ELSEVIER

Agricultural Economics 17 (1997) 35–44

AGRICULTURAL ECONOMICS

Identifying international rice research spillovers in New South Wales

John P. Brennan [a,*], Inder Pal Singh [a], Laurie G. Lewin [b]

[a] NSW Agriculture, Agricultural Research Institute, Wagga Wagga, NSW 2650, Australia
[b] NSW Agriculture, Yanco Agricultural Institute, Yanco, NSW 2703, Australia

Accepted 20 May 1997

Abstract

The rice industry in New South Wales, Australia, has benefited from the international flow of germplasm, as have other industries. The aim in this paper is to identify those international flows, and to value their contributions to the industry. Analysis is made of the origins and pedigrees of the rice varieties grown in New South Wales since the 1960s, and the contribution of different germplasm sources are identified, using the geometric rule of partitioning contributions. The analysis reveals that New South Wales has had a significant contribution from international sources, notably breeding programs in the USA. The analysis also reveals that the International Rice Research Institute has had no impact on the germplasm used in New South Wales rice varieties. The changes over time on the role of international germplasm flows are also identified. © 1997 Elsevier Science B.V.

1. Introduction

1.1. Australian rice industry

The rice industry is a major contributor to Australia's agricultural production. Australia's rice industry began in 1924, with production of 225 tonnes of paddy rice by eight farmers using Japonica rice seed and cultural methods imported from California (Lewis, 1994). In 1995, more than 2400 farmers produced in excess of 1.25 million tonnes of paddy (Australian Grain, 1996). As a result of increases in area and yield, the Australian rice production has almost increased ninefold over the past 30 years. Rice in this temperate region is usually sown from September to October and harvested in April–May.

The rice breeding program at Yanco, first established in 1928, has been a major influence on the development of the Australian rice industry (Brennan et al., 1994). The industry has sought a number of characteristics to be incorporated in the varieties, including maturity type, high yield and various quality parameters. The breeding program has imported and tested varieties and lines from overseas programs, and used them as a basis for breeding long- and medium-grain and specialty varieties adapted to the Australian conditions and continually changing market requirements. As a result, the Australian rice industry has benefited from the international flow of germplasm.

1.2. Previous studies of international germplasm flows

The impacts of international germplasm flows in wheat in developing countries have been studied in

* Corresponding author.

PII S0169-5150(97)00007-8

detail (Dalrymple, 1986b; Byerlee and Moya, 1993), as well as the spillover effects into developed countries (Brennan and Fox, 1995; Thomas, 1996; Pardey et al., 1996). The impacts of germplasm flows in rice in developing countries have also been studied (Herdt and Capule, 1983; Dalrymple, 1986a), but the spillover impacts into developed countries had not been examined in detail until the recent work of Pardey et al. (1996).

These studies have shown a significant impact of the international flows and exchange of germplasm, in both developing and developed countries. The importance of the impact of the International Agricultural Research Centres under the auspices of the Consultative Group on International Agricultural Research has been highlighted. This paper is intended to redress the shortage of information about the impact of international germplasm flows on the Australian rice industry.

1.3. Aims in this paper

The aims in this paper are to examine the impacts of international germplasm flows on the New South Wales (NSW) rice industry, with a particular objective of identifying what impact the International Rice Research Institute (IRRI) in the Philippines has had on Australia. The scope of the analysis in this paper is limited to the rice industry in NSW. Apart from some scattered production in other areas, the Australian rice industry has been centred on the irrigation areas of the Murrumbidgee and Murray valleys in southern NSW. The NSW rice industry has contributed more than 97% of total Australian rice production over recent decades.

2. Identification of origins of Australian rice varieties

2.1. Rice varietal development in Australia

The Australian rice industry has been importing rice varieties and germplasm from overseas rice breeding programs since its inception. Early rice farming in NSW was founded on the variety Caloro, developed in California from a Japanese variety and brought into Australia in 1920s. NSW rice breeders and a local farmer selected Late Caloro, Caloro II and Early Caloro, which were more suited to local conditions. In 1952, Calrose was introduced from USA; its yield and adaptability together with its milling and cooking qualities made it very popular. Rice breeders at Yanco successfully developed their first locally crossed, high yielding long grain variety Kulu in 1967, followed by another long grain variety Inga in 1972. Only in 1987 was a locally crossed medium grain variety, Amaroo, released for commercial cultivation. The germplasm currently being used in the breeding program is locally developed and taken from different breeding programs around the world. Changes over time in the use of varieties on farms are illustrated in Fig. 1.

2.2. Pedigrees of varieties released in NSW

Twenty rice varieties were released in Australia between 1924 and 1995. The pedigrees and features of those varieties are shown in Table 1. The early varieties (Caloro, Calrose, Bluebonnet 50) were selected from material imported directly from the USA, although that was not necessarily their place of origin. The first Australian-developed variety was Kulu (1967), which was a cross between two of those imported varieties. The pattern of developing Australian varieties from crosses between imported lines continued until the 1990s, with all the intervening varieties being bred in Australia but from crosses between imported varieties. The use of Australian parents has been repeated with some more recent varieties.

The use of germplasm over time has had four stages: (a) importing finished lines; (b) making selections from imported lines; (c) making crosses between imported lines; and (d) making crosses using the locally-developed varieties.

In recent years, there has been a push for more diverse range of rice types. Within those new types, some newly imported lines have been grown, such as Bahia, which is based on an introduced Spanish arborio line. Thus, the cycle of germplasm use is being repeated for the new types of rice being developed.

The relationships between NSW varieties are evident from Fig. 2, where the parentage of the commercial varieties is shown. It is apparent that there is

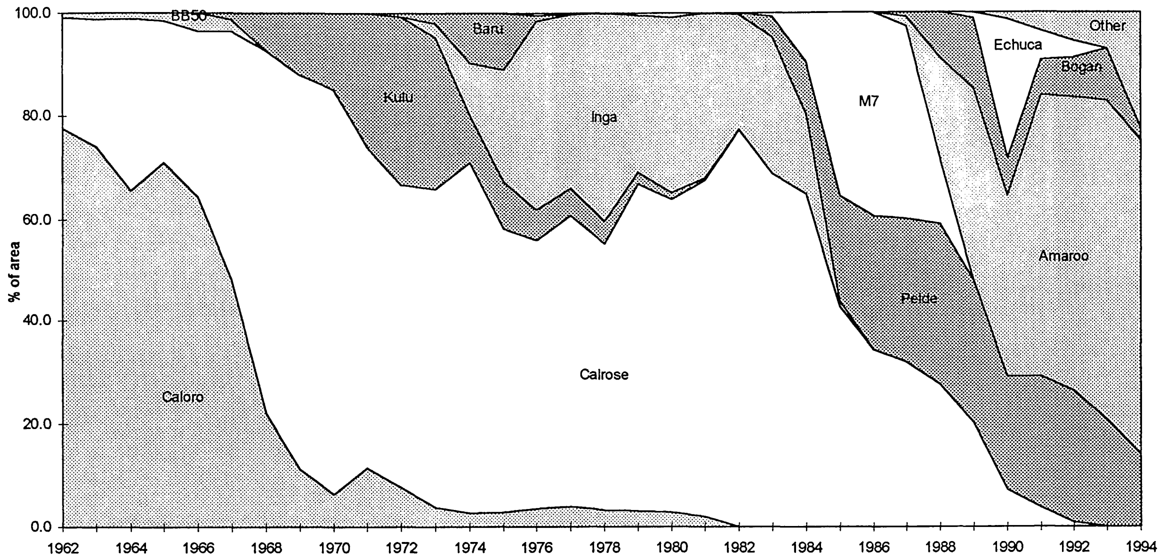

Fig. 1. Percentage of area sown to each variety.

a narrow genetic background to the Australian varieties, as most are derivatives of Caloro and Bluebonnet, with a significant input from M7 in later varieties.

2.3. Sources of material in pedigrees

The genetic materials used in the pedigrees of NSW varieties are listed in Table 2. It is apparent

Table 1
Pedigree details of varieties released by Yanco rice breeding program

Variety	Year of release	Grain type	Place of release	Australia	Pedigree/Origin
Caloro	1924	medium grain	California, USA	Selection	Japan
Calrose	1956	medium grain	California, USA	Selection	Caloro/Calady
Bluebonnet 50	1961	long grain	Texas	Selection	Selection from Bluebonnet
Kulu	1967	long grain	YAI, Yanco	Developed	Calrose/Bluebonnet 50
Inga	1973	long grain	YAI, Yanco	Developed	Century Patna/Calrose
Baru	1973	long grain	YAI, Yanco	Developed	Century Patna/Caloro II
Pelde	1982	long grain	YAI, Yanco	Developed	Century Patna/Calrose//Bluebelle
M7	1983	medium grain	California	Introduced	Calrose 76/CS-M3
Amaroo	1987	medium grain	YAI, Yanco	Developed	Calrose/M7
Bogan	1987	medium grain	YAI, Yanco	Developed	Calrose/M7
Doongara	1989	long grain	YAI, Yanco	Developed	Calrose/Bluebelle//Jojulta
Echuca	1989	medium grain	YAI, Yanco	Developed	Calrose * 4/M7
Bahia [a]	1990	Arborio	Spain	Introduced	Arborio
Goolarah	1991	long grain	YAI, Yanco	Developed	Della/Kulu
Harra	1991	medium grain	YAI, Yanco	Developed	Saint Andrea/M7
Illabong	1993	medium grain	YAI, Yanco	Developed	Saint Andrea/M7
Jarrah	1993	medium grain	YAI, Yanco	Developed	M7 * 2/Somewake
Kyeema	1994	Fragrant	YAI, Yanco	Developed	Pelde//Della/Kulu
Langi	1994	long grain	YAI, Yanco	Developed	Kulu/CI9187//M7///Pelde
Millin	1995	Japanese	YAI, Yanco	Developed	M7 * 2/Somewake

[a] Introduced after some testing.

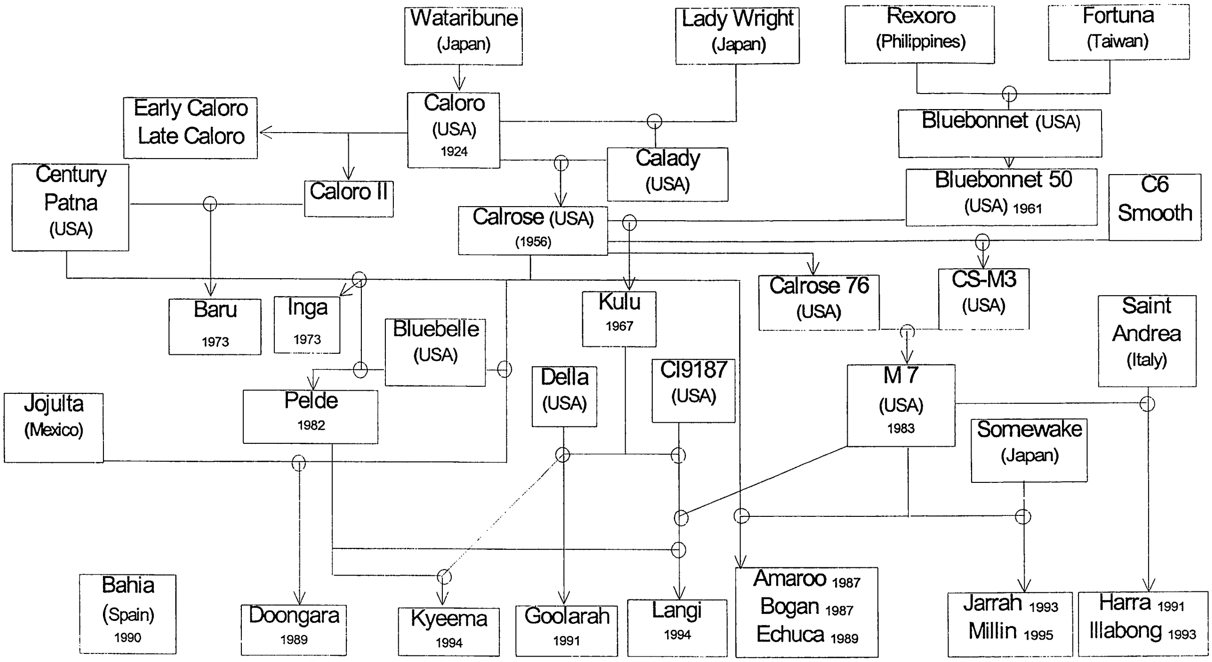

Fig. 2. Pedigree of rice varieties released in NSW.

that they have been sourced strongly from the US programs in Louisiana, California and Texas. Other materials have come from Japan, Taiwan, China, Philippines, Mexico, Italy and Spain. Initially, the varieties were imported directly from the US, then they were developed by crossing the varieties suc-

Table 2
Origin of varieties used in crossing by Yanco rice breeding program

Variety	Year of release	Grain type	Place of release	Pedigree/Origin
Bluerose	1912	medium grain	Louisiana, USA	Japan
Supreme Bluerose	1914	medium grain	Louisiana, USA	Japan
Fortuna	1918	long grain	Louisiana, USA	Taiwan
Lady Wright	1920	long grain	Louisiana, USA	Japan
Rexoro	1928	long grain	Louisiana, USA	Maron-Paroc (Philippines)
Calady	1934	medium grain	California, USA	Lady Wright/Caloro
Zenith	1936	medium grain	Arkansas, USA	Selected from Bluerose
Texas Patna	1942	long grain	Texas, USA	Rexoro/*C15094*
Bluebonnet	1944	long grain	Texas, USA	Rexoro/Fortuna
Century Patna	1951	long grain	Texas, USA	Texas Patna//Rexoro/Supreme Bluerose
Bluebelle	1965	long grain	Texas, USA	CI9214//Century Patna/CI9122
CS-M3	1970	medium grain	California, USA	C6Smooth(unknown)/Calrose
Jojulta	na [a]	long grain	Mexico	Mexico
Della	1973	long grain	Louisiana, USA	Rexoro/Zenith selection/)R-D
Saint Andrea	na [a]	large grain	Italy	Italy
Somewake	na [a]	Japanese	Japan	Japan

[a] Data not available.

cessful in NSW. Subsequently, new varieties have been developed using the NSW varieties as parents, but again have US varieties as their grandparents.

2.4. Germplasm flows to Australia

Rice lines have been regularly imported into NSW from many countries since the first introductions. The pace of introduction increased after the modern breeding program commenced at Yanco Agricultural Institute in the late 1950s. Cultivars or lines are selected for introduction based on published reports, personal contacts, through the germplasm bank at IRRI and the international nurseries distributed through the International Network for Genetic Evaluation of Rice system based at IRRI. The material is generally selected for desired characteristics including quality, performance, maturity or cold tolerance.

Until recently, the costs of germplasm imports and the associated quarantine costs were met by the Australian Quarantine Inspection Service (AQIS), so that there was very little direct cost to the breeder. However, in recent years AQIS has introduced cost-recovery into the process, and the direct costs of quarantine services are now met by the breeding programs themselves. That has changed the perceptions of the importance of the costs involved. However, the overall costs of the germplasm imports are small in relation to the size of the benefits identified in this analysis.

The germplasm flows to Australia from overseas can be offset to an extent by any flow of Australian material to other breeding programs. Australian germplasm has been made available to other breeding programs at various times. Some of the varieties developed by the NSW rice breeding program, such as Pelde and Doongara, have been grown in China, Spain and Colombia, but there are no data available to estimate the extent of any such spill-out effects.

2.5. Role of International Rice Research Institute

It is of interest to note here that the International Rice Research Institute (IRRI) has made no contribution to the germplasm of NSW's commercial rice varieties. There are a number of IRRI-based lines in the breeding program at present, but it is apparent that IRRI germplasm does not confer any particular production advantage in NSW. It is, of course, possible that there will be some contribution to future varieties, but by 1996 there had not been any identifiable contribution from IRRI to NSW in the form of germplasm. The difference in the production environments is the likely explanation for the lack of influence of IRRI on NSW [1] production.

The importance of IRRI to rice variety development in NSW has been much greater than indicated by its contribution of germplasm. IRRI has been a primary source of information and technology. This has been particularly true for breeding methodology, genetic resource data, grain quality analysis methods and as a source of rice literature. IRRI has also been a focus for exchange of information and germplasm with other countries.

International Nurseries, as managed by IRRI, have also contributed to information on genetic variability. The International Cold Tolerance Nurseries, for example, have been used as a benchmark for cold reaction of locally developed cultivars and to provide genetic variability for physiological studies. The possibility, indeed likelihood, that IRRI may have played a role in terms of its international nursery system, breeding methodologies, training, agronomy, etc., (other than germplasm) is not explored in this paper.

3. Analysing contributions to benefits

3.1. Means of determining relative contributions

Pardey et al. (1996) have provided a number of alternative ways of determining the contribution of a fixed source of germplasm (such as IRRI) to varietal improvement. These include: (a) binary rule; (b) antecedent rule; (c) geometric rule; and (d) any ancestor rule. A description of the features of each method is provided in Pardey et al. (1996).

The measure best suited to evaluate the contribu-

[1] International Institutes have contributed to rice cultivar development in the minor rice growing states of Australia. The major cultivar in Western Australia and the Northern Territory in earlier years was a line introduced from IRRI (IR661), and varieties from the International Center for Tropical Agriculture (CIAT) in Colombia contributed to one variety released in Queensland.

tion of more than one source of germplasm is the geometric rule. Since the aim in this paper is to identify and value the contribution of the different international sources of germplasm to Australia, we have used Pardey's geometric rule to determine the contribution of the range of germplasm sources used in Australia.

3.2. Applying geometric rule to NSW rice varieties

The geometric rule attributes geometrically declining weights to the sources of its parents and grandparents (Pardey et al., 1996). Weights are assigned as follows: half of the benefits from a variety are attributed to its breeder, 1/8 to the breeder of each of its parent, 1/32 to the breeder of its four grandparents, and 1/64 to each of its eight great-grandparents.

The geometric rule does not describe how to assign weight to the current breeding program when a variety is imported to Australia as an advanced line, and is re-selected and tested here before final release to the industry. Modifications to Pardey's approach were made to account for the input that the current breeding program has into testing and evaluating an imported line.

In allocating the contribution to imported lines, the 50% allocated to the crossing program is apportioned on the basis of the contribution of the different organisations to the total costs of the variety's development. To assign the benefits to the current breeding program in case of introduced varieties, 50% of benefits are apportioned by using the annual costs of the breeding program as weights (Table 3). Details of the breeding program for all locally developed varieties were analysed. In the past, it has taken from 6 to 7 years to select a line before it enters the final stages of evaluating, testing, and release to the industry. The stage of final selection for each locally-developed variety is shown in Table 4. It is assumed that an imported variety is introduced at the F_7 generation in the breeding program. The breeders then test and evaluate the line, along with other advanced lines, before its final release.

From Table 3, a line that is imported as an advanced line and evaluated in Australia has had 74% of its development costs incurred by the F_7 stage. Therefore, 74% of the *breeder contribution* is allocated to the originating program, and Australia is allocated the remaining 26% of the benefits, since it has incurred 26% of the total costs of variety development (F_8 to F_9 and beyond).

Based on these assumptions, and given that the

Table 3
Variable costs of operations of Yanco rice breeding program

Generation	Total ($)	Percent of total	Cumulative	Breeder benefits
Crossing/F_1	7180	2%	2%	1%
F_2	23042	5%	6%	3%
F_3	21850	5%	11%	5%
F_4	57119	12%	23%	11%
F_5	72103	15%	38%	19%
F_6	78607	16%	54%	27%
F_7	92837	19%	74%	37%
F_8	63721	13%	87%	44%
F_9	61258	13%	100%	50%
Total variable costs	477717			
Benefits attributed to current breeding program				
– Varieties developed (geometric rule)				50%
– Introduced variety, assuming introduced line equivalent to F_7				13%

Source: Updated from Singh and Brennan (1996).

Table 4
Prices and final selection stage for locally developed varieties

Variety	% premium	Price [a]	Developed/	Final
Caloro	0%	200	improved	
Calrose	0%	200	improved	
Bluebonnet 50	20%	240	improved	
Kulu	20%	240	developed	F_7
Inga	20%	240	developed	F_6
Baru	20%	240	developed	F_7
Pelde	20%	240	developed	F_7
M7	0%	200	improved	
Amaroo	0%	200	developed	F_7
Bogan	0%	200	developed	F_6
Doongara	10%	220	developed	F_6
Echuca	0%	200	developed	F_6
Goolarah	90%	380	developed	F_6
Harra	0%	200	developed	F_7
Illabong	0%	200	developed	F_6
Jarrah	0%	200	developed	F_5
Kyeema	25%	250	developed	F_6
Langi	10%	220	developed	F_7
Millin	0%	200	developed	F_7
Bahia	10%	220	improved	

[a] Using a base price for medium-grain rice of $200/ton.

breeder contribution is 50% of the total benefits, 13% of the total benefits of an imported line are assigned to the current breeding program, and 37% to the program making the cross. The remaining 50% of the benefits are distributed on geometrically declining weights.

The analysis was extended to the country from where the variety has been introduced. If the variety is developed in that country, then 37% of the total benefits are assigned to the breeding program of that country. But if it has also been introduced there (e.g. Caloro in USA), then 13% of those benefits (i.e. 10% of the total) are assigned to that breeding program and the remaining breeding contribution is assigned to the original breeding program. For locally developed varieties, the geometric rule as described by Pardey et al. (1996) was used, without modification.

In identifying the overall average contribution to the benefits across all varieties, the difference in price of the different types of rice were also taken into account. The price differences used are shown in Table 4 for each locally-developed variety, using a base price of $200 per tonne for medium-grain rice.

The results of the analysis are summarised in Table 5, where the contribution of each germplasm source to each commercial variety is shown. On the basis of the geometric rule, Calrose is estimated as 13% Australia, 78% USA, and 9% Japanese. More recent varieties, with the exception of the imported line Bahia, have an international contribution of between 20% and 50%.

3.3. Allocating benefits of rice improvement between countries

From the above calculations, the contribution of each relevant country and/or organisation has been identified for each year since 1962, based on the proportion of rice production by each variety in each year (see Fig. 1). Thus, in 1962, when 77.5% of the total production came from Caloro, 21.5% from Calrose and 1.0% from Bluebonnet 50, the contribution to the germplasm of each (from Table 5) was weighted by those proportions. As the varietal mix produced on farms changed over time, the contributions of the different germplasm sources also changed. The changes of contribution through time are presented in Table 6, where the contributions of each source of germplasm are shown for each year

Table 5
Contribution of countries to varietal germplasm in Australia (geometric rule)

Variety	Year	Australia	USA	Japan	Taiwan	China	Philippines	Italy	Mexico	Spain	IRRI	Total
Caloro	1924	13	10	77	0	0	0	0	0	0	0	100
Calrose	1956	13	78	9	0	0	0	0	0	0	0	100
BB 50	1961	13	62	0	13	0	13	0	0	0	0	100
Kulu	1967	50	44	0	3	0	3	0	0	0	0	100
Inga	1973	50	44	2	0	0	5	0	0	0	0	100
Baru	1973	63	25	8	0	0	5	0	0	0	0	100
Pelde	1982	63	34	0	0	0	3	0	0	0	0	100
M7	1983	13	87	0	0	0	0	0	0	0	0	100
Amaroo	1987	50	50	0	0	0	0	0	0	0	0	100
Bogan	1987	50	50	0	0	0	0	0	0	0	0	100
Doongara	1989	50	25	0	0	0	0	0	25	0	0	100
Echuca	1989	50	50	0	0	0	0	0	0	0	0	100
Bahia	1990	13	0	0	0	0	0	0	0	87	0	100
Goolarah	1991	63	31	3	0	0	3	0	0	0	0	100
Harra	1991	50	28	3	0	6	0	13	0	0	0	100
Illabong	1993	50	28	3	0	6	0	13	0	0	0	100
Jarrah	1993	63	31	6	0	0	0	0	0	0	0	100
Kyeema	1994	78	22	0	0	0	0	0	0	0	0	100
Langi	1994	80	20	0	0	0	0	0	0	0	0	100
Millin	1995	63	31	6	0	0	0	0	0	0	0	100

from 1962 to 1994. It is apparent that Australia's contribution increased throughout the period, increasing from 13% in the early years to more than 50% in the 1990s. Another significant change has been the increase in the contribution of the USA during the 1960s, and its contribution of approximately 60% or more for the 20 years to 1987. Japan had a major contribution during the 1960s, but has had little influence since. Other countries have made smaller contributions at different times, but IRRI has made no genetic contribution to the improvement. While this has been the experience in the past, some changes can be expected in the future. In the most recent years, the contribution of the US has declined to around 40%. In addition, the current US varieties have a strong IRRI component (Pardey et al., 1996), so that if Australian breeders use the more recent US material, there will be an increased indirect impact from IRRI in NSW. To the extent that there is an increase in specialty varieties in future, there may also be an increase in the influence of germplasm from countries such as Japan and Italy.

3.4. *Estimating value of contributions to Australian rice improvement*

To enable comparisons to be made between the results of this study and others, an attempt was made to estimate the monetary value of the contributions of international germplasm to Australian rice im-

Table 6
Annual contribution to genetic improvement in rice (%)

Year	Australia	USA	Japan	Taiwan	China	Philippines	Italy	Mexico	Spain	IRRI	Total
1962	13.1	24.7	61.9	0.1	0	0.1	0	0	0	0	100
1963	13.1	27.1	59.4	0.2	0	0.2	0	0	0	0	100
1964	13.1	32.8	53.7	0.2	0	0.2	0	0	0	0	100
1965	13.1	29.2	57.2	0.2	0	0.2	0	0	0	0	100
1966	13.1	33.3	52.5	0.5	0	0.5	0	0	0	0	100
1967	13.7	44.2	41.4	0.4	0	0.4	0	0	0	0	100
1968	16.3	59.8	23.4	0.3	0	0.3	0	0	0	0	100
1969	18.2	65.4	15.5	0.4	0	0.4	0	0	0	0	100
1970	19.4	67.5	11.9	0.5	0	0.5	0	0	0	0	100
1971	24.0	60.2	14.0	0.9	0	0.9	0	0	0	0	100
1972	27.0	59.9	10.8	1.1	0	1.2	0	0	0	0	100
1973	27.6	61.8	8.3	1.0	0	1.3	0	0	0	0	100
1974	26.5	62.8	9.0	0.3	0	1.4	0	0	0	0	100
1975	31.7	57.9	8.1	0.3	0	2.0	0	0	0	0	100
1976	31.1	58.8	7.7	0.2	0	2.2	0	0	0	0	100
1977	29.1	60.5	8.3	0.2	0	1.9	0	0	0	0	100
1978	31.3	58.8	7.5	0.2	0	2.2	0	0	0	0	100
1979	26.6	63.1	8.5	0.1	0	1.7	0	0	0	0	100
1980	27.8	62.3	8.1	0	0	1.8	0	0	0	0	100
1981	26.6	64.0	7.7	0	0	1.7	0	0	0	0	100
1982	22.7	68.7	7.3	0	0	1.2	0	0	0	0	100
1983	26.4	65.5	6.6	0	0	1.5	0	0	0	0	100
1984	25.3	67.4	6.1	0	0	1.2	0	0	0	0	100
1985	25.4	70.0	3.8	0	0	0.8	0	0	0	0	100
1986	27.9	68.1	3.1	0	0	0.9	0	0	0	0	100
1987	29.8	66.4	2.8	0	0	1.0	0	0	0	0	100
1988	40.6	55.9	2.4	0	0	1.1	0	0	0	0	100
1989	47.0	50.2	1.8	0	0	1.0	0	0	0	0	100
1990	50.3	47.4	0.6	0	0	0.8	0	0.1	0.7	0	100
1991	51.7	45.1	0.3	0	0	0.9	0	0.5	1.4	0	100
1992	53.6	44.3	0.2	0	0.1	1.0	0.2	0.5	0	0	100
1993	53.5	44.6	0.3	0	0.1	0.9	0.3	0.3	0	0	100
1994	56.0	41.8	0.6	0	0	0.6	0.1	0.9	0	0	100

Table 7
Allocation of benefits between germplasm sources

	1962 to 1994 (discounted)			1994 only	
	Total ($m)	Average ($m)	%	Total ($m)	%
Australia	306	9.3	36.1	33.0	56.0
USA	482	14.6	56.8	24.6	41.8
Japan	46	1.4	5.5	0.4	0.6
Other countries	13	0.4	1.5	0.9	1.6
IRRI	0	0.0	0.0	0.0	0.0
Total	848	25.7	100.0	59.0	100.0

provement. Brennan et al. (1994) estimated that the rate of varietal yield improvement in Australian rice over the thirty years to 1993–1994 was 0.68% per year. That was extended to 1994–1995, meaning that yields had increased as a result of varietal improvement by 24.2% since 1962.

On the basis of the above assumptions, the benefits from each source of germplasm to Australian rice industry can be estimated. To calculate the benefits, constant prices were used, based on current price levels, and a real discount rate of 5% per annum was used to compound the benefits from earlier years to 1994 values. Details of the estimated benefits are shown in Table 7.

It is estimated that, on average over the past 33 years, 64% of the benefits accruing to rice improvement in Australia can be attributed to international germplasm. Of that 64%, 58% is attributable to the US, 5% to Japan, 1% to the Philippines, and smaller proportions to Mexico, Spain, Taiwan and Italy. In 1994, the contribution of international germplasm had declined to 44%, reflecting the increased use of Australian materials in recent years.

In monetary terms, the total benefit of varietal yield improvement was estimated at $848 million (in compounded 1994 dollars) over the period 1962 to 1994. Of that total, $306 million was attributable to Australian breeders, so that the total contribution to Australia of the international germplasm flows was $541 million over that period, averaging $17 million per year. This compares with a figure of $81 million per year from international germplasm flows in the wheat industry over the past twenty years (Brennan and Fox, 1995).

4. Summary and conclusions

This study has addressed the issue of quantifying the contribution of international germplasm flows to the NSW rice industry. It is apparent that the industry has drawn heavily on international germplasm over the past decades, either directly for use on farms or indirectly as parents of commercial varieties. There is little evidence of off-setting international spill-outs from the Australian rice breeding program.

The major source of germplasm has been the United States programs in Louisiana, California and Texas. There has been a contribution from a range of countries, but the US contribution has dominated the international benefits. In view of the pervasive influence of the international agricultural research centres in other crops and other countries, it is significant to note that the International Rice Research Institute (IRRI) in the Philippines has had no measurable influence on NSW's rice genetic improvement.

Nevertheless, NSW clearly has been a major beneficiary of international germplasm flows in rice. The relationship that has developed between the Australian breeding program and those in the US has been very fruitful for the NSW industry. The analysis reveals the success of the relationship.

One consequence of the germplasm flows is the impact on returns to the Australian rice breeding program. If all the benefits of yield improvement are allocated to the Australian program (as in Brennan et al., 1994), the economic returns to that research will be overstated. If the impact of the international flows is taken into account, the returns to the Australian breeding efforts will be reduced by about 64%. That still leaves a solid economic return to the funds spent on the Australian breeding program.

The negative side of the significant influence of the US programs is the relatively narrow genetic base in which NSW varieties are currently founded. The move in the industry towards a greater range of rice types and specialty products is likely to bring with it additional benefits in the form of a greater genetic diversity in varieties in farmers' fields. In addition to providing benefits to growers by meeting market opportunities, the development of different types of rice is likely to have benefits of broadening the genetic base of NSW production. The cost of quarantine procedures is possibly one of the factors limiting the capacity of the Australian breeding program to increase genetic diversity.

Overall, the Australian rice breeders have been very successful in exploiting germplasm from other countries for the benefit of the NSW industry by selecting and adapting those best suited to local conditions. Any activities that improve the movement of genetic materials internationally are likely to lead to continuing benefits for the NSW industry, building on those that have already been received from the use of international germplasm in rice breeding and production.

Acknowledgements

We wish to acknowledge the financial support of the Rural Industries Research and Development Corporation in carrying out this work.

References

Australian Grain (1996) Grain Yearbook 1996, pp. 34–35.

Brennan, J.P., Fox, P.N., 1995. Impact of CIMMYT wheats in Australia: Evidence of international research spillovers. Economics Research Report No. 1/95, NSW Agriculture, Wagga Wagga.

Brennan, J.P., Lewin, L.G., Marshall, G.R., Reinke, R.F., 1994. An economic assessment of rice breeding in New South Wales. Aust. J. Exp. Agri. 34, 89.

Byerlee, D., Moya, P., 1993. Impacts of international wheat breeding research in the developing world, 1966–1990. International maize and wheat improvement centre, Mexico, D.F.

Dalrymple, D.G., 1986a. Development and spread of high-yielding rice varieties in developing countries. Bureau for Science and Technology, Agency for International Development, Washington, DC.

Dalrymple, D.G., 1986b. Development and spread of high-yielding wheat varieties in developing countries. Bureau for Science and Technology, Agency for International Development, Washington, DC.

Herdt, R.W., Capule, C., 1983. Adoption, spread, and production impact of modern rice varieties in Asia. International Rice Research Institute, Los Baños, Laguna, Philippines.

Lewis, G.J., 1994. An illustrated history of the Riverina Rice Industry. Ricegrowers Cooperative Limited, Leeton, NSW.

Pardey, P.G., Alston, J.M., Christian, J.E., Fan, S., 1996. Summary of a productive partnership: The benefits from U.S. participation in the CGIAR. EPTD Discussion Paper No. 18, Environment and Production Technology Division, International Food Policy Research Institute, Washington, DC, October 1996.

Singh, I.P., Brennan, J.P., 1996. An economic analysis of potential changes to a rice breeding program. Contributed paper presented at the 40th Annual Conference of the Australian Agricultural and Resource Economics Society, Melbourne.

Thomas, N., 1996. Use of germplasm in Canadian crop breeding programs: Spillovers to Canada from the CGIAR and some outflows from Canada. Canadian International Development Agency.