australia, the lines have been used extensively in Australian wheat breeding programs.

CIMMYT-based varieties derived from these introductions occupy almost one half of the total area sown to wheat in Australia. From trial results, CIMMYT-based varieties were found to have a yield advantage of 7 per cent over other leading varieties, although there is wide variation between the different States. Using an index of varietal improvement, CIMMYT-based varieties were estimated to have increased yields in Australia by an average of 3.6 per cent by 1983, and ranging from 0.3 per cent in Western Australia to 7.2 per cent in Queensland.

In monetary terms, the value of the increased production in the period 1974 to 1983 was estimated at $A825 million (in 1983-84 dollars at a real interest rate of 5 per cent), at an annual average of $A82 million. On the basis of the pedigrees of Australian wheats, about two-thirds of this value can be attributed to the lines from CIMMYT.

PREFACE

This report was prepared in conjunction with a major study being carried out by Professor J.R. Anderson under the auspices of the Consultative Group on International Agricultural Research, Washington D.C. on the impact of the International Agricultural Research Centres.

A number of colleagues in the Department of Agriculture New South Wales have contributed to this report. Cedric May, Ron Martin, Akram Khan, Gordon Murray, Barbara Ballantyne, Malcolm Glennie Holmes and Helen Allen of the Agricultural Research Institute, Wagga Wagga, all made comments on drafts or assisted with valuable suggestions and discussion. In particular, John Fisher, Agricultural Research Institute, Wagga Wagga, made detailed comments and suggestions, and tolerated many interruptions in assisting me to understand the issues involved. Albert Pugsley, formerly of Agricultural Research Institute, Wagga Wagga, and University of Melbourne, made a valuable contribution through discussions, suggestions and comments. Col Wellings and Bob McIntosh of the National Rust Control Programme, Sydney University, provided valuable information. Michael Mackay, Curator of the Australian Wheat Collection, Tamworth, provided valuable data on the wheat varieties in Australia, their pedigrees and their origins. Roger Fitzsimmons, Department of Agriculture New South Wales, Sydney, assisted with data on the area sown to wheat varieties. Data for variety yields was obtained from reports of the Interstate Wheat Variety Trials. The comments of Jock Anderson, Derek Byerlee, Jim Syme, Jim Ryan, David Godden and Bob Lindner on various drafts of this report were also valuable. Of course, none of these bear responsibility for the interpretations or any inaccuracies that remain.

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GLOSSARY OF ABBREVIATIONS USED

ASW	Australian Standard White
CBV	CIMMYT-based variety
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center)
GVP	Gross value of production
N.S.W.	New South Wales
Qld.	Queensland
S.A.	South Australia
SNB	Septoria nodorum blotch
STB	Septoria tritici blotch
Vic.	Victoria
W.A.	Western Australia

1. INTRODUCTION

1.1 Semi-Dwarf[1] Wheats

Varieties of dwarf wheats with very short stature were introduced into the U.S.A. from Asia in the late 1940s. Most important among these was Norin 10, a Japanese wheat with two dominant genes for dwarfness (Rht1 and Rht2). The history of this introduction is outlined in Dalrymple (1980). Several crosses were made with these wheats at Pullman in Washington State, U.S.A., with one cross, Norin 10/Brevor, being the foundation of later semi-dwarf varieties developed in the CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo) program in Mexico. Virtually all current semi-dwarf varieties of the Australian breeding programs are derived from this cross[2].

1.2 Role of Rht Genes

The incorporation of the Rht genes from Norin 10/Brevor progeny 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 (and, therefore, were sensitive to applications of gibberellin). Plants carrying the dominant genes Rht1 and Rht2 produce unusually high levels of endogenous gibberellin (and have a negative response to gibberellin applications).

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 effects, such as reduced plant height (which is valuable in controlling crop lodging), increased 'harvest index' (the ratio of grain to straw in the plant), and synchronous tillering (Syme, 1983; A.T. Pugsley, personal communication).

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(1) For convenience, the lines with two Rht genes are called 'dwarf' wheats, and those 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 per cent Australian from its pedigree. Thus, Brevor could be considered 3/8 Australian, and Norin 10/Brevor could be considered 3/16 Australian.

In addition, the Australian variety Gabo was amongst the varieties used by Borlaug early in the Mexican program, and figured prominently in the pedigree of many lines from Mexico (such as WW80).

1.3 Non-CIMMYT Semi-Dwarf Varieties in Australia

In 1956, Dr A.T. Pugsley introduced into Australia the dwarf wheat, Norin 10/Brevor (selection 14). This line was unsuitable for commercial cultivation in Australia, but was used in a large number of crosses, the first of which were made in September, 1956 (Pugsley, 1974).

For some time prior to this, there had been a move towards shorter-strawed wheats in Australia. Short-strawed wheats like Gluriks were widely grown in Australia in the 1930s, and varieties such as Insignia (1946) and Heron (1959) were considerably shorter than many of their predecessors. However, the semi-dwarf wheats originating from Norin crosses were 35-50 per cent shorter as a group than the popular standard varieties (Pugsley, 1964).

Initially, emphasis in Australia was placed on examining the usefulness of semi-dwarf lines under irrigation (Pugsley, 1964). Further crossing and selection led to the naming and registration of Australia's first Norin 10 derivative, Wren, in 1968 (seven years after the first semi-dwarf wheat was released in the U.S.A.). However, Wren failed to meet the milling quality standards required in New South Wales and, despite its high yield potential, was not recommended for general cultivation (Pugsley, 1974).

The cultivar Kite, registered in 1973, was produced with further crossing from the original material by R.H. Martin. Kite is still a popular wheat, especially in northern New South Wales, and has been used as a parent for several more recent varieties (such as Harrier and Takari).

1.4 CIMMYT Materials in Australia.

Since the initial introduction of semi-dwarfs, other sources of semi-dwarf material (especially CIMMYT in Mexico and Chile, and more recently from other overseas countries) have been used in Australian wheat breeding programs.

In 1960, Pugsley introduced two lines from the Rockefeller Foundation, Mexico 120 and Chile 1B. The former was a dwarf line from the breeding program in Mexico, the precursor of CIMMYT, and the latter was a semi-dwarf line from the breeding program in Chile. The evaluation of Mexico 120 revealed the dramatic yield potential of the semi-dwarf varieties of spring habit (A.T. Pugsley, personal communication). Neither line was grown commercially, but both were used in Australian breeding programs.

In 1963, Pugsley introduced into Australia several hundred spring wheat lines from the Rockefeller Foundation breeding program containing the semi-dwarf genes originally obtained from the Washington State program. This was the same year that this material was first introduced into the U.S.A. (Dalrymple, 1980). Some of the introductions were found to be well adapted to the dryland conditions of the Australian wheat belt.

One of these accessions, named WW15 by Dr J.R. Syme who selected it, proved to be outstanding. It had wide adaptability, with higher yield under good conditions than all other varieties, and resistance to most strains of stem rust then present in Australia. However, WW15 had red grain and was not acceptable to the Australian wheat industry which had a policy of producing only white wheats. The same line was released in New Zealand as Karamu, in California as Anza, and in the Sudan as Mexicani, but was rejected in Mexico because of susceptibility to strains of rust there (Syme and Pugsley, 1975).

In 1967, after its outstanding combination of characters was realised, Syme began developing white-grained derivatives of WW15. With so many excellent qualities, it was considered an ideal recurrent parent in a program of 'restricted back-crossing' (Pugsley, 1974). Among several parents used to donate white grain colour in this back-crossing program were another Mexican crossbred, WW80, and the Australian variety Heron (Fisher and Martin, 1974).

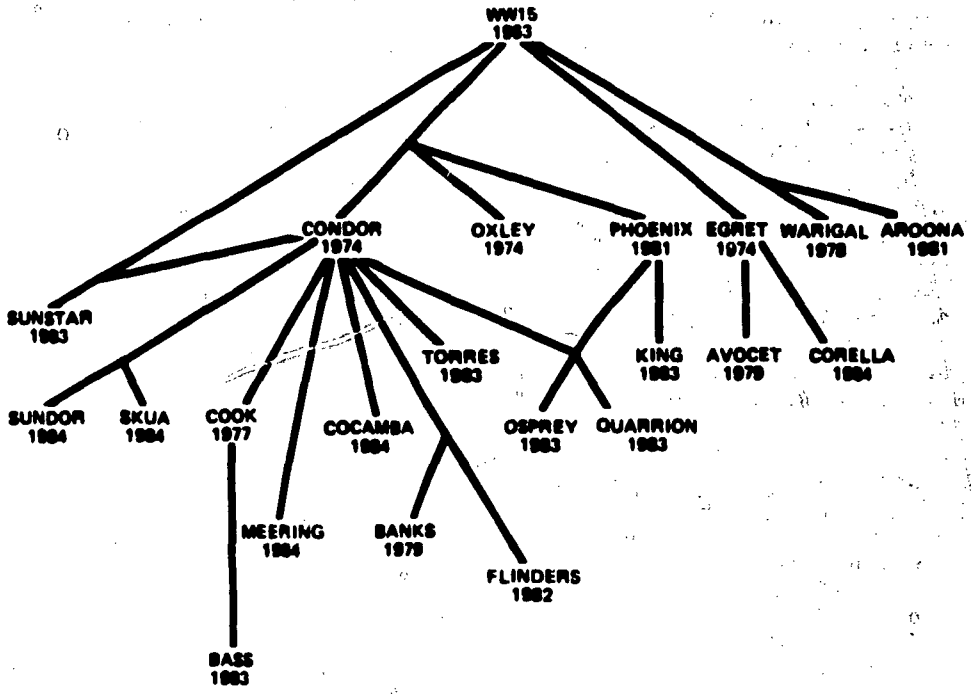
In subsequent selections, a number of valuable lines emerged, each different from the others but all noted for good field characteristics, high yield and excellent milling quality (Pugsley, 1974). Single back-crosses of WW15 made by Syme, and selected for white grain and improved quality, gave rise to the cultivars Condor (hard), Egret (soft) and Oxley (hard) (Martin, 1982). The first semi-dwarf cultivars released commercially in Australia (apart from the durum wheat Duramba in 1970 - see below) were Condor, Egret and Kite in 1973 and Oxley in 1974. Of these, Condor, Egret and Oxley were derived from CIMMYT material. These varieties outyielded all previous Australian wheats, with the exception of Halberd in some areas and Gamenya in others (mainly Western Australia), and were rapidly accepted by farmers, especially those in the more fertile red-brown earth areas (Wrigley and Rathjen, 1981). Many other semi-dwarf varieties have since been released to Australian growers.

WW15 has been used as a parent in a number of subsequent wheat varieties, and Condor has also been used extensively in Australian wheat breeding programs. The progeny of WW15 are shown in Figure 1.

Between 1973 and 1984, 58 new varieties were released for commercial cultivation in Australia. Of these, 45 (or 78 per cent) were based on CIMMYT material, 7 (12 per cent) were semi-dwarf of other origin, and 6 (10 per cent) were non-semi-dwarfs. A list of the semi-dwarf varieties released for commercial production in Australia is given in Table 1, and their pedigrees are shown in Table 2.

A total of 14 CIMMYT lines have appeared in pedigrees of commercial Australian varieties (Table 2). Apart from WW15 (which appears in 20 pedigrees) and WW80 (15 pedigrees), the CIMMYT lines most used in Australian breeding programs have been Sonora 64, Siete Cerros (also known as Kalyansona, 8156 or Mexico 22A), Ciano and Mexican Dwarf Durum. Thousands of other lines from CIMMYT have since been tested in Australia, including material from the International Bread Wheat Nurseries. Up to 1984, only three (Millewa, Hartog and Cranbrook) were released for commercial cultivation without further crossing.

Figure 1: Progeny of the Semi-Dwarf Wheat WW15 Developed in Australia.



Source: Adapted from Syme (1983), with assistance from J. Fisher.

Table 1: Semi-Dwarf Wheat Varieties Released in Australia(a)

Variety	Year of Registration	State of Origin
CIMMYT-BASED		
Duramba (d)	1970	N.S.W.
Condor	1973	N.S.W.
Egret	1973	N.S.W.
Oxley	1974	N.S.W.
Jabiru	1975	N.S.W.
Songlen	1975	N.S.W.
Timson	1975	N.S.W.
Warimba	1976	S.A.
Shortim	1977	N.S.W.
Cook	1977	Qld.
Durati (d)	1977	N.S.W.
Warigal	1978	S.A.
Avocet	1979	N.S.W.
Banks	1979	Qld.
Miling	1979	W.A.
Jacup	1979	W.A.
Millewa	1979	Vic.
Bindawarra	1980	S.A.
Hybrid Titan	1980	N.S.W.
Aroona	1981	S.A.
Sunkota	1981	N.S.W.
Bodallin	1981	W.A.
Canna	1981	W.A.
Eradu	1981	W.A.
Flinders	1982	Qld.
Kamilaroi (d)	1982	N.S.W.
Hartog	1982	Qld.
Suneca	1982	N.S.W.
Matong	1982	Vic.
Hyden	1982	W.A.
King	1983	Qld.
Bass	1983	Qld.
Torres	1983	Qld.
Osprey	1983	N.S.W.
Quarrion	1983	N.S.W.
Sunstar	1983	N.S.W.
Spear	1983	S.A.
Dagger	1983	S.A.
Bayonet	1984	S.A.
Cocamba	1984	Vic.
Wyuna	1984	Vic.
Meering	1984	Vic.
Skua	1984	N.S.W.
Corella	1984	N.S.W.
Sundor	1984	N.S.W.
Cranbrook	1984	W.A.
NON-CIMMYT SEMI-DWARFS		
Wren	1968	N.S.W.
Kite	1973	N.S.W.
Tincurrin	1977	W.A.
Lance	1978	S.A.
Harrier	1981	N.S.W.
Gutha	1982	W.A.
Takari	1983	N.S.W.
Sunelg	1984	N.S.W.

(a) This list may include some varieties with semi-dwarf parents but which do not themselves have the Rht genes.
(d) Durum wheat
Source: Ferns et al. (1975, 1978), Australian Wheat Collection Bulletin (various issues).

Table 2: Pedigrees of Semi-Dwarf Wheat Varieties

Variety	Pedigree
(a) CIMMYT-Based	
Duramba	Mexican Dwarf Durum/3* Durul
Condor	WW80/2*WW15
Egret	Heron/2*WW15
Oxley	WW80/2*WW15
Jabiru	Pinnacle/3/Pinnacle*2/Mexico 120//Pinnacle/PWTH
Songlen	Lerma Rojo 64/Sonora 64A/2/Timgalen sib.
Timson	Lerma Rojo 64/Sonora 64A/2/Timgalen sib.
Warimba	Mengavi/Mexico 22A
Shortim	Sonora 64/P41603//3*Timgalen sib.
Cook	Timgalen/Condor sib.//Condor
Durati	Zenati Bouteille/Wells//Mexican Dwarf Durum
Warigal	WW15/Raven
Avocet	WW119/WW15//Egret
Banks	PWTH/Condor sib.//2*Condor
Miling	Bencubbin/3/Charter//Sword/Kenya C8041/4/Mexico/5/Gamenya
Jacup	Bencubbin/3/Charter//Sword/Kenya C8041/4/Mexico/5/Gamenya
Millewa	Sonora 64/Yaqui 50E//Gaboto/Mexico 8156
Bindawarra	Mexico 120/Koda//Raven
Hybrid Titan	F1 hybrid between: Male sterile triticum timopheevi derivative/3/Gabo backcross/Gamut//Sonora 64A and Fertility Restorer/Gaines//Norin 53/3/Kite sib.
Aroona	WW15/Raven
Sunkota	Timson/IRN67-451
Bodallin	Bokal/Siete Cerros
Canna	Gamenya/Siete Cerros
Eradu	Ciano/Gamenya
Flinders	PWTH/Condor sib.//2*Condor
Kamilaroi	Durati sib./Leeds
Hartog	Vicam 71//Ciano 'S'/7C/3/Kalyansona/Bluebird
Suneca	Ciano/2/Spica/Sonora 64A
Matong	Kalyansona/Olympic
Hyden	Gamenya/Inia
King	PWTH/2*Condor sib.
Bass	Flinders sib./2*Cook
Torres	3Ag3/3*Condor
Osprey	Condor*2/WW33B
Quarrion	Condor/TA3PNB3P//WW33G/3/Condor/WW33B
Sunstar	Condor/4/WW15/3/Steinwedel/WC356//La Prevision
Spear	Sabre/MEC3//Insignia
Dagger	Sabre/MEC3//Insignia
Bayonet	Pitic sib./Glaive
Cocamba	AUS10894/4*Condor
Wyuna	DX3-134/Olympic
Meering	Condor selection
Skua	3Ag14/4*Condor
Corella	Huelquen/4/Mayo/Norin 10/2/Yaktana 54/3/Kenya/Lincoyan/5/2* Egret
Sundor	3Ag14/4*Condor
Cranbrook	Wren//Ciano 'S'/Noroeste 66/3/Zambezi

Table 2: Pedigrees of Semi-Dwarf Wheat Varieties (Continued)

Variety	Pedigree
(b) Non-CIMMYT-Based	
Wren	Norin 10/Brevor (Seln 14)//Javelin 48*2/3/Bearded Derivative of Javelin 48
Kite	Norin 10/Brevor (Seln 14)//4*Eureka 2/3/T-A/3* Falcon/4/T-A/4*Falcon/5/T-A/5* Falcon
Tincurrin	Gluclub/3/Chile 1B//Insignia/Falcon
Lance	Collafen/Raven
Harrier	Norin 10/Brevor (Seln 14)/Kite sib.//Kite
Gutha	Gamenya//Gabo*3/Khapstein/3/Falcon*3/Chile 1B
Takari	Kite/3/Frocor/Kentana//2*Festiguay
Sunelg	3Agl4/4*Kite sib.

Note: PWTH = Thatcher/Agropyron translocation//4*Heron

Source: Derived from Ferns *et al*. (1975, 1978) and Australian Wheat Collection Newsletter (various issues).

Semi-dwarf durum wheats from the Rockefeller Foundation program in Mexico were introduced into Australia in 1961 (Pugsley, 1964). After crossing with a local variety Dural, the semi-dwarf variety Duramba was released in 1970. This was the first commercial release of a semi-dwarf-based variety in Australia, although the very small size of the Australian durum industry made its impact of minor importance on a national scale. However, Abbott (1972) attributed a large increase in durum wheat production in 1971-72 to the new variety. Mexican Dwarf Durum was also used to produce another durum variety Durati, and in turn Durati was used to produce Kamilaroi. Durum wheat remains a very small part of Australia's total wheat production.

There were two main reasons that Australian breeders made such extensive use of the CIMMYT semi-dwarf material in preference to material from the U.S.A. and other sources (J. Fisher, personal communication). First, CIMMYT recognised at an early stage the benefits of semi-dwarfs and the emphasis on adaptability and earliness resulted in many CIMMYT lines performing well in Australia. Second, the CIMMYT international nurseries made it easy for breeders to obtain this material.

1.5 Aim of This Study

The aim of this study was to examine the adoption of the CIMMYT-based varieties and other semi-dwarfs in Australia and to determine the impact that these varieties have had on the Australian wheat industry. In particular the aim was to quantify the impact of these varieties on the value of wheat production in Australia. Sufficient data are available to examine the impact of CIMMYT material on Australian wheat production up to 1983.

1.6 Outline of the Study

In Section 2, the adoption of CIMMYT-based and other semi-dwarf varieties in Australia is examined. In Section 3, the advantages of these wheats in terms of yield, quality and disease reactions are discussed, and in Section 4 an examination is made of changes in other inputs. An analysis of the impact of CIMMYT-based varieties in Australia is carried out in Section 5, and an attempt is made to partition the contribution made to these varieties in Section 6.

2. ADOPTION OF CIMMYT-BASED AND SEMI-DWARF VARIETIES IN AUSTRALIA

2.1 Delay in Adoption

In comparison with other countries, the initial release and adoption of semi-dwarf wheats was delayed in Australia, partly by the industry's requirements that the wheats be white and of good milling quality, and partly because some local varieties were already relatively short and high-yielding (Syme and Pugsley, 1975). Not until 1974 did limited seed supplies of semi-dwarf varieties become available to commercial growers in Australia. In 1975, Condor, Egret, Oxley and Kite became significant varieties in the eastern and southern Australian wheat-growing areas.

In the period 1963-1981, no original CIMMYT lines were released directly for commercial production in Australia. The variety Millewa, registered in 1979, was the first direct selection from CIMMYT lines to be released for commercial production. All other introductions had to be crossed (or back-crossed) with other wheats (often other CIMMYT lines) before commercial varieties were produced. This need to undertake further crossing with the CIMMYT material delayed the release of this material to Australian farmers. The release of Hartog in 1982 was the first instance of a line from the CIMMYT program being directly released for commercial cultivation in Australia without further selection. Cranbrook (released 1984) is the second CIMMYT line to be so released.

This general need for further crossing makes this study a little ambiguous in that other improvements were often made at the same time. In this study, all varieties with CIMMYT lines in their parentage are considered as CIMMYT-based varieties (CBVs), even if the CIMMYT input was small. The relative contributions of CIMMYT and other breeding programs to these varieties is quantified in Section 6.

2.2 Total Semi-Dwarf Area

The adoption of semi-dwarf wheats in Australia is shown in Table 3. From the time of release in 1973, the adoption of the semi-dwarf varieties was rapid. By 1976, over 1.5 million hectares were sown to semi-dwarfs, over 1.2 million hectares of which were CBVs. By 1983 the area of semi-dwarfs had reached over 6.8 million hectares, or 53 per cent of total Australian wheat area. Of these semi-dwarf wheats, 5.8 million hectares (45 per cent of total wheat area) were CBVs.

2.3 Adoption by Variety

The adoption of individual semi-dwarf varieties is shown in Table 4. The initial rapid adoption of Condor and Oxley is evident, as is the later rapid adoption of Egret (which was initially released as an irrigated wheat, but subsequently recommended for dryland as well as for irrigation). Songlen, the first premium-quality semi-dwarf wheat, was adopted rapidly after its release in 1975. Later releases have been adopted more slowly, with the notable exception of Banks.

Table 3: Area Sown to Semi-Dwarf and Standard Wheats, Australia

Season	Semi-Dwarfs						Other(a)	Total
	CIMMYT-based		Other		Total		Varieties	Wheat Area
	000 ha	%	000 ha	%	000 ha	%	000 ha	000 ha
1974-75	91	1.1	28	0.3	119	1.4	8,288	8,407
1975-76	481	5.6	103	1.2	584	6.8	8,050	8,634
1976-77	1,287	14.2	278	3.1	1,565	17.3	7,489	9,054
1977-78	2,539	27.1	389	4.2	2,928	31.2	6,442	9,370
1978-79	3,122	30.2	399	3.9	3,521	34.1	6,800	10,321
1979-80	4,237	37.7	515	4.6	4,752	42.2	6,497	11,249
1980-81	4,607	40.3	624	5.5	5,231	45.7	6,205	11,436
1981-82	5,096	42.5	716	6.0	5,812	48.5	6,183	11,995
1982-83	5,059	43.0	708	6.0	5,767	49.1	5,989	11,756
1983-84(p)	5,892	45.3	992	7.6	6,884	52.9	6,133	13,017

a: Includes unspecified varieties.
p: Preliminary

Source: Australian Bureau of Statistics to 1978-79. Later figures estimated from data provided by the Australian Bureau of Statistics for New South Wales, Grain Elevators Board of Victoria, State Wheat Board (Queensland), South Australian Co-Operative Bulk Handling and Western Australian Co-Operative Bulk Handling.

Table 4: Adoption of Individual Semi-Dwarf Wheats, Australia
(000 hectares)

Variety	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Condor	54	371	930	1335	1276	1296	1258	1189	930	926
Egret	27	63	177	573	786	1348	1523	1191	841	485
Oxley	2	41	158	228	241	276	295	287	297	348
Jabiru			3	5	6	6	2	1	-	-
Songlen			13	368	605	600	523	668	378	463
Timson			-	19	81	81	43	28	7	5
Warimba				2	10	45	87	88	95	91
Shortim				-	38	205	196	157	107	120
Cook				2	73	356	513	737	558	717
Warigal						3	52	103	209	236
Avocet							7	62	180	142
Banks						1	59	257	876	1337
Miling						-	17	96	156	81
Jacup							-	-	-	12
Millewa							14	194	367	695
Bindawarra							1	13	20	34
Hybrid Titan								-	-	1
Aroona									3	24
Sunkota									6	47
Bodallin									-	30
Canna									-	17
Eradu									-	5
Flinders									12	50
Hartog									1	7
Durums	8	6	6	7	6	20	17	25	16	19
TOTAL CIMMYT BASED	91	481	1287	2539	3122	4237	4607	5096	5059	5892
Kite	28	103	278	389	399	471	513	560	503	633
Tincurrin					-	41	78	101	122	131
Lance						3	33	55	67	68
Harrier									16	160
TOTAL OTHER	28	103	278	389	399	515	624	716	708	992
TOTAL SEMI-DWARF	119	584	1565	2928	3521	4752	5231	5812	5767	6884

- not recorded separately

Source: Australian Bureau of Statistics to 1978-79. Later figures estimated from data provided by the Australian Bureau of Statistics for New South Wales, Grain Elevators Board of Victoria, State Wheat Board (Queensland), South Australian Co-Operative Bulk Handling and Western Australian Co-Operative Bulk Handling.

2.4 Adoption by State

The adoption of semi-dwarfs by State and variety is shown in Tables 5 to 9 and illustrated in Figure 2. Semi-dwarfs have been most rapidly adopted in New South Wales and Queensland (Tables 5 and 7) where, by 1983, about 75 per cent of the wheat area was sown to CBVs and over 85 per cent to all semi-dwarfs. Adoption was slower in Victoria and South Australia (Tables 6 and 8), due largely to the apparent superiority of Olympic and Halberd in many regions of these States. Nevertheless, by 1983, semi-dwarfs occupied 65 per cent of the wheat area in Victoria (virtually all CBVs) and 52 per cent in South Australia (mostly CBVs).

While semi-dwarfs made a large and rapid impact in eastern and southern Australia, their contribution in Western Australia has been small, reaching only 14 per cent of total wheat area by 1983 (Table 9). Of this, only 9 per cent were CBVs. Syme (1983) could find no precise explanation why Western Australia's was such an exception, although presumably it is related to the combination of soils and climate in the Western Australian wheat belt, and possibly to the breeding strategies of Western Australian breeders. Byerlee (1983) pointed out that a large part of the variation in adoption of semi-dwarfs followed rainfall patterns. The use of semi-dwarfs was favoured in areas with a higher rainfall and/or longer growing season. Byerlee noted that Western Australia is a drier State, where even in the better rainfall areas the growing season is shorter than in the eastern States. In all States except Victoria, significant areas were sown to semi-dwarfs of non-CIMMYT origins, notably Kite (Tables 5 to 9).

2.5 Adoption by Wheat Type

Australian wheats are predominantly spring wheats and all are white-grained. Of the 38 hard wheats released in Australia between 1973 and 1984, 36 (or 95 per cent) were semi-dwarfs. Of the 15 soft wheat released over the same period, 11 (or 73 per cent) were semi-dwarfs. The 3 wheats classified as winter wheats over this period were CIMMYT-based semi-dwarfs, as were the two durum wheats (M. Mackay, Australian Wheat Collection, personal communication).

2.6 Adoption by Wheat Class and Grade

There are no direct data which allow a clear picture to be given of the adoption of CBVs by wheat class and grade. Although separate data are not collected for individual durum wheats, Duramba and Durati became the dominant varieties for the Australian Durum class shortly after their release in 1970 and 1977, respectively. More recently, Kamilaroi has become the dominant variety.

For the premium wheat types, Australian Prime Hard and Australian Hard, Songlen (released in 1975) was rapidly adopted. Whilst most Prime Hard and Hard wheat varieties are semi-dwarfs, a large proportion are Kite or Kite derivatives, and these are based on the original U.S.A. material.

Figure 2: Percent of Total Wheat Area Sown to Semi-Dwarf Varieties.

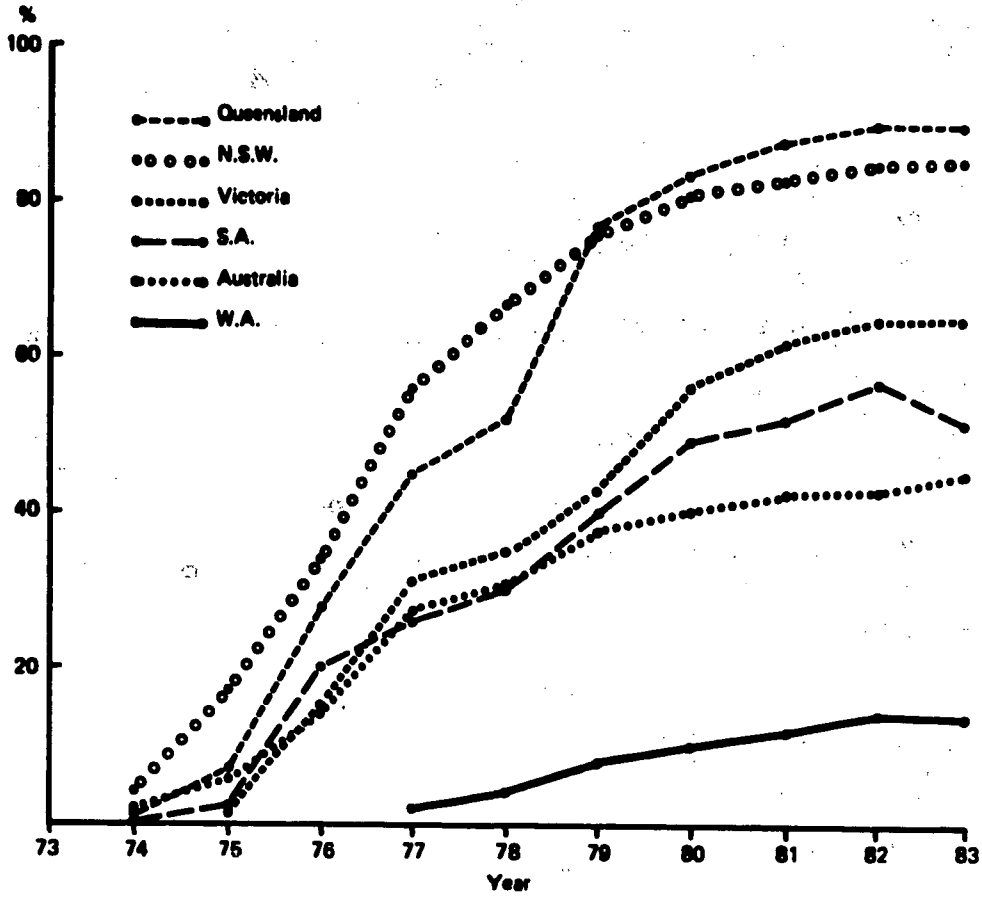


Table 5: Adoption of Semi-Dwarf Wheats, New South Wales
(Percentage of area sown to wheat)

Variety	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
CIMMYT-based										
Condor	2.0	12.1	22.5	26.4	25.2	23.9	22.7	20.6	17.5	12.0
Egret	1.0	2.2	4.5	11.4	14.7	20.7	23.6	19.0	10.3	4.2
Oxley	-	-	0.2	0.3	0.2	0.1	0.1	0.2	0.5	0.6
Jabiru		-	0.1	0.2	0.2	0.1	..	..	-	-
Songlen		-	0.4	10.2	16.8	15.0	14.0	16.8	10.2	10.6
Timson		-	-	0.6	2.6	2.3	1.3	0.8	0.2	0.1
Shortim				-	1.2	5.3	5.6	4.3	3.2	3.1
Cook				-	0.3	3.0	6.8	10.0	9.4	9.6
Avocet						-	0.2	1.7	4.4	2.7
Banks						-	0.3	2.6	20.1	26.0
Millewa						-	-	-	0.8	2.6
Sunkota									0.2	1.2
Durums	0.3	0.2	0.2	0.2	0.2	0.6	0.5	0.7	0.5	0.5
TOTAL CIMMYT	3.3	14.5	27.9	49.3	61.4	71.0	75.1	76.7	77.3	73.2
Other Semi-Dwarf										
Kite	1.0	2.8	5.8	6.4	5.3	5.2	6.1	6.9	7.4	8.3
Harrier									0.5	4.0
Total Other	1.0	2.8	5.8	6.4	5.3	5.2	6.1	6.9	7.9	12.3
TOTAL SEMI-DWARF	4.3	17.3	33.7	55.7	66.7	76.2	81.2	83.6	85.2	85.5

- Not recorded separately
.. Less than 0.05 per cent

Source: Australian Bureau of Statistics, and Grain Handling Authority of New South Wales.

Table 6: Adoption of Semi-Dwarf Wheats, Victoria
(Percentage of area sown to wheat)

Variety	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
CIMMYT-based										
Condor	-	1.4	12.5	23.2	23.0	19.4	23.1	21.3	18.1	18.4
Egret	-	-	2.1	7.7	11.2	22.1	28.5	23.5	13.6	6.3
Oxley	-	-	-	0.3	0.7	1.8	3.5	3.0	5.5	6.3
Avocet							0.1	1.9	3.0	2.0
Banks							-	0.1	2.5	3.6
Millewa							0.8	12.3	22.1	28.0
Bindawarra							..	..	0.1	0.3
Total CIMMYT	-	1.4	14.6	31.2	34.9	43.3	56.0	62.1	64.9	64.9
Other Semi-Dwarf										
Kite	-	-	-	-	-	-	0.4	0.3	0.1	0.1
Total Other	-	-	-	-	-	-	0.4	0.3	0.1	0.1
TOTAL SEMI-DWARF	-	1.4	14.6	31.2	34.9	43.3	56.4	62.4	65.0	65.0

- Not recorded separately
.. Less than 0.05 per cent

Source: Australian Bureau of Statistics and Grain Elevators Board of Victoria.

Table 7: Adoption of Semi-Dwarf Wheats, Queensland
(Percentage of area sown to wheat)

Variety	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
CIMMYT-based										
Oxley	0.4	7.0	25.4	33.1	24.9	18.9	13.5	9.9	8.9	10.5
Songlen		-	-	3.3	10.0	10.7	8.8	8.3	6.8	4.7
Timson		-	-	-	-	0.2	-	-	-	-
Shortim					-	2.8	1.6	0.6	0.3	0.1
Cook				0.4	8.8	31.4	39.1	39.7	32.9	32.4
Banks						0.2	6.7	17.3	25.0	24.9
Flinders								..	1.5	4.8
Hartog								..	0.1	0.7
Total CIMMYT	0.4	7.0	25.4	36.8	43.7	64.2	69.7	75.8	75.5	78.1
Total Other										
Kite	-	0.4	2.9	8.1	8.5	12.4	14.2	12.6	14.3	11.4
Harrier										0.1
Other semi-dwarf	-	0.4	2.9	8.1	8.5	12.4	14.2	12.6	14.3	11.5
TOTAL SEMI-DWARF	0.4	7.4	28.3	44.9	52.2	76.6	83.9	88.4	89.8	89.6

- Not recorded separately
.. Less than 0.05 per cent

Source: Australian Bureau of Statistics, and State Wheat Board (Queensland).

Table 8: Adoption of Semi-Dwarf Wheats, South Australia
(Percentage of area sown to wheat)

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Variety										
CIMMYT-based										
Condor	-	1.8	9.5	12.1	12.9	13.6a	12.8a	12.2a	9.1a	8.2a
Egret	-	0.1	1.4	2.0	2.2	4.9a	5.3a	3.5a	3.9a	2.3a
Oxley	-	-	0.2	1.0	3.0	6.5a	10.3a	10.3a	10.0a	6.3a
Jabiru		-	-	-	-	..a	0.1a	..a	..a	..a
Warimba			..	0.2	0.8	2.6a	2.8a	1.2a	0.6a	0.5a
Cook				-	-	0.3a	0.4a	0.6a	0.5a	0.3a
Warigal					-	0.2a	3.6a	7.2a	14.7a	14.3a
Avocet						-	-	0.1a	0.1a	..a
Millewa						-	..a	0.6a	3.4a	4.5a
Bindawarra						-	0.1a	0.9a	1.5a	1.8a
Aroona						-	-	..a	0.2a	1.5a
Total CIMMYT	-	1.9	11.1	15.3	18.9	28.1a	34.4a	36.7a	44.0a	39.7a
Other Semi-Dwarf										
Kite	0.1	2.3	9.2	10.3	11.0	11.3a	12.1a	12.0a	9.0a	9.2a
Lance						0.2a	2.3a	3.2a	3.5a	2.6a
Total Other	0.1	2.3	9.2	10.3	11.0	11.5a	14.4a	15.2a	12.5a	11.8a
TOTAL SEMI-DWARF	0.1	4.2	20.3	25.6	29.9	39.6a	48.8a	51.8a	56.5a	51.5a

a Percentage of deliveries to South Australian Co-Operative Bulk Handling Limited, rather than of area sown.
- Not recorded separately
.. Less than 0.05 per cent

Source: Australian Bureau of Statistics and South Australian Co-Operative Bulk Handling Limited.

Table 9: Adoption of Semi-Dwarf Wheats, Western Australia
(Percentage of area sown to wheat)

Variety	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
CIMMYT-based										
Condor	-	-	-	-	-	0.1	-	-	-	-
Egret	-	-	-	1.7	3.8	6.0	5.9	5.4	5.5	3.7
Warimba			-	-	-	0.2	1.1	1.6	1.8	1.8
Warigal									0.2	0.2
Miling						-	0.4	2.1	3.2	1.7
Jacup							-	-	-	0.3
Millewa							-	-	-	0.4
Bodallin									-	0.6
Canna									-	0.4
Eradu									-	0.1
Total CIMMYT	-	-	-	1.7	3.8	6.3	7.4	9.1	10.7	9.2
Other Semi-Dwarf										
Kite	-	-	-	0.2	0.6	0.8	0.8	0.6	0.7	1.0
Tincurrin						1.0	1.8	2.2	2.5	2.8
Lance								0.2	0.4	0.6
Total Other	-	-	-	0.2	0.6	1.8	2.6	3.0	3.6	4.4
TOTAL SEMI-DWARF	-	-	-	1.9	4.4	8.1	10.0	12.1	14.3	13.6

- Not recorded separately
.. Less than 0.05 per cent

Source: Australian Bureau of Statistics, Co-Operative Bulk Handling of Western Australia.

Australian Soft is predominantly semi-dwarf. The most important soft wheats in the period since 1974 have been the CBVs, Egret and Avocet, and the non-CIMMYT semi-dwarf, Tincurrin.

For Australian Standard White (ASW), the predominant class of Australian wheat, the picture is mixed. In eastern and southern Australia, adoption of semi-dwarfs was rapid, and a large majority of ASW wheat from these areas is from CBVs. Only the lack of a suitable competitor for the early-sown variety Olympic, and the superiority in some districts of the South Australian-bred Halberd, prevented ASW wheat from being almost totally from semi-dwarfs in these States. However, Western Australia, the largest producer of ASW wheat, has defied the trend and, in many areas, semi-dwarfs are generally inferior to varieties such as Gamenya. On a national basis, therefore, ASW wheat would have the lowest proportion of CBVs because of the very low adoption in Western Australia.

2.7 Contribution to Production

There are no data available at a national level on wheat production by variety. The only data relate to area sown or to deliveries to the Australian Wheat Board. To the extent that semi-dwarfs are higher yielding than other varieties, it would be expected that their contribution to production would be greater than their contribution to area planted (Dalrymple, 1980).

Data on deliveries to the Australian Wheat Board by variety may not accurately reflect the mix of wheats in production, since some 5-10 per cent of production is normally retained on farms for feed and seed. Also, there may be mis-statement of varieties on delivery, especially since some dockages and premiums are determined on a varietal basis.

As a result, no specific estimates of the contribution of CBVs and semi-dwarf wheats to Australian production are attempted here. However, the analysis of the economic impact of these wheats (Section 5) is carried out on the basis of the gross value of production.

3. ADVANTAGES OF CIMMYT-BASED VARIETIES

3.1 Yields of CIMMYT-Based Varieties (CBVs)

Syme and Pugsley (1975) indicated that the yield advantage of WW15 over the best commercial varieties then available in Queensland was of the order of 10-30 per cent. They suggested that, since the grain size of WW15 was not large, the high yield potential came from its ability to set larger numbers of grains per unit area. Syme (1969, 1970) found that under Australian conditions the yield advantage of WW15 and other semi-dwarfs resulted from increased efficiency of grain production relative to vegetative growth rather than resistance to lodging or day-length insensitivity. The reduced lodging (through reduced plant height) was less important since lodging is not a widespread problem in Australia.

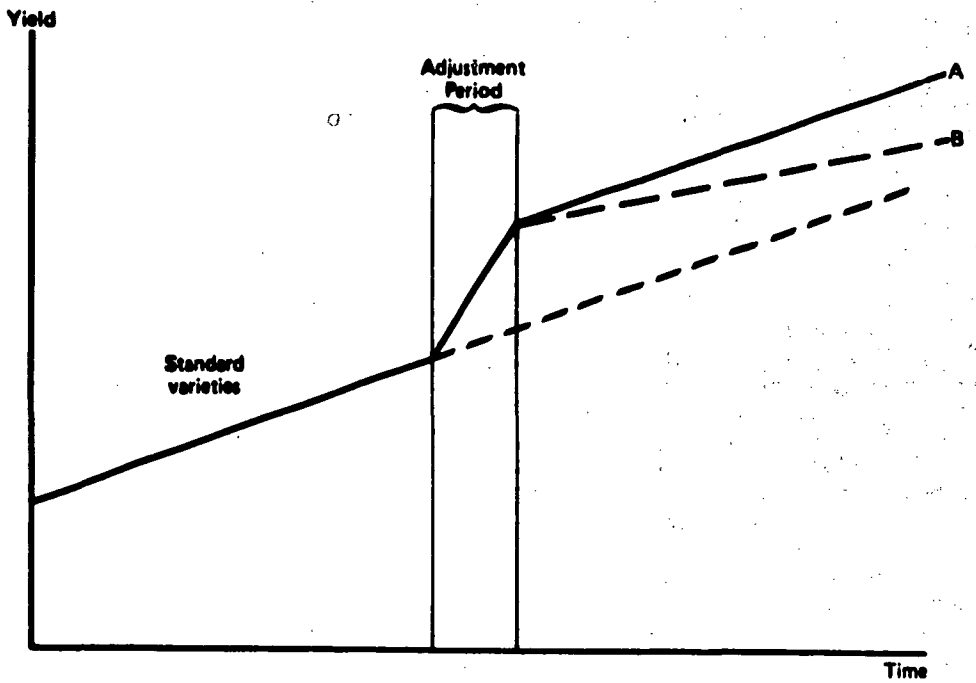
It is necessary to estimate the impact of semi-dwarf varieties with some caution. Although virtually all semi-dwarfs released commercially in Australia have involved selection from, or further crossing with, CIMMYT material, other facets of progress in breeding have been incorporated at the same time. Thus, ideally, the study should make a comparison between the progress (in yield and quality) which has actually occurred in the presence of CIMMYT material, and that which would have occurred without the CIMMYT material.

The nature of the impact of new varieties is important to the form of analysis to be used. The variety can lead to a permanent shift to a higher yield potential trend line, with the same slope, or the gain can be a 'one-off' increase that is eroded over time (Figure 3). Breeders appear to have made regular, though variable, progress with yields throughout the past 80-100 years (O'Brien, 1982; Reeves, Perry and Johnston, 1984). Thus the yield advance as a result of the use of CIMMYT lines should be discounted for the progress that could have been expected in the absence of this material. The question is whether the CIMMYT material allowed merely a once-and-for-all jump in yields that will be eroded over time, or whether it allowed a quantum leap from which progress can be expected to continue. While the latter would be most likely, it appears that in the decade since the release of Condor, Egret and Oxley, only slow progress has been made with yields, although there has been improved disease resistance. There may be a case for discounting some of the yield progress over time because of the erosion of that advantage. The theory of cycles in research productivity (Evenson and Kislev, 1975) would, if correct, have considerable bearing on the likely rate of progress with and without the new material from the CIMMYT program.

Nevertheless, the analysis used here is based on the proposition that the semi-dwarf varieties have led to a permanent upward shift in yield potential (that is, A rather than B in Figure 3). Given that this is the case, the important question is the size of that upward shift.

Relative yields will vary with different environmental conditions. An ideal study of this kind would be disaggregated into relatively

Figure 3: Effect of New Germplasm on Rate of Yields Increase.



small geographical areas, to allow for differences within States. However, for simplicity, this study disaggregates only on a State basis, and the results are qualified to this extent.

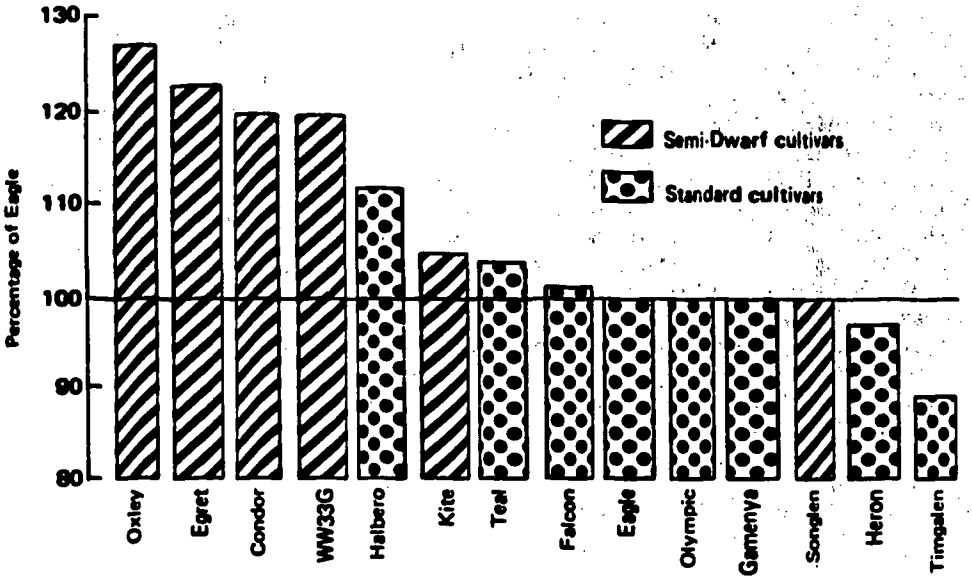
As there are no reliable data on yields of individual varieties at the farm level, the only method of estimating the relative yields of CBVs is to use trial results. Many yield trials have been conducted in which semi-dwarfs have been compared with standard varieties. For example, Martin (1981) demonstrated the yield advantage of semi-dwarf wheats in central and southern New South Wales (see Figure 4). From these data, an approximate yield advantage of 10 per cent could be deduced for the CBVs over the leading non-CIMMYT varieties, Kite and Halberd. In a series of trials at Wagga Wagga (G. Murray, personal communication), the semi-dwarfs were shown to have clear yield advantages over standard cultivars. However, the advantage of CBVs over Kite was less evident, since the yield of Kite was found to be not significantly below Condor and Egret in these trials. An estimate of the yield advantages of CBVs in Victoria can be obtained from O'Brien (1982), where a yield advantage of approximately 10 per cent was again evident. Reeves, Perry and Johnston (1984) have provided some information on yields in Western Australia, where varieties with CIMMYT backgrounds (Egret, Warimba and Miling) appeared to have no overall yield advantage. Only with the release of Bodallin in 1982 did CIMMYT-derived material produce a generally higher-yielding variety, and even then it was still below the yield level of the non-CIMMYT semi-dwarf Tincurrin. No similar data have been located for other parts of the Australian wheat belt.

The use of these results for each State requires the compilation of results from trials in all parts of the wheat belt over a number of years. The greatest difficulty with this approach is that the varieties included in the trials vary from site to site, as well as from year to year. Although a procedure such as modified joint regression (Digby, 1979) could be useful, the results would still be subject to variation due to the differences in the varieties grown in the trials in each State or region.

One set of trials which overcomes some of these difficulties is the Interstate Wheat Variety Trials. Groups of approximately 20 advanced lines are grown, with several check varieties, in each of the mainland States in two successive years; the first generally at one site in each State, and the second at several sites in each State. Thus, in each year two sets of trials are conducted: a new group of lines ('year 1' of the trials), and further, more extensive, trials with the previous year's group ('year 2'). As well as the consistency of the cultivars included at each site, the Interstate Wheat Variety Trials have the advantage that the results are readily available.

However, there are a number of difficulties associated with using these results to draw inferences about the contribution of new varieties to improved yields on farms. Trial yields are measured at limited locations and, because they are drawn from a small geographical area, the results may not be widely applicable. Also, where they are aggregated over a wide range of environments they may understate the gains; for example, one variety may have a yield advantage of up to 10 per cent in northern N.S.W. but be inferior to

Figure 4: Yields of Semi-Dwarf and Standard Cultivars: Southern New South Wales.



Source: Re-drawn from Martin (1981).

many varieties in southern N.S.W.; another may be similarly superior in the south and inferior in the north. If these varieties are included in trials over all of N.S.W., the net result may be a yield gain of less than 5 per cent for each, whereas the true impact may be that each in its optimum region has a yield advantage of 10 per cent. Thus averaging across sites leads to a likely underestimate of the yield superiority of the new varieties. The data from O'Brien (1982) and Reeves, Perry and Johnston (1984) also suffer in this way.

In addition, these yields are based, necessarily, on experiments. Davidson and Martin (1965) have shown that yields on farms do not equal yields in experiments. The present analysis implies that a given percentage increase in experimental yields is reflected by the same percentage increase in farm yields.

The yield comparison required between CBVs and other varieties is not between the CBVs released since the mid-1970s and the earlier non-CIMMYT wheats, but between CBVs and what would have been the yields if CBVs had not been available. Interstate Wheat Variety Trials allow a comparison to be made between the yields of the most advanced lines of CBVs, other semi-dwarf and standard lines. Thus the overall yield advantage of CBVs can be estimated for each State. It is assumed that the yield advantage revealed in these trials is the same inherent advantage which CIMMYT-based material released to growers could expect to have over the non-CIMMYT material which would have been released if the CIMMYT-based material had not been available. This involves the assumption that, had the CIMMYT material not been available, and thus resources devoted to breeding CIMMYT material released for use in breeding standard lines, there would have been no increased rate of improvement in the standard lines.

The results are, of course, also dependent on the lines chosen for the trials and the check varieties which are included. It is assumed that the varieties chosen as checks represent the standard in each State, and that the lines being compared are representative of the new wheats in the process of being released.

The procedure for estimating the yield advantage for CBVs is detailed in Appendix A. The pedigree of each line was examined and, from its parentage, it was classified as 'CIMMYT-based', 'other semi-dwarf' or 'standard' variety. Where the origin was unknown or unclear, the line was omitted. The mean yields for each group were then calculated for each site. This was repeated for the years 1975 to 1982. The overall average of each group was estimated for each State. In total, data covered 176 site-years, with an average of 25 lines at each site and an average of 4 sites per State per year.

An alternative approach would have been to compare the best varieties of each group, rather than the average of the groups. This was not used because the aim was to identify the benefits of the CIMMYT-based and semi-dwarf varieties as a group rather the possible advantages of one particular variety, since farmers in any State grow a mix of varieties and do not rely on only one variety.

The overall yield advantages were calculated as a weighted average of these annual figures (Table 10). The advantage of CIMMYT-based varieties over non-CIMMYT ones was 7.1 per cent[3]. There was wide variability between States: the advantage of CBVs was 9.0 per cent for New South Wales, 9.2 per cent for Queensland, 8.1 per cent for Victoria, 6.1 per cent for South Australia and 2.7 per cent for Western Australia. The ranking of these mean yield increases by State is generally in line with the rate of adoption of CBVs in each State.

As mentioned earlier, this study is somewhat ambiguous, as there were other sources of semi-dwarf genes besides those obtained from CIMMYT material, and the need for crossing with better-adapted lines meant that other characteristics were also incorporated at the same time. In order to examine the impact of semi-dwarfs as a group, the analysis was repeated comparing all semi-dwarfs (that is CBVs and other semi-dwarfs) with standard varieties. The weighted average of CIMMYT-based and other semi-dwarf lines was compared with the yield of standard varieties from the Interstate Wheat Variety Trials. The results are shown in Table 10. The overall yield advantage of semi-dwarfs was 8.6 per cent. In all States the yield advantages are higher than for CIMMYT-based lines alone: 12.9 per cent for Queensland, 10.2 per cent for Victoria, 9.4 per cent for New South Wales, 8.0 per cent for South Australia and 5.5 per cent for Western Australia.

3.2 Area Changes Due to CBVs

It is possible that the wide adaptability of the semi-dwarfs, especially the WW15 derivatives, has been a contributing factor in the rapid increase in the area sown to wheat in Australia in recent years. There is no direct evidence on this question, although it is likely that any general yield increase would have made wheat a relatively more profitable enterprise for farmers, compared to alternative enterprises. However, while the wheat area has increased in all States, the greatest increases since the early 1970s have taken place in Western Australia, where semi-dwarfs have had a minimal effect. Thus, it is unlikely that any major contribution to the changes in area, over and above the yield increases, can be identified and quantified in a study such as this.

3.3 Quality of CBVs

Because of the insistence of the Australian wheat industry on white wheats, the major defect of WW15 for commercial use was its red grain colour. However, Syme and Pugsley (1975) indicated that it was also of poor quality for both bread and biscuit production. For bread, the protein level was low and loaf texture was uneven, and being a hard wheat WW15 was unsuitable for biscuits. However, it had a very high milling yield and test weight.

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3. In year 1 (or series A) of the trials, a CBV was the overall leading variety in each year of trials from 1975 to 1982. In year 2 (or series B), the overall leading variety was a CBV in all years except 1977 and 1979, when an 'other semi-dwarf' line was highest-yielding.

Table 10: Yield Comparisons from Interstate Wheat Variety Trials(a) 1975 to 1982

	Percentage yield advantage of:	
	CIMMYT-based lines over non-CIMMYT-based lines	Semi-dwarf lines(b) over non-semi-dwarfs
	%	%
New South Wales	9.0	9.4
Victoria	8.1	10.2
Queensland	9.2	12.9
South Australia	6.1	8.0
Western Australia	2.7	5.5
AUSTRALIA	7.1	8.6

a: Results from Interstate Wheat Variety Trials, series A and B, from 1975 to 1982. Results shown are weighted averages of A and B series results, weighted by the number of entries.
b: Includes CIMMYT-based lines.

Source: Calculated from analysis described in text.

Marshall, Ellison and Mares (1984) indicated that a major reason for the improvement in milling quality in Australian wheats in recent years can be traced to WW15, which gave a high flour yield when milled. WW15 passed this characteristic on to derivatives such as Cook, Condor and Banks. Marshall, Ellison and Mares attributed much of this improvement in milling yield to improvement in the ease of separation in milling rather than any increase in the proportion of endosperm in the grain. Syme, Law and Rees (1980, p.42) had previously noted the outstanding milling quality of Cook:

> "The combination of high flour yield with low flour colour suggests that it has better milling quality than all other Australian varieties."

With respect to dough quality, some of the progeny of WW15 have been the subject of some controversy. While varieties such as Cook have some outstanding dough properties, other CBVs have had only marginal dough properties for Australian Standard White. Higher yields were often associated with lower levels of protein on the infertile Australian soils, and the dough was then found to be of inadequate quality for many end-uses at low protein levels. Curtis (1982, p. 15) stated that 'many researchers have reported an apparent link between dwarfing genes and a reduction in protein content'.

Of the original Australian CBVs, Condor was most acceptable as a moderately hard wheat with high milling extraction, excellent baking quality and good protein content (Syme and Pugsley, 1975). On the other hand, the quality of the soft milling wheat Egret caused considerable concern for bakers as dough made from this variety lacks extensibility (Wrigley and Rathjen, 1981). Egret was initially released as a soft biscuit-wheat for the relatively small irrigated areas of southern New South Wales. It was later recommended for dryland cultivation following evidence of its yield potential and in order to maintain a balance of wheat types in the ASW class in southern N.S.W. Following this change in recommendation, Egret has since been regarded as of inferior quality for ASW, and the Australian Wheat Board has applied a dockage to it since 1982 (that is, growers delivering Egret have received a price lower than ASW). Oxley was accepted as Prime Hard in Queensland, but was initially considered to be too hard at lower protein levels for ASW, causing difficulties for some end-uses. However, as the markets have changed and the overall hardness of ASW has increased in recent years, Oxley is now considered an acceptable ASW-type for Victoria and southern New South Wales.

Another WW15 derivative was the line with winter habit, WW33G, developed by Dr Pugsley. It was rejected for commercial release on the grounds of inferior dough qualities (it has since been released in California as Phoenix). After a delay of about eight years, suitable quality wheats with winter habit became available to growers in Australia, with the release of Quarrion, Osprey and King, in 1983.

Thus, the overall impact of CBVs on the quality of Australian wheat has been mixed. While many lines have led to quality improvements, others have caused difficulties because their dough properties were judged to be unsuitable for the ASW category.

3.4 Impact of CBVs on Disease Resistance

3.4.1 Stem rust and leaf rust

Because of the importance of the wheat diseases stem rust (*Puccinia graminis*) and leaf rust (*Puccinia recondita*) in Australia, all present Australian varieties have been selected in the presence of these diseases. All eastern State varieties need some resistance to these diseases. However, many varieties grown in southern and Western Australia do not have a high level of resistance to these diseases. While the breeding of stem rust resistant cultivars is not technically difficult, the problem is made complex by the constant changes and mutations that take place in the rust pathogens. Many cultivars originally resistant to known strains of the disease have since become susceptible to newer strains.

Much of the semi-dwarf material introduced from the CIMMYT program has resistance to Australian races of stem and leaf rust. For example, WW15 had resistance to most Australian races of stem rust, and had mixed reaction to leaf rust (Syme and Pugsley, 1975). It appears that the CIMMYT material has contributed a broader background of durable resistance genes to Australian varieties (R.A. McIntosh, personal communication).

3.4.2 Stripe rust

Since stripe (or yellow) rust of wheat (*Puccinia striiformis*) was first recorded in Australia only in 1979, current commercial Australian varieties have been selected in the absence of this disease. The introduction from CIMMYT of semi-dwarf material which had been selected for stripe rust resistance led to the fortuitous incorporation of stripe rust resistance in many varieties (C. Wellings, personal communication). This had particular impact in Queensland and N.S.W. where, due to the heavier reliance of these States on CBVs, the resistance of cultivars to this disease is greatest.

However, research is now showing that the major genes for stripe rust resistance found in CIMMYT material are relatively few and can be quickly overcome by mutation in the pathogen. Overseas workers have suggested that some CIMMYT lines such as Anza (that is, WW15) have durable resistance (Johnson, 1983), and this character may have been transferred to Australian varieties such as Condor, Cook and Banks.

The introduction of dwarfing genes through CIMMYT germplasm has thus resulted in the chance introduction of stripe rust resistances, some of which may be more useful and long-lasting than others (C. Wellings, personal communication).

3.4.3 Septoria diseases

There are two septoria diseases of agricultural significance in Australia: septoria tritici blotch (STB) (*Mycosphaerella graminicola*), which is most important in the south-eastern States; and septoria nodorum blotch (SNB) (*Leptosphaeria nodorum*), which has been important in Western Australia.

Shorter-strawed wheats are more prone to damage from these diseases because of wetter conditions in the denser crop canopy (B. Ballantyne, personal communication). However, certain of the semi-dwarf wheats, such as Oxley, Cook, Banks, Millewa, Aroona and Hartog, have partial STB resistance. Therefore, many of the Australian semi-dwarf varieties have had better STB resistance than the varieties they have replaced. No very susceptible wheat varieties have been released in the eastern States since the semi-dwarfs came into prominence (B. Ballantyne, personal communication). Thus, the level of resistance to STB has increased, despite the shorter-strawed wheats being inherently more prone to the disease.

There has so far been little impact on SMB through the CIMMYT material, since this disease is only important in Western Australia where the CBVs have made the smallest impact. However, lines with SMB resistance are being evaluated.

3.4.4 Other diseases

CIMMYT lines such as WW15 provided a useful source of resistance to Barley Yellow Dwarf Virus, a disease of potential importance in southern parts of Australia. Similarly, CIMMYT materials can introduce useful resistance to other diseases not at present in Australia, since the lines are likely to have been selected in their presence.

4. CHANGES IN OTHER INPUTS

There are many other inputs in wheat production apart from the varieties grown. Ideally, the approach used should take account of the effects of changes in inputs such as rainfall, fertilisers, herbicides and tillage methods, and the effects of interactions between these inputs and the varieties used. This is discussed more fully in Brennan (1984) where it is argued that a complete evaluation of the contribution of new varieties should involve some account of changes in other inputs, perhaps by using a regional production function.

The aggregated nature of this study makes this approach difficult. It requires the development of a rainfall measure for each State, and the large geographical differences within States mean that such a measure may not be sufficiently precise to be useful. Also, the production function approach requires detailed data on the use of inputs such as fertilisers and herbicides on wheat farms in each State. Such detailed data are not generally available for wheat farms.

There are some data specific to wheat crops on the fertilisers applied and the area of wheat fertilised (see Tables 11 and 12). Since 1973-74, even though there has been an increase in the area of wheat fertilised (Table 11), the proportion of the crop that has been fertilised has changed little. Similarly, although the amount of superphosphate used on wheat crops has increased since 1976-77, the average rate per hectare has changed little over that period (except for a sharp decline in 1984). The amount of other (including mixed and nitrogenous) fertilisers applied to wheat has increased rapidly since the early 1970s. This may reflect the rapid increase in the area sown to wheat in Western Australia, since about three-quarters of these other fertilisers are used in that State. The figures may also reflect a shift from single superphosphate to double and triple super and to compound fertilisers. Thus, there may have been no overall increase in the rate of fertilisers applied to wheat crops. As there has been little change in the fertiliser input per hectare in the States in which semi-dwarfs have made a significant impact since the mid-1970s, this suggests that little would be lost in this analysis by ignoring the interaction between fertiliser and varieties at the aggregated level.

Data are not available to enable a similar examination to be made of changes in herbicides used on wheat over the same period. Similarly, statistics are inadequate to enable an assessment of changes in tillage practices and rotations to be made, although in some States there have been rapid changes towards the replacement of traditional methods of cultivation with methods based on the use of herbicides (Pratley and Cornish, 1985). At the moment, there is no firm evidence of an interaction between these methods and the varieties grown.

Table 11: Area of Wheat and Area Fertilised, Australia

Season	Area sown to wheat	Area fertilised	Area unfertilised	Percentage fertilised
	000 ha	000 ha	000 ha	%
1973-74	8,948	7,147	1,801	80
1974-75	8,308	6,358	1,950	77
1975-76	8,555	6,276	2,279	73
1976-77	8,956	6,745	2,211	75
1977-78	9,955	7,827	2,128	79
1978-79	10,249	8,004	2,245	78
1979-80	11,153	8,607	2,545	77
1980-81	11,283	8,723	2,560	77
1981-82	11,885	9,361	2,524	79
1982-83	11,546	9,299	2,247	81
1983-84	12,931	9,672	3,259	75

Source: Industries Assistance Commission (1982), and Australian Bureau of Statistics 7411.0 (1985), and previous issues.

Table 12: Use of Fertiliser on Wheat, Australia

Season	Quantity used (000 t.)		Quantity per hectare sown (kg)		
	Superphosphate	Other Fertilisers(b)	Superphosphate	Other	Total
1973-74	804(a)	88	90(a)	10	98
1974-75	728(a)	105	88(a)	12	99
1975-76	665(a)	120	78(a)	14	91
1976-77	615	161	69	18	86
1977-78	635	213	64	23	91
1978-79	634	213	62	21	82
1979-80	716	258	64	23	87
1980-81	756	238	67	21	87
1981-82	801	254	67	21	88
1982-83	777	305	67	26	92
1983-84	721	333	55	26	81

a: All superphosphate reduced to 'single super equivalent'. In later years, double and triple superphosphate are not converted to single super equivalent.

b: Includes compounds and mixtures containing phosphorus.

Source: Industries Assistance Commission (1982), Australian Bureau of Statistics 7411.0 (1984).

5. ANALYSIS OF IMPACT OF CIMMYT-BASED VARIETIES

5.1 Introduction

The measurement of the impact of wheat variety changes on farm yields is discussed in Brennan (1984) and the analysis below is based solely on varietal improvement and the proportion of total sowings accounted for by CBVs. Ideally, the impact on farm yields would be determined in conjunction with the impact of other input changes, using regional production functions. A measure such as an index of varietal improvement could be used to incorporate varietal change in the production function. In practice, the lack of data (especially on inputs such as rotations and machinery) and the limited resources of this study do not allow the use of detailed production functions.

5.2 Index of Varietal Improvement

Given the average yield advantages for each State, and the data on adoption of the varieties, it is possible to calculate a simplified relative yield index or '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 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-based varieties in State i; and p_{it} is the proportion of the area sown to CIMMYT-based varieties in State i in year t. Note that V_i remains constant over time. Thus in New South Wales, with a yield advantage of 9.0 percent (V_i = 9.0), and 71.0 percent of the area sown to CIMMYT-based varieties in 1979 (p_{it} = 0.710), the index for 1979 is 106.39. The index has a base value of 100 for all years in which these varieties were not grown in the State.

These indicies have been calculated for each State for each year from 1974 to 1983 (Tables 13 to 17), and are summarised in Table 18. The index increases steadily for each State with the increasing adoption of these varieties. For CBVs, the index increased between 1973 and 1983 by 6.6 percent for New South Wales, 5.3 percent for Victoria, 7.2 percent for Queensland, 2.4 percent for South Australia and 0.3 percent for Western Australia. The overall increase over this period for Australia was 3.6 percent.

A similar index was calculated the semi-dwarfs as a group for each State (Tables 13 to 18). For this group, there were larger increases in the index, ranging from 11.6 per cent for Queensland to 0.8 per cent for Western Australia. These were greater than the index for CBVs alone, since both the yield advantage and the adoption rate were higher. For Australia as a whole, the index increased by 5.0 per cent over the period 1973 to 1983.

Table 13. Gains from CIMMYT-Based and Semi-Dwarf Wheats, New South Wales

Year	Yield advantage (%)	% of area (%)	Index of varietal improvement a	Production increase (%)	Gross value of production ($Am)	Estimated benefit Current value ($Am)	Estimated benefit Constant value ($Am)b
CIMMYT-BASED							
1974	9.0	3.3	100.30	0.30	420	1.2	2.9
1975	9.0	14.5	101.31	1.31	449	5.8	12.4
1976	9.0	27.9	102.51	2.51	455	11.1	20.8
1977	9.0	49.3	104.44	4.44	382	16.2	27.8
1978	9.0	61.4	105.53	5.53	837	43.8	69.6
1979	9.0	71.0	106.39	6.39	914	54.9	79.0
1980	9.0	75.1	106.76	6.76	436	27.6	36.4
1981	9.0	76.7	106.90	6.90	938	60.6	72.3
1982	9.0	77.3	106.96	6.96	261	17.0	18.1
1983	9.0	73.2	106.59	6.59	1474	91.1	91.1
TOTAL(c)	-	-	-	-	-	-	506.1
ALL SEMI-DWARFS							
1974	9.4	4.3	100.40	0.40	420	1.7	4.0
1975	9.4	17.3	101.63	1.63	449	7.2	15.4
1976	9.4	33.7	103.17	3.17	455	14.0	26.3
1977	9.4	55.7	105.24	5.24	382	19.0	32.6
1978	9.4	66.7	106.27	6.27	837	49.4	78.4
1979	9.4	76.2	107.16	7.16	914	61.1	87.9
1980	9.4	81.2	107.63	7.63	436	30.9	40.7
1981	9.4	83.6	107.86	7.86	938	68.3	81.5
1982	9.4	85.2	108.01	8.01	261	19.4	20.8
1983	9.4	85.5	108.04	8.04	1474	109.7	109.7
TOTAL(c)	-	-	-	-	-	-	585.1

a: Base 1973 = 100.0
b: 1983-84 values; deflated by Consumer Price Index.
c: Compounded at real rate of interest of 5 per cent per annum.

Source: Column 1, Table 10; column 2, Table 5; column 3, calculated from columns 1 and 2; column 4, derived from column 3; column 5, Australian Bureau of Statistics; column 6, derived from columns 4 and 5; column 7, derived from column 6.

Table 14. Gains from CIMMYT-Based and Semi-Dwarf Wheats, Victoria

Year	Yield advantage (%)	% of area (%)	Index of varietal improvement a	Production increase (%)	Gross value of production ($Am)	Estimated benefit Current value ($Am)	Estimated benefit Constant value ($Am)b
CIMMYT-BASED							
1974	8.1	-	100.00	0.00	232	-	-
1975	8.1	1.4	100.11	0.11	163	0.2	0.4
1976	8.1	14.6	101.18	1.18	158	1.9	3.5
1977	8.1	31.2	102.53	2.53	150	3.7	6.4
1978	8.1	34.9	102.83	2.83	394	10.8	17.2
1979	8.1	43.3	103.51	3.51	501	17.0	24.4
1980	8.1	56.0	104.54	4.54	409	17.7	23.4
1981	8.1	62.1	105.03	5.03	392	18.8	22.4
1982	8.1	64.9	105.26	5.26	68	3.4	3.6
1983	8.1	64.9	105.26	5.26	649	32.4	32.4
TOTAL(c)	-	-	-	-	-	-	153.8
ALL SEMI-DWARFS							
1974	10.2	-	100.00	0.00	232	-	-
1975	10.2	1.4	100.14	0.14	163	0.2	0.5
1976	10.2	14.6	101.49	1.49	158	2.3	4.4
1977	10.2	31.2	103.18	3.18	150	4.6	8.0
1978	10.2	34.9	103.56	3.56	394	13.5	21.5
1979	10.2	43.3	104.42	4.42	501	21.2	30.5
1980	10.2	56.4	105.75	5.75	409	22.3	29.3
1981	10.2	62.4	106.36	6.36	392	23.5	28.0
1982	10.2	65.0	106.63	6.63	68	4.2	4.5
1983	10.2	65.0	106.63	6.63	649	40.4	40.4
TOTAL(c)	-	-	-	-	-	-	192.0

a: Base 1973 = 100.0
b: 1983-84 values; deflated by Consumer Price Index.
c: Compounded at real rate of interest of 5 per cent per annum.

Source: Column 1, Table 10; column 2, Table 6; column 3, calculated from columns 1 and 2; column 4, derived from column 3; column 5, Australian Bureau of Statistics; column 6, derived from columns 4 and 5; column 7, derived from column 6.

Table 15. Gains from CIMMYT-Based and Semi-Dwarf Wheats, Queensland

Year	Yield advantage	% of area	Index of varietal improvement	Production increase	Gross value of production	Estimated benefit Current value	Estimated benefit Constant value
	(%)	(%)	a	(%)	($Am)	($Am)	($Am)b
CIMMYT-BASED							
1974	9.2	0.4	100.04	0.04	79	0.0	0.1
1975	9.2	7.0	100.64	0.64	94	0.6	1.3
1976	9.2	25.4	102.34	2.34	73	1.7	3.1
1977	9.2	36.8	103.39	3.39	59	1.9	3.3
1978	9.2	43.7	104.02	4.02	252	9.7	15.5
1979	9.2	64.2	105.91	5.91	134	7.5	10.8
1980	9.2	69.7	106.41	6.41	77	4.6	6.1
1981	9.2	75.8	106.97	6.97	236	15.4	18.4
1982	9.2	75.5	106.95	6.95	134	8.7	9.3
1983	9.2	78.1	107.19	7.19	314	21.1	21.1
TOTAL(c)	-	-	-	-	-	-	102.1
ALL SEMI-DWARFS							
1974	12.9	0.4	100.05	0.05	79	0.0	0.1
1975	12.9	7.4	100.95	0.95	94	0.9	1.9
1976	12.9	28.3	103.65	3.65	73	2.6	4.8
1977	12.9	44.9	105.79	5.79	59	3.2	5.6
1978	12.9	52.2	106.73	6.73	252	15.9	25.2
1979	12.9	76.6	109.88	9.88	134	12.1	17.3
1980	12.9	83.9	110.82	10.82	77	7.5	9.9
1981	12.9	88.4	111.40	11.40	236	24.2	28.8
1982	12.9	89.8	111.58	11.58	134	13.9	14.9
1983	12.9	89.6	111.56	11.56	314	32.5	32.5
TOTAL(c)	-	-	-	-	-	-	161.9

a: Base 1973 = 100.0
b: 1983-84 values; deflated by Consumer Price Index.
c: Compounded at real rate of interest of 5 per cent per annum.

Source: Column 1, Table 10; column 2, Table 7; column 3, calculated from columns 1 and 2; column 4, derived from column 3; column 5, Australian Bureau of Statistics; column 6, derived from columns 4 and 5; column 7, derived from column 6.

Table 16. Gains from CIMMYT-Based and Semi-Dwarf Wheats, South Australia

Year	Yield advantage (%)	% of area (%)	Index of varietal improvement a	Production increase (%)	Gross value of production ($Am)	Estimated benefit Current value ($Am)	Estimated benefit Constant value ($Am)b
CIMMYT-BASED							
1974	6.1	-	100.00	0.00	164	-	-
1975	6.1	1.9	100.12	0.12	118	0.1	0.3
1976	6.1	11.1	100.68	0.68	74	0.5	0.9
1977	6.1	15.3	100.93	0.93	50	0.5	0.8
1978	6.1	18.9	101.15	1.15	265	3.0	4.8
1979	6.1	28.1	101.71	1.71	357	6.0	8.7
1980	6.1	34.4	102.10	2.10	254	5.2	6.9
1981	6.1	36.7	102.24	2.24	270	5.9	7.1
1982	6.1	44.0	102.68	2.68	121	3.7	3.4
1983	6.1	39.7	102.42	2.42	466	11.0	11.0
TOTAL(c)	-	-	-	-	-	-	49.9
ALL SEMI-DWARFS							
1974	8.0	0.1	100.01	0.01	164	0.0	0.0
1975	8.0	4.2	100.34	0.34	118	0.4	0.9
1976	8.0	20.3	101.62	1.62	74	1.2	2.2
1977	8.0	25.6	102.05	2.05	50	1.0	1.7
1978	8.0	29.9	102.39	2.39	265	10.2	16.2
1979	8.0	39.6	103.17	3.17	357	11.0	15.8
1980	8.0	48.8	103.90	3.90	254	9.5	12.6
1981	8.0	51.8	104.14	4.14	270	10.7	12.8
1982	8.0	56.5	104.52	4.52	121	5.2	5.6
1983	8.0	51.5	104.12	4.12	466	18.4	18.4
TOTAL(c)	-	-	-	-	-	-	99.6

a: Base 1973 = 100.0
b: 1983-84 values; deflated by Consumer Price Index.
c: Compounded at real rate of interest of 5 per cent per annum.

Source: Column 1, Table 10; column 2, Table 8; column 3, calculated from columns 1 and 2; column 4, derived from column 3; column 5, Australian Bureau of Statistics; column 6, derived from columns 4 and 5; column 7, derived from column 6.

Table 17. Gains from CIMMYT-Based and Semi-Dwarf Wheats, Western Australia

Year	Yield advantage	% of area	Index of varietal improvement	Production increase	Gross value of production	Estimated benefit Current value	Estimated benefit Constant value
	(%)	(%)	a	(%)	($Am)	($Am)	($Am)b
CIMMYT-BASED							
1974	2.7	-	100.00	0.00	361	-	-
1975	2.7	-	100.00	0.00	427	-	-
1976	2.7	-	100.00	0.00	290	-	-
1977	2.7	1.7	100.05	0.05	293	0.1	0.2
1978	2.7	3.8	100.10	0.10	547	0.6	0.9
1979	2.7	6.3	100.17	0.17	571	1.0	1.4
1980	2.7	7.4	100.20	0.20	509	1.5	2.0
1981	2.7	9.1	100.25	0.25	763	1.9	2.2
1982	2.7	10.7	100.29	0.29	983	2.8	3.0
1983	2.7	9.2	100.25	0.25	702	1.7	1.7
TOTAL(c)	-	-	-	-	-	-	12.7
ALL SEMI-DWARFS							
1974	5.5	-	100.00	0.00	361	-	-
1975	5.5	-	100.00	0.00	427	-	-
1976	5.5	-	100.00	0.00	290	-	-
1977	5.5	1.9	100.10	0.10	293	0.3	0.5
1978	5.5	4.4	100.24	0.24	547	1.3	2.1
1979	5.5	8.1	100.45	0.45	571	2.5	3.6
1980	5.5	10.0	100.55	0.55	509	2.8	3.7
1981	5.5	12.1	100.67	0.67	763	5.0	6.0
1982	5.5	14.3	100.79	0.79	983	7.7	8.2
1983	5.5	13.6	100.75	0.75	702	5.2	5.2
TOTAL(c)	-	-	-	-	-	-	32.5

a: Base 1973 = 100.0
b: 1983-84 values; deflated by Consumer Price Index.
c: Compounded at real rate of interest of 5 per cent per annum.

Source: Column 1, Table 10; column 2, Table 9; column 3, calculated from columns 1 and 2; column 4, derived from column 3; column 5, Australian Bureau of Statistics; column 6, derived from columns 4 and 5; column 7, derived from column 6.

Table 18. Indexes of Varietal Improvement for CIMMYT-Based and Semi-Dwarf Wheats(a)

Year	N.S.W.	Victoria	Queensland	S.A.	W.A.	Australia(b)
CIMMYT-BASED						
1974	100.30	100.00	100.04	100.00	100.00	100.10
1975	101.31	100.11	100.64	100.12	100.00	100.50
1976	102.51	101.18	102.34	100.68	100.00	101.24
1977	104.44	102.53	103.39	100.93	100.05	102.16
1978	105.53	102.83	104.02	101.15	100.10	102.55
1979	106.39	103.51	105.91	101.71	100.17	103.09
1980	106.76	104.54	106.41	102.10	100.20	103.33
1981	106.90	105.03	106.97	102.24	100.25	103.57
1982	106.96	105.26	106.95	102.68	100.29	103.42
1983	106.59	105.26	107.19	102.42	100.25	103.64
ALL SEMI-DWARFS						
1974	100.40	100.00	100.05	100.01	100.00	100.14
1975	101.63	100.14	100.95	100.34	100.00	100.65
1976	103.17	101.49	103.65	101.62	100.00	101.68
1977	105.24	103.18	105.79	102.05	100.10	102.81
1978	106.27	103.56	106.73	102.39	100.24	103.28
1979	107.16	104.42	109.88	103.17	100.45	104.00
1980	107.63	105.75	110.82	103.90	100.55	104.40
1981	107.86	106.36	111.40	104.14	100.67	104.75
1982	108.01	106.63	111.58	104.52	100.79	104.61
1983	108.04	106.63	111.56	104.12	100.75	104.99

a: Base 1973 = 100.00
b: Weighted average, weighted by area sown.

Source: Tables 13-17.

Godden (1985, 1986) pointed out that relative yield indexes are a biased estimator of genetic improvement unless there is no interaction between the varieties and the level of inputs used. While this is so, a brief examination of input levels in Australia (Brennan 1986) showed that there was scant evidence of any major changes in input levels for wheat production for Australian wheat in the period since the early 1970s, except in Western Australia (where CBVs were only of minor importance). Thus the extent of the possible bias in this study, while unknown, is likely to be relatively small.

On the other hand, if the CBVs were adopted mainly in the areas where their superiority over other varieties was greatest, then the index of varietal improvement would understate the true contribution of these CBVs. Given the other limitations on the precision of this index, it is not appropriate to attempt to estimate the size of this bias. Nevertheless, it is a possible further source of bias in the results of this study.

5.3 Impact of CBVs on Gross Value of Production

If it is assumed that the new varieties do not interact with changes in other inputs (see section 4), the contribution of CBVs to increases in the gross value of production (GVP) can be estimated from these indexes. The estimates are also based on the assumption that proportional increases in farm and experimental yields are the same.

On this basis, the percentage increase in the index of varietal improvement can be taken as the percentage increase in the GVP attributable to CBVs. Thus an increase of 10 per cent in the index means that the GVP was 10 per cent higher than it would have been without CBVs, so that 9.1 per cent (10/110) of the GVP in that year can be attributed to CBVs.

The estimated benefits from CBVs are shown in Tables 13 to 17. These are deflated by the Consumer Price Index to give estimated benefits in constant 1983-84 dollars, and are summarised in Table 19. After the initial small benefits during the early adoption phase, the annual benefits reached $124 million in 1979, fell to $37 million in the drought-affected season of 1982, and increased to $157 million in 1983. In the period 1974 to 1983, total benefits in 1983-84 dollars (compounded at a real interest rate of 5 per cent per annum) were $825 million, or an average of $82 million per year. Approximately half of the total benefits were received in New South Wales (average $51 million per year), with Victoria ($15 million per year) the next biggest beneficiary. Benefits were smaller but still substantial in Queensland ($10 million per year) and South Australia ($5 million per year). In Western Australia, the benefits averaged only about $1 million per year.

The benefits from all semi-dwarfs are also shown in Table 19. The total benefits in 1983-84 dollars (compounded at a real interest rate of 5 per cent per annum) were $1071 million between 1974 and 1983, or an average of $107 million per year. Again, New South Wales accounted for over half of the total benefits from semi-dwarf wheats.

Table 19. Gains from CIMMYT-Based and Semi-Dwarf Wheats, Australia ($Am) (1983-84 values)

Year	N.S.W.	Victoria	Queensland	S.A.	W.A.	Australia
CIMMYT-BASED						
1974	2.9	-	0.1	-	-	3.0
1975	12.4	0.4	1.3	0.3	-	14.4
1976	20.8	3.5	3.1	0.9	-	28.3
1977	27.8	6.4	3.3	0.8	0.2	38.5
1978	69.6	17.2	15.5	4.8	0.9	108.0
1979	79.0	24.4	10.8	8.7	1.4	124.3
1980	36.4	23.4	6.1	6.9	2.0	74.8
1981	72.3	22.4	18.4	7.1	2.2	122.4
1982	18.1	3.6	9.3	3.4	3.0	37.4
1983	91.1	32.4	21.1	11.0	1.7	157.3
TOTAL(a)	506.1	153.8	102.1	49.9	12.7	824.6
ALL SEMI-DWARFS						
1974	4.0	-	0.1	0.0	-	4.1
1975	15.4	0.5	1.9	0.9	-	18.7
1976	26.3	4.4	4.8	2.2	-	37.7
1977	32.6	8.0	5.6	1.7	0.5	48.4
1978	78.4	21.5	25.2	16.2	2.1	143.4
1979	87.9	30.5	17.3	15.8	3.6	155.1
1980	40.7	29.3	9.9	12.6	3.7	96.2
1981	81.5	28.0	28.8	12.8	6.0	157.1
1982	20.8	4.5	14.9	5.6	8.2	54.0
1983	109.7	40.4	32.5	18.4	5.2	206.2
TOTAL(a)	585.1	192.0	161.9	99.6	32.5	1071.1

a: Compounded at real rate of interest of 5 per cent per annum.

Source: Tables 13-17.

5.4 Effect of CBVs on Costs

There is no evidence that costs of wheat production per hectare have changed with the introduction of CBVs. Apart from the purchase of the initial seed of the new varieties, there need be no increase in production costs. Seed for subsequent years is generally retained on farms from the previous harvest. Although semi-dwarf lines are generally at their best in the more fertile environments, the uncertainty of adequate rainfall over most of the Australian wheat belt makes the adoption of high-input strategies uneconomic.

There is, however, a potential for increased fertiliser requirements, because the higher yields mean that increased amounts of soil nutrients per hectare are harvested in the grain, and need to be replaced, at least in the long run. The optimum level of inputs such as fertilisers may also be higher with the higher-yielding wheats. Nevertheless, there does not appear to have been any change in cost per hectare as a direct result of the introduction of CBVs or other semi-dwarf material. Of course, with higher yields, costs per tonne would be lower if there was no change in costs per hectare.

5.5 Effect of CBVs on Prices

Although individual varieties may have suffered some quality defects (Section 3.3) and therefore lower prices, other quality aspects of CBVs were positive. Thus there appears to be no reason for assuming that CBVs have caused any change in the prices received for Australian wheat on the export market through quality changes. Prices have been administered on the domestic market over this period, so it would appear that there was no price effect on the domestic market.

It is possible that the increased production resulting from the semi-dwarfs has affected the prices received for Australia's wheat exports. If the export market is perfectly elastic (that is, Australia is a price-taker on the world wheat market), the increased production would not have influenced world prices. However, there is some debate as to whether Australia faces a perfectly elastic demand for its export wheat (for example, see Alaouze, Sturgess and Watson, 1978a, 1978b, 1979; Grennes and Johnson 1979; Longworth and Knopke, 1980). The present analysis was based on the assumption that the export demand is perfectly elastic, as argued by Alaouze, Sturgess and Watson (1978a,b) and Longworth and Knopke (1980). To the extent that the market is less than perfectly elastic, the increased production would have reduced the price. If the estimated export elasticity suggested by Longworth and Knopke (1980) of −10 were accepted, then the overall 5 per cent increase in Australian production would have led to a fall in export prices of 0.5 per cent. Thus the gains indicated by this analysis would be overstated by approximately 0.5/5.0 = 10 per cent.

5.6 Effect of CBVs on Profitability

From the above discussion, yields have increased but prices and costs are assumed not to have changed with the introduction of CBVs.

Therefore profitability has increased by a greater proportion than the gross value of production. The extent of this increase depends on the level of profits without CBVs, and would vary widely between different wheat-producing regions.

6. PARTITIONING OF CONTRIBUTIONS

The benefits of the CBVs 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. It is of interest to examine the relative contribution of the CIMMYT and Australian programs to these gains.

A simplified partitioning of CIMMYT and non-CIMMYT benefits uses the pedigree of each variety (see Table 2) 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 per cent of its benefit attributed to CIMMYT. A variety such as Condor, the product of a cross between two CIMMYT lines, is allocated 100 per cent to CIMMYT, even though the crossing, selection, evaluation and testing were all carried out in Australia.

For the purposes of this analysis, a distinction is made between the 'first generation' and 'second generation' pedigree. In the 'first generation', the country of origin of the direct parent lines is used. In the 'second generation', rather than the country of origin of the parent lines, the 'bloodlines' (and the contribution of CIMMYT to those lines) are used. In the first generation, a variety such as Osprey (a cross between Condor and WW33B) used all Australian material in its parentage and is considered wholly Australian. In the second generation, the fact that Condor and WW33B have 100 per cent CIMMYT blood[4] denotes Osprey as 100 per cent CIMMYT. In this analysis, no account is taken of the earlier contribution that has been made to the CIMMYT material by Australian varieties (see footnote 2).

It is evident that such an allocation will be arbitrary, and can be no more than indicative. This allocation is likely to understate the contribution of Australian breeders to the development of many varieties, and overstate their contribution to others. Nevertheless, calculations have been carried out on this basis to provide an indication of the contribution of CIMMYT to the impact of CBVs in Australia.

The percentage contribution of CIMMYT to each variety's pedigree is shown in Table 20. In the first generation, the contribution of CIMMYT ranges from 0 per cent in varieties such as Cook, Banks and Osprey to 100 per cent for varieties such as Condor, Oxley, Millewa and Hartog. In the second generation, 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 second generation since the list has been restricted to those with some CIMMYT material in their pedigrees.

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4. The term 'blood' is used for convenience. It is used rather than 'genes' since there is no direct knowledge of the genetic constitution of these varieties.

Table 20: CIMMYT Contribution to CIMMYT-Based Varieties Released in Australia

Variety Pedigree(a) Generation	Percentage of CIMMYT 'Blood' in First Generation	Second
Durumba	12	12
Condor	100	100
Egret	75	75
Oxley	100	100
Jabiru	6	6
Senglen	50	50
Timson	50	50
Warimba	50	50
Shortim	6	6
Cook	0	75
Durati	50	50
Warigal	50	50
Avocet	25	75
Banks	0	88
Miling	25	25
Jacup	25	25
Millewa	100	100
Bindawarra	25	25
Hybrid Titan	12	12
Arcona	50	50
Sunbota	0	25
Bedallin	50	50
Cunna	50	50
Erudu	50	50
Flinders	0	88
Kamilarei	0	25
Hartog	100	100
Sunson	75	75
Matong	50	50
Hyden	50	50
King	0	75
Bass	0	78
Torres	0	88
Osprey	0	100
Quarrion	0	88
Sunstar	25	75
Spear	25	25
Dagger	25	25
Bayonet	50	50
Cocomba	0	94
Wyuna	50	50
Moering	0	100
Skua	0	94
Corella	31	64
Sundor	0	94
Crambrook	100	100

(a) Based on pedigrees. The distinction is made between the 'first' generation pedigree, based on the origin of the parent lines used, and the 'second' generation, based on the bloodlines of the parent lines.

Source: Derived from Table 2, with assistance from J. Fisher.

By using the percentage area sown to each variety in each State, it is possible to obtain a measure of the contribution of CIMMYT to the area sown in each State in each year (Table 21). This measure of the contribution of CIMMYT in the first generation, W_t, is calculated as follows:

$$W_t = \Sigma_i (X_i . P_{it}),$$

where X_i is the proportional 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-based varieties in Australia shown in Table 3, the actual CIMMYT contribution in the first generation peaked at 27 per cent in 1980 and has declined since. This is illustrated in Figure 5 and Table 21.

The analysis of monetary benefits was re-worked in order to identify the CIMMYT contribution to these benefits. This was achieved by using this measure of the contribution to area (Table 21) rather than the total proportion of area sown to CBVs in the calculation of the index of varietal improvement and the estimates of monetary benefits. The results are shown in Table 22. The monetary value of the CIMMYT contribution peaked at $88 million in 1979 (in 1983-84 dollars), and averaged approximately 66 per cent of the total benefits attributable to CBVs over the period 1974 to 1983. The total benefits (compounded at a real interest rate of 5 per cent per annum) attributable to CIMMYT were $554 million over this period.

Although this simplified analysis is no more than indicative, the CIMMYT program appears to have made a substantial direct and indirect contribution to Australian wheat production, mainly through the use of CIMMYT lines as parents. Subsequently, the new varieties have been used as parents in further Australian-developed varieties.

Table 21: Contribution of CIMMYT to Area Sown to Wheat

(Based on First Generation Pedigree)
(%)

Year	N.S.W.	Victoria	Queensland	S.A.	W.A.	Australia
1974	2.9	-	0.4	-	-	1.0
1975	13.9	1.4	7.0	1.9	-	5.4
1976	26.4	14.1	25.4	10.8	-	13.6
1977	40.8	29.3	34.8	14.7	1.3	23.4
1978	46.3	32.1	29.9	18.0	2.9	23.8
1979	48.8	37.8	24.5	25.2	4.7	26.4
1980	48.8	48.8	18.0	30.3	5.1	27.0
1981	44.9	54.7	14.1	30.2	5.4	25.6
1982	33.3	56.7	12.4	33.6	6.9	22.8
1983	25.0	58.0	13.6	29.4	5.3	21.9

Figure 5: Partitioning of Contribution of CIMMYT.

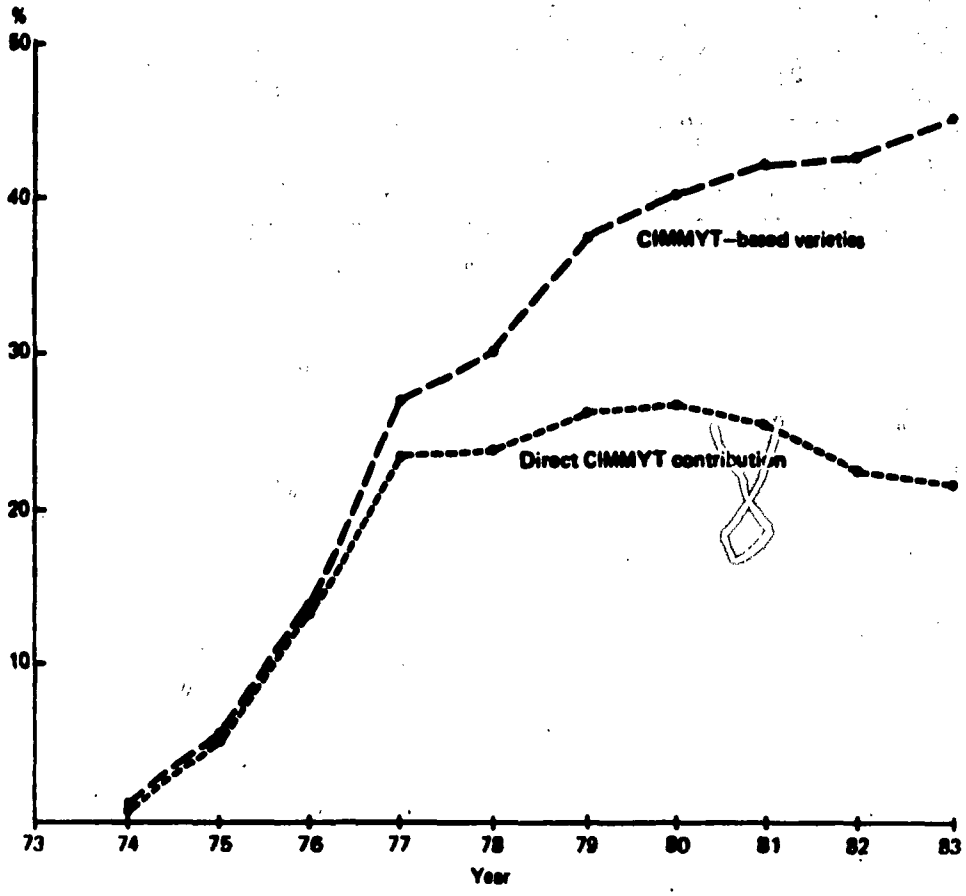

Table 22: Benefits from CIMMYT, Based on First Generation Pedigrees

($Am) (1983-84 values)

Year	N.S.W.	Victoria	Queensland	S.A.	W.A.	Australia
1974	2.5	-	0.1	-	-	2.6
1975	11.8	0.4	1.3	0.3	-	13.8
1976	19.7	3.4	3.1	0.9	-	27.1
1977	22.9	6.0	3.1	0.8	0.2	33.0
1978	52.4	15.8	10.6	4.6	0.7	84.1
1979	54.0	21.3	4.1	7.8	1.0	88.2
1980	23.5	20.4	1.6	6.1	1.4	53.0
1981	46.3	19.7	3.4	5.8	1.3	76.5
1982	7.7	3.1	1.5	2.6	1.7	16.6
1983	31.1	29.0	3.7	8.1	1.0	72.9
TOTAL(a)	326.2	137.2	40.1	42.3	8.1	553.9

a: Compounded at real rate of interest of 5 per cent per annum.

Source: Derived from Tables 13-17 and 21.

7. SUMMARY AND CONCLUSIONS

The CIMMYT wheat breeding program in Mexico has led to large increases in wheat yields in many countries throughout the world. Australia has been importing material from this program and its precursor, the Rockefeller Foundation program, since the 1950s. Several important Australian varieties have been based on the material imported from these programs. Their major feature is their semi-dwarf nature, based on the dominant semi-dwarfing genes Rht1 or Rht2.

The majority of varieties released since 1973 have been semi-dwarfs. Although not all of these have obtained their semi-dwarf habit through the Mexican program, the contribution of the Mexican program to the Australian wheat industry has been substantial.

CIMMYT-based varieties occupy almost half of the total area sown to wheat in Australia. All eastern States have a majority of their area devoted to CIMMYT-based varieties, and South Australia has over 40 per cent of its area. These varieties have made only a small contribution in Western Australia.

An examination of Interstate Wheat Variety Trial yield data has revealed that CIMMYT-based varieties have a yield advantage over non-CIMMYT-based varieties of 7 per cent in the period 1975 to 1982. The yield advantage was found to vary from 3 per cent in Western Australia to 9 per cent in Queensland and New South Wales.

Using these data and data on wheat varieties grown by farmers in each State, an 'index of varietal improvement' was constructed to indicate the contribution of the CIMMYT-based varieties to increased production in Australia. The contribution averaged 3.6 per cent in 1983, and varied from 0.3 per cent in Western Australia to 7.2 per cent in Queensland.

Based on the gross value of wheat production in each State, the yield gains from CIMMYT-based varieties are estimated to have contributed $825 million (in 1983-84 values, at a real interest rate of 5 per cent per annum) in the period 1974 to 1983, at an annual average of $82 million. While these figures are based on a number of assumptions, they indicate that the contribution of these varieties to the Australian wheat industry has been large.

An attempt has been made to apportion the contribution of the CIMMYT and Australian wheat breeding programs to these CIMMYT-based varieties, almost all of which had further crossing, selection and evaluation in Australia. On the basis of pedigrees, about two-thirds of the genetic make-up of these varieties was CIMMYT material. From these estimates, the importance of the CIMMYT program is evident.

The CIMMYT wheat breeding program in Mexico has made an outstanding contribution to the Australian wheat industry. While there have been few varieties imported directly for commercial production in Australia, material from this program has made a vital contribution to Australian

wheat breeding. The value of international co-operation in agricultural research is clearly demonstrated by this analysis of the impact of CIMMYT wheats on Australian production.

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APPENDIX A

CALCULATION OF YIELD ADVANTAGE FROM INTERSTATE WHEAT VARIETY TRIALS

Results of the Interstate Wheat Variety Trials from 1975 to 1982 (Series 6 to 12, year 1, and Series 5 to 11, year 2) were examined. The pedigree of each line in these trials was examined, and the lines were classified as:

(a) CIMMYT-based lines,
(b) Non-CIMMYT semi-dwarf lines, or
(c) Non-semi-dwarf lines.

Mean yields for each category

The yield of CIMMYT-based line j at site i in year t is designated as yc_{ijt}. Similarly, the yield of other semi-dwarf line j at site i in year t is ys_{ijt}, and the yield of non-semi-dwarf line j at site i in year t is yw_{ijt}.

If m_{it} is the number of CIMMYT-based lines at site i in year t, then the mean yield of the CIMMYT-based lines at that site in that year (YC_{it}) was calculated as

$$YC_{it} = (\Sigma_j . yc_{ijt})/m_{it}.$$

Similarly, the mean yield of the s_{it} other semi-dwarf lines (YS_{it}) and of the n_{it} non-semi-dwarf lines (YN_{it}) were calculated as

$$YS_{it} = (\Sigma_j . ys_{ijt})/s_{it}, \text{ and}$$

$$YN_{it} = (\Sigma_j . yw_{ijt})/n_{it}.$$

The total number of lines at site i in year t, p_{it}, is given by:

$$p_{it} = m_{it} + s_{it} + n_{it}.$$

For some purposes, the mean yield of all non-CIMMYT lines (YQ_{it}) was required, while for other purposes the mean yield of all semi-dwarf lines (YR_{it}) was required, where Q is used to designate 'non-CIMMYT' and R is used to designate 'semi-dwarf of any origin'. These were calculated as follows

$$YQ_{it} = (s_{it}.YS_{it} + n_{it}.YN_{it})/(s_{it} + n_{it}), \text{ and}$$

$$YR_{it} = (m_{it}.YC_{it} + s_{it}.YS_{it})/(m_{it} + s_{it}).$$

Annual site yield advantage for each group of lines

The yield advantage at each site for each year was then calculated from these mean yields. Thus, for example, the yield advantage of CIMMYT-based lines over non-CIMMYT-based lines at site i in year t ($A_{C/Q_{it}}$) was calculated as

$$A_{C/Q_{it}} = (YC_{it} - YQ_{it})/YQ_{it}.$$

Similarly, the yield advantage of all semi-dwarf over non-semi-dwarf lines ($A_{R/N_{it}}$) was calculated as

$$A_{R/N_{it}} = (YR_{it} - YN_{it})/YN_{it}.$$

Overall site yield advantage

The overall yield advantage at each site for all years in which the trials were held at that site was calculated from these annual yield advantages. The overall yield advantages at site i were calculated as:

$$Ac/oi = [\Sigma_t(p_{it}.Ac/oi_t)]/\Sigma_t(p_{it}), \text{ and}$$

$$An/ni = [\Sigma_t(p_{it}.An/ni_t)]/\Sigma_t(p_{it}).$$

State yield advantage

The State yield advantage was calculated by averaging the site advantages over the sites in that State. A weighted average was used, with the advantages being weighted by the number of years in which trials were held at each site. Thus, the State average yield advantage of CIMMYT-based lines over non-CIMMYT-based lines over all sites in that State (SAc/oi) was calculated as

$$SAc/oi = [\Sigma_i(k_i.Ac/oi)]/[\Sigma_i(k_i)],$$

where k_i is the number of years the trials were held at site i.

Similarly, the State average yield advantage of all semi-dwarf over non-semi-dwarf lines over all sites in a State (SAn/ni) was calculated as

$$SAn/ni = [\Sigma_i(k_i.An/ni)]/[\Sigma_i(k_i)].$$

This is the yield advantage shown in Table 10, and used in subsequent calculations.