Impact of ICRISAT Research on Australian Agriculture

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List of Acronyms and Abbreviations Used in the Report

ACIAR	Australian Centre for International Agricultural Research (Canberra)
APSIM	Agricultural Production Systems Simulation Model
APSRU	Agricultural Production Systems Research Unit (Toowoomba)
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center (Mexico)
CLIMA	Centre for Legumes in Mediterranean Environments (Perth)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GRDC	Grains Research and Development Corporation
ICARDA	International Center for Agricultural Research in Dry Areas (Syria)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IPM	Integrated Pest Management
NSW	New South Wales
QDPI	Queensland Department of Primary Industries
ROW	Rest of World
SAT	Semi-Arid Tropics
UK	United Kingdom
WA	Western Australia

Impact of ICRISAT Research on Australian Agriculture

Executive Summary

The project, “Spillover impact of ICRISAT research on breeding programs and agricultural production in Australia”, was developed with the Australian Centre for International Agricultural Research (ACIAR), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and NSW Agriculture. The aim of the project is to investigate and document the impact of ICRISAT research on Australian agriculture.

The purpose of this report is not to question whether or not Australia should support ICRISAT. Australia’s support for the international agricultural research centres such as ICRISAT should be based on a number of factors including altruism and a desire for aid payments to be directed to improving the lot of producers and consumers in developing countries. The question of whether Australia receives some spillover benefits from that support is just one consideration, and any gains from spillovers should be seen as a bonus from overseas aid, rather than a rationale for the initial financial support.

The first task in the analysis was to identify the links between ICRISAT and the relevant Australian research programs for each of the mandate crops. The linkages differed for each crop, but there was good collaboration between the Australian programs and their ICRISAT counterparts. There was regular exchange between Australia and ICRISAT, and several Australians work at ICRISAT or have worked there in the past. In addition, a number of ICRISAT researchers have spent time visiting and working in Australia.

A large amount of ICRISAT material either has been used in the past or is being used at present in Australian breeding programs. In addition, there had been some direct acquisitions and releases in Australia of Indian varieties, often made available via the ICRISAT germplasm exchange distribution system. However, despite these strong linkages, there was little evidence of any direct impact of ICRISAT research on Australian production to date. There appeared to be no varieties or hybrids in any of the crops that were being grown commercially in 1996 based on ICRISAT germplasm, although some of the crops had ICRISAT material with particular desirable characteristics in the advanced lines in the breeding programs.

Therefore, while it is likely that there will be future impacts, as some of these lines are released by breeders and grown by Australian farmers, there has been no direct impact on farms to date. The analysis, then, relied on being able to project future benefits for some of the crops.

While there were relatively strong links with ICRISAT for several of the mandate crops, only in sorghum and chickpeas were there both strong links and a substantial Australian industry to provide the necessary conditions for a significant benefit flowing back to Australia. For example, there had been an especially strong relationship in pigeonpeas, with ICRISAT materials being closely tested in Australia, and with a strong personal connection between the Australian and ICRISAT researchers. However, there is no significant pigeonpea industry in Australia, so that the strong research links

were not translated into significant monetary benefits to Australia. On the other hand, for groundnut/peanut, while there is a small but significant industry in Australia, there has been no identifiable impact of ICRISAT material on the Australian program or the varieties being grown. A similar situation applied to millets, as there is minor production of millet in Australia, but no evidence that there had been any direct impact from ICRISAT on the materials being grown.

In addition, a significant part of resource management research at ICRISAT, such as physiological modelling, has relevance to Australia. However, it was not possible in this report to put an economic value on those areas of collaborative research.

As a result, the empirical analysis was restricted to the impact on sorghum and chickpea production. For the other crops, the size of any benefits identified would have been insignificant at this time. It is, of course, possible that in the future there will be some important identifiable impacts for the other mandate crops or from resource management research.

For sorghum, the most significant contribution from ICRISAT to Australian agriculture has been the introduction of improved midge resistance combined with desirable white grain and tan plant colour through material such as ICSV 745 and PM 13654. There are several advanced breeding lines that have the resistance and combination of characteristics incorporated from ICRISAT-derived materials in them. As a result, industry experts expect that hybrids with this resistance will be available to the growers in the near future, and that the resistance of such materials will have a significant economic impact on the sorghum industry. On the basis that such resistance is likely to increase yields by 5% in the 50% of the crop affected by midge each year, the expected gains to Australia in terms of yield are estimated at 2.5%. That translates to a cost reduction of $4.02 per tonne, or an annual cost saving of $4.69 million at recent average production levels.

For chickpeas, the impact of ICRISAT research is likely to be different in Western Australia (WA) from the rest of Australia. As a result, the WA impact is assessed separately in this analysis. In WA, two ICRISAT varieties, Heera and Sona, were released in July 1997. They are seen as having a significant impact on the chickpea industry in WA. They have significant levels of cold tolerance, and are expected to yield an average of 10% higher than alternative varieties that will be available over the next 5 years. At the same time, the area of chickpeas in WA is estimated to double to 100,000 ha by 2002. In the other States, there are no such clearly identifiable benefits from the use of ICRISAT's chickpea materials. However, material either developed from or incorporating ICRISAT background is prevalent throughout the breeding materials currently in use in Australia, and a weighted average of 42% of the breeding materials have ICRISAT background. On the basis of these figures, the future gains from improved chickpea varieties in the other States will have a strong impact from ICRISAT material. It is estimated that ICRISAT will contribute 2.1% of the expected 5.0% yield growth in the five years to 2002. That is equivalent to a cost reduction of $39.18 per tonne for WA and $8.78 per tonne for the rest of Australia, or an annual cost saving of $5.21 million for Australia at the expected production levels.

The economic analysis also assesses the impact on Australia of ICRISAT's research in the rest of the world, via an impact on prices. To the extent that ICRISAT's research in the rest of the world has increased production, there will be a downward impact on price. Given finite supply and demand elasticities, any increase in production will mean a decline in price for the traded goods sector. Work at ICRISAT has led to development of estimates of the likely impact in future of ICRISAT's research. The increases in the world's production of chickpeas and sorghum are likely to have a downward impact on prices for the predominantly export-oriented sorghum and chickpeas industries in Australia.

On that basis, the Australian industry faced lower prices as a result of ICRISAT's research, at the same time as they were experiencing yield gains. The economic analysis of those spillover impacts in an economic welfare framework revealed that the overall net effect for Australia was a reduction in benefits gained by producers. Australian sorghum producers will lose more through the lower prices than the benefits they gain from the higher yields, resulting in an overall loss of $0.55 million per year. For chickpeas, Australian producers will also lose more from the price fall than they will gain from higher yields, with a resultant loss of $0.81 million per year. Overall, sorghum and chickpea producers will lose an average of $1.36 million per year. These losses occur because Australian producers are unable to make use of the productivity gains from ICRISAT research to the same extent as producers in the rest of the world, and hence cost reductions gained by other producers are larger than those gained by Australian producers. It should be noted that Australian producers are enjoying productivity gains from domestic research programs unrelated to ICRISAT that have not been considered in this project. No attempt has been made to assess whether Australian producers are becoming more or less efficient than producers in the rest of the world.

On the other hand, Australian consumers of those grains (that is, primarily the livestock sector) will make significant gains. Sorghum consumers will gain an average of $1.69 million per year, while for chickpeas the gains will average $1.19 million per year.

Overall, the net gain to Australia as a result of the overall research effort at ICRISAT averages $1.28 million per year, or an aggregate of $30.8 million (in 1996 dollars) over the period to 2022 (see Table). Approximately three-quarters of those gains are achieved in the sorghum industry, and one-quarter for chickpeas.

Summary of Benefits to Australia from ICRISAT Research

Crop	**Aggregate Benefit, 1999-2022[a]** *(\$ million)*	**Average Annual Benefit** *(\$ million)*
Sorghum	27.3	1.14
Chickpeas	9.1	0.38
Total	36.4	1.52

a: In 1996 Australian dollars, discounted at 8% per annum.

This study has produced significant findings at two levels. The first level has been the identification of anticipated spillover benefits in terms of cost reduction for producers in two of the ICRISAT mandate crops, namely sorghum and chickpeas. Those cost reductions are expected to result from yield increases attributable to germplasm developed at ICRISAT or collected by passing through ICRISAT and incorporated into genotypes that will be grown in Australia.

The second level at which significant findings have emerged for the first time is in the incorporation of the price effects of international agricultural research for these crops. In these two industries, the price effects resulting from successful ICRISAT research were found to be significant. The lower prices for sorghum and chickpeas led to significant income reductions for Australian producers, and these were only partly offset by the increased yields. The gains for the Australian consumers of these grains (that is, the Australian livestock sector) from the lower prices were less than the losses from price effects for Australian producers, because the significance of exports meant that overseas consumers received many of the consumer benefits. Thus producers have incurred losses from the price effects because they have been unable to capture the benefits of ICRISAT research to the same extent as producers in the rest of the world..

These findings have some important implications for Australian agriculture:

(a) International Centres such as ICRISAT remain a source of materials for potential yield gains for Australian crops, even those crops grown in systems and environments significantly different from those targeted by the international centres;

(b) Australian producers will be affected by the price implications of the successful research that is undertaken by the international centres such as ICRISAT, whether or not they take advantage of the possible yield gains spilling over;

(c) Consumers, which for feed grains in developed countries means livestock industries, are likely to be significant benefactors of any research advances in the grains industries;

(d) Australia's gains from international spillovers are likely to be greatest for those industries where there are significant links between Australian researchers and the researchers and programs being undertaken in the international research centres;

(e) Australian researchers need to maintain their vigilance over international agricultural research developments. Because of the contributions of the international centres, producers throughout the world are becoming more efficient and prices are falling. There is a need for a strong domestic research program, partly to maximise benefits from international spillovers, to ensure that Australian producers achieve gains similar to those of their competitors.

Recognition of these factors can assist in leading to better-informed decision-making for research resources, and is likely to lead to a more efficient and more cooperative research system worldwide. That improved system will deliver expected improvements in the efficiency of production and in the delivery of appropriate food cheaply to the consumers most in need of it.

1. Introduction

1.1 International Crops Research Institute for the Semi-Arid Tropics

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) is located at Patancheru, near Hyderabad, in India. The semi-arid tropics (SAT) encompass parts of 48 developing countries including most of India, parts of south-east Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population (ie, almost 1 billion people) live in the SAT, most of them very poor. Unpredictable weather, limited and erratic rainfall, and nutrient-poor soils typify the SAT. Australia is the developed country with the greatest area within the semi-arid tropics, although most of that area in northern Australia is not generally used for cropping.

ICRISAT focuses on sorghum, millets, chickpea, pigeonpea and groundnut (peanut); these mandate crops are staple crops for the ever-increasing populations of the SAT. ICRISAT's mission is to conduct research that can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT.

ICRISAT was established in 1972, and its mandate (ICRISAT 1995) is to:

(a) Serve as a world centre for the improvement of grain yield and quality of sorghum, millets, chickpea, pigeonpea and groundnut; and act as a world repository for the genetic resources of these crops;

(b) Develop improved farming systems that will help to increase and stabilise agricultural production through more effective use of natural and human resources in the seasonally dry SAT;

(c) Identify constraints to agricultural development in the SAT and evaluate means of alleviating them through technological and institutional changes;

(d) Assist in the development and transfer of technology to the farmer through cooperation with national and regional research programs, and by sponsoring workshops and conferences, operating training programs, and assisting extension activities.

ICRISAT is one of 16 non-profit, research and training centres funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organisation of the United Nations, the World Bank, and the United Nations Development Program.

Developed countries such as Australia support the CGIAR system, and hence ICRISAT, through donor or foreign aid contributions. In 1994-95, Australia provided a total of $8 million to the CGIAR system. Of that, approximately $500,000 flowed to ICRISAT.

1.2 Project on ICRISAT's Impact in Australia

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been developing germplasm and other technologies for the crops in its research mandate (sorghum, millets, chickpea, pigeonpea and groundnuts) since 1972. Although ICRISAT aims to improve the production of these crops for developing countries, its germplasm and other technologies have been made freely available to developed countries. Australia has been regularly testing material from ICRISAT, and ICRISAT germplasm has been incorporated into a number of varieties released in Australia. However, the utilisation of ICRISAT research in Australia has not been documented.

A project was developed with the Australian Centre for International Agricultural Research (ACIAR), ICRISAT and NSW Agriculture to investigate and document the impact of ICRISAT research on Australian agriculture. The project "Spillover impact of ICRISAT research on breeding programs and agricultural production in Australia" is funded by ACIAR. The study aims to:

(a) Enable ICRISAT to understand better the role of its germplasm products in varietal development;
(b) Identify the constraints and limitations of ICRISAT products and germplasm lines for Australian conditions and whether there has been any flow of Australian material back to ICRISAT;
(c) Provide a basis for assessing whether other types of research outputs from ICRISAT are applicable to developed countries such as Australia; and
(d) Identify any implications for Australia's investment in ICRISAT through foreign aid payments.

The main emphasis in this report is on (b), (c) and (d). Identification and assessment of those impacts on Australia will enable the first objective to be met by allowing ICRISAT to understand better the role of its different outputs in one developed country.

The purpose of this report is not to question whether or not Australia should support ICRISAT. Australia's support for the international agricultural research centres such as ICRISAT, through ACIAR, should be based on altruism and a desire for aid payments to be directed to improving the lot of producers and consumers in developing countries. The question of whether Australia receives some spillover benefits from that support is secondary. To the extent that there are gains from spillovers, they should be seen as a bonus from overseas aid, rather than a rationale for the initial financial support.

ICRISAT makes contributions in a wide range of areas, and will have made some critical contributions that are not captured in this report (Bantilan *et al.* 1997). In particular, ICRISAT has the unique role of collecting, evaluating and distributing germplasm to breeding programs worldwide. While the analysis in this report does not identify the value of those activities, ICRISAT plays a critical role as a source of diversity in Australian breeding programs. For example, the characterisation of germplasm carried out at ICRISAT has produced critical evaluation information on germplasm, which is expected to improve the efficiency of breeding research.

1.3 Outline of the Report

In sections 2 to 6 of this report, the impact of ICRISAT's research in each of the mandate crops (sorghum, chickpea, pigeonpea, groundnut and millet) is examined in turn. In section 7, the relationship between Australia and ICRISAT for resource management research is discussed. An economic framework is developed and a detailed evaluation of the economic impacts of sorghum and chickpea research on Australia is carried out in section 8. In the final section, the implications of the results and some conclusions are drawn out. Appendices are attached with details of aspects of the ICRISAT impact on Australia.

2. Impact in Australia of ICRISAT's Sorghum Research

2.1 ICRISAT's Research on Sorghum

There are a number of major target environments/cropping systems for sorghum improvement at ICRISAT:

1. Early maturity (southern Africa);
2. Medium maturity (global, India);
3. Late maturity (western Africa);
4. Post-rainy season crops;
5. High-altitude, low-temperature environments (East Africa);
6. Acid soil tolerance (Latin America).

ICRISAT's achievements to date have been mainly in the medium-maturity areas, which have 50% of world production of sorghum.

Initially, in the early to mid-1970s, the aim was to breed for all these regions from ICRISAT Asia Centre at Patancheru. By the early 1980s, it was evident that it was not appropriate to address the region-specific issues from one centre in India. As a result, a number of other Research Centres were established in West Africa, Kenya (high altitude, low temperature), Southern Africa, and Latin America.

In recent years, ICRISAT has withdrawn from its earlier emphasis on finished varieties, to the production of intermediate products, particularly: (a) parent lines for hybrids (male-sterile lines and restorer lines); and (b) stress-resistant lines for breeders to use as parents. Since 1987, only trait-specific material has been distributed.

Midge resistance has been a significant target for work at ICRISAT since late 1970s. From the 1970s, screening was used to identify sources of resistance; from about 1980, breeding for resistance was a major objective. Second-round derivatives such as ICSV 745 (midge resistance combined with white grain and tan plant type) were used extensively in the breeding programs from the late 1980s. ICRISAT has also developed standardised screening methods for midge resistance that are now generally used (Sharma *et al.* 1992), and has studied the mechanisms, diversity and inheritance of resistance; it is difficult to value such an output.

2.2 Australian Sorghum Industry

Production of sorghum in Australia has changed little over the past 20 years. It is a significant crop in Queensland (the leading producer) and NSW (Appendix Table A.1). Only small areas of grain sorghum are grown in other States. On average in the ten years to 1996-97, 551,000 hectares were sown each year, and production averaged 1,166,000 tonnes.

Grain sorghum is grown mainly for the domestic livestock industries. Australia exported an average of 247,000 tonnes of grain sorghum per year in the five years to 1996-97, approximately 23% of production. Over that period, the gross value of production averaged $188 million, while exports have been valued at $51 million per year (ABARE 1997). Australian crop yields have averaged 2.12 t ha^{-1} over the past ten years.

The Australian sorghum industry is concentrated in Queensland, mainly on the Darling Downs, and in northern NSW. In these regions, sorghum midge has been a major constraint to production. Sowing time is important in handling sorghum midge. Crops sown in October-November can avoid midge, but later-sown crops that flower between mid-January and mid-March are likely to have a serious midge problem. The availability of midge resistance has provided farmers with a window to adjust planting times according to rainfall pattern and crop rotations.

Sorghum is also used as a forage crop, particularly for the dairy industry, in some regions.

2.3 Australian Sorghum Improvement Program

The Australian sorghum improvement program is a mixture of public and private breeding efforts. The aim of the public sorghum breeding program is the development of germplasm (that is, breeding lines) for Australian conditions. Useful genetic material is made readily available by the public sector, and is sold to the private sector on the basis of an up-front fee plus royalties if the material is used for producing varieties and hybrids. The development of hybrids for sale to farmers is carried out in the private sector. Approximately 80 lines were sold to the private sector breeders between 1989 and 1996.

The nationally-focused germplasm-development program is managed by Dr Bob Henzell of Queensland Department of Primary Industries, and is based at the Hermitage Research Station, Warwick. That program involves a number of streams:

(a) Core breeding, germplasm development;
(b) Molecular markers;
(c) Nitrogen-use efficiency;
(d) Physiology of the “staygreen” character;
(e) Entomology, midge resistance;
(f) Honeydew, corn-leaf aphids;
(g) Pedigree analysis by molecular markers;
(h) Coordination of activities.

There are a number of private sector breeders aiming at developing hybrids for commercial use by farmers. Two of the major companies are Pioneer and Pacific Seeds.

A Midge-Tested rating scheme has been developed to enable the midge resistance of all lines to be assessed, and the information is provided to farmers. The general level of midge-resistance ratings has increased significantly from high susceptibility (8-9) to medium-to-high resistance (1-5), over the past 20 years. However, spraying for midge control is still required for hybrids with the current level of midge resistance.

2.4 Use of ICRISAT Sorghum Material in Australia

2.4.1 ICRISAT material of interest to Australia

In Australia, the main interest in ICRISAT material has been for the medium maturity group. The ICRISAT-developed medium maturity (65-70 days to flowering) types tend to delay in maturity further under Australian conditions; hence, they can not be adapted directly. However, the traits associated with these materials have been of value to Australia. In particular, the specific traits of use in Australia have been: (a) midge resistance; (b) white grain colour; (c) tan plant colour; and (d) stay-green trait.

Tan plant colour is associated with leaf disease resistance, as well as with reduced grain staining when pigmented glumes are washed in rain. The stay-green trait confers stronger stalks, less terminal lodging and drought resistance. Australia has tended to use US (Texas) sources rather than ICRISAT (for stay-green); so ICRISAT is not a primary source for it.

Recent ICRISAT materials (such as ICSV 745 and PM 13654) combine midge resistance with desirable white grain and tan plant colour, and are being used extensively in Australia. They have the same combination of characteristics as the earlier ICRISAT resistant materials, but only more recently have these characteristics been recognised as desirable in Australia.

Midge causes significant losses for sorghum in Australia. Australia has benefited from the information on the sources identified by the early screening. US sources of resistance were used in Australia's early screening program, but they were difficult to work with because of their different agronomic background. While Australia has benefited from the information on resistance sources identified by the earlier screening, ICRISAT could not claim much of an impact in the early development of sources in Australia.

Earlier efforts in midge resistance research started in the Queensland Department of Primary Industries (QDPI) in the 1970s. Progress towards incorporating midge resistance began in earnest in 1984, with research aiming to develop midge resistance and to develop the understanding to enable farmer management practices to be effective. At present, some 80% of sorghum cultivars have some level of midge resistance, originally sourced from the USA, although it is mainly low level resistance. On average, midge attacks 50% of the Australian sorghum crop each year.

Some of ICRISAT's earlier breeding derivatives (notably ICSV 197) were evaluated in Australia from 1984 onwards. The International Sorghum Midge Nursery has been sent to Australia for 10 years or so. Some of the early lines have also been used, but the main use is of ICSV 745. The level of resistance that ICSV 745 can confer is equivalent to a 5% increase in midge-affected crops (ie, 2.5% of all crops) (R.G. Henzell, personal communication, 1996). Further, as ICSV 745 is different from other sources in use in Australia, it is expected to add to the genetic diversity of the materials. An addition to genetic diversity is also expected from the wild sorghums that have recently been collected in Australia. They are expected to add significantly to the genetic material in the germplasm collection, as they are believed to contain some important resistances.

2.4.2 ICRISAT material in QDPI's sorghum breeding program

Of a total of 303 F_2 plants in the program in 1996, only six (2%) involved ICRISAT material, and each of those contained, by pedigree, 12.5% PM 13654. PM 13654 was chosen originally for its midge resistance (which was moderate), but also for its large white seeds and tan plant colour.

Of the 6,993 F_3 plants in 1996, 992 (14%) involved ICRISAT material. About one-third of those involved ICSV 745 and ICSV 197, and they constituted 50% by pedigree of those F_3 lines. The remainder involved lines 31945-2-2 and 31925-2, each of which had 25% of PM 13654 in its pedigree. It is those two lines that are involved in the six F_2 lines above. Line 31945-2-2 has a good level of stay-green and a moderate level of midge resistance and red grain with the "I" gene, and is showing some grain weathering resistance. Line 31925-2 also has stay-green and midge resistance, and is white grained and tan plant colour, although it has proved to be a poor restorer line.

Of the 500 F_4 lines in 1996, five (1%) involved ICRISAT material, being from the same cross as 31945-2-2. There were no lines with ICRISAT background in the F_5 and F_6 generations of the program in 1996.

In F_7 generation, there were two lines: 31945-2-2 and 31976, which have the same pedigree, but the latter is white-grained with tan plant colour. By early 1996, only 31945-2-2 had been sold to the seed industry (as a hybrid restorer line). At that time, no hybrids based on it were being grown by farmers, although it was anticipated that the first use of that material by farmers could occur in 1997-98.

It is expected that the materials currently in F3/F4 stage will reach the final stage five years from now and may find their way into farmers' fields. The reason for this possible delayed impact is that the midge resistant lines developed at ICRISAT tend to be late under Australian conditions. Hence the first cycle derivatives from such materials cannot readily compete with the advanced highly-adapted Australian materials. It is anticipated therefore that the second-cycle materials derived from ICRISAT sources are those that would have perceptible impact on farmers' fields in the Australian environment. Attempts are therefore being made to combine the resistance from DJ 6514, using ICSV 197 and ICSV 745, with the midge resistant lines produced in Australia. The two forms of resistance are reported to operate through different mechanisms.

During 1996, seed has been imported into Australia from ICRISAT from the random mating "Head Pest Population" and 50 pairs of midge-resistant maintainer lines. This material can be used to extract lines with diverse mechanisms of resistance, as well as to incorporate resistance from maintainer lines into the Australian sorghum male-sterile lines. This will have a significant bearing on sorghum improvement, and midge resistance in particular, over the years to come.

Also, in a collaborative effort between ICRISAT and QDPI scientists, major insights have been gained in relation to diversity and mechanisms of resistance to midge, disposition and host selection behaviour of midge, and evaluation of wild relatives of sorghum as alternative sources of resistance to this insect (H.C. Sharma, Personal communication, 1996). The information gained will have a major impact on the selection of suitable midge-resistant parents, breeding strategies, and the development of cultivars with a stable and durable resistance to sorghum midge.

2.4.3 Use of ICRISAT material by private breeding programs

From 1987 onwards, Pioneer has been testing selections from ICRISAT, imported through Pioneer's Indian program (Bruce Boucher, personal communication, 1996). In total, 400-600 lines have been imported, primarily for midge resistance. The process of introducing and evaluating these lines has been slow because of quarantine regulations. The material has now been screened, and the majority of the material has been shown to have much higher resistance than the existing Australian lines. These lines have also been found to have useful quality characteristics, including seed size and mould resistance. ICSV 197 has been the most successful. There are now 66 in-bred pedigree lines in F_4 and F_5, with an average infusion of 13% of ICSV 197 in the restorer lines. Other progenies that are derived from ICRISAT material are in advanced stages in the program; their ICRISAT source materials include DJ 6514, PM 13957, PM 15952 and PM 15949.

In addition, Pioneer's program in 1996 had a number of ICRISAT lines being evaluated for midge resistance and dual-purpose or forage sorghum, both as restorer lines and female lines. The lines in the back-crossing stage have about 10% ICRISAT infusion, with a slightly higher level (13-15%) in the restorer lines.

Pioneer expects a release of a commercial hybrid from the ICRISAT materials in 2-4 years. The main characters sought in the Pioneer program are midge resistance and "standability". Pioneer releases an average of one hybrid each year (there were 5 in 1996). The aim is to have a replacement variety in advanced trials by the time a hybrid is three years old. The average life-span of a hybrid is approximately eight years. Pioneer plans to have 3-4 potential hybrids in farmers' trials each year, with one likely to be released. The aim for each variety is to have at least 5% yield gain, or multiple trait improvement. Yield has been increasing at around 1.0-1.5% per year (equivalent to 5% every 4 years).

Pacific Seeds also find ICRISAT a useful source of germplasm, with similar emphasis on midge resistance. However, no grain sorghum varieties or hybrids have been released with ICRISAT materials in their pedigrees, and in 1996 there were no advanced grain sorghum lines containing ICRISAT materials. For forage sorghums, one late maturing forage hybrid had one parent from ICRISAT, and several more were being developed by pedigree crossing, especially using late-maturity B-lines in single crosses. Pacific Seeds also uses the midge screening techniques developed at ICRISAT.

2.5 ICRISAT's Impact on Australian Sorghum Production

It is apparent that there is no direct benefit to date for the Australian sorghum industry from sorghum research at ICRISAT. However, there are a number of avenues by which ICRISAT material has been incorporated into advanced breeding materials now in use by breeding programs. The value of that material in commercial hybrids when grown in farmers' fields has yet to be established. However, it appears likely that hybrids with midge resistance and other useful characteristics from ICRISAT sorghum lines will be released for commercial use by farmers in the relatively near future. When that occurs, it is likely that there will be a significant benefit for Australian sorghum producers, as the level of midge resistance conferred by the ICRISAT lines appears to provide a significant level of yield improvement.

One means of estimating the likely future impact is to assess the relative contribution of the yield improvement provided by the ICRISAT midge resistance. An estimate of the impact at full adoption can be obtained on the basis of the following assumptions:

(a) Midge resistance from ICRISAT material (as in ICSV 745), in combination with other favourable plant traits such as tan plant colour and white grain, would provide a 5% higher yield than the resistance that would be available otherwise;
(b) On average, midge attacks 50% of the Australian crop each year;
(c) Sorghum price is $165 per tonne, equivalent to total production costs per tonne (GRDC 1992);
(d) Annual area sown to grain sorghum averages 551,000 hectares, with average yields 2.12 t/ha.

On the basis of these assumptions, ICRISAT midge resistance would provide a cost reduction of $4.02 per tonne, resulting in a benefit of $4.7 million per year, at full adoption (Table 2.1).

This is a simplified analysis and provides only a partial measure of the full impact of ICRISAT sorghum research on the Australian sorghum industry. Other effects are likely to be felt through the impact on prices of ICRISAT's research. In Section 8, a more complete analysis of the full impacts on Australia is carried out.

Table 2.1: Estimating Value[a] of ICRISAT's Midge Resistance for Australia

	NSW	Queensland	Victoria	WA	Australia
Base Data[b]					
Average sorghum area (000 ha)	135	414	1	1	551
Average yields (t/ha)	2.45	2.01	1.67	2.88	2.12
Average production (000 t)	330	832	2	2	1166
Yield impact:					
Yield increase from ICRISAT resistance (%)	5.0	5.0	5.0	5.0	5.0
Proportion of area with midge (%)	50	50	50	50	50
Overall yield impact (%)	2.5	2.5	2.5	2.5	2.5
New yield (t/ha)	2.51	2.06	1.71	2.95	2.17
Cost reduction:					
Price/Total cost ($/t)	165.00	165.00	165.00	165.00	165.00
Gross income/Total cost per ha ($/ha)	403.82	331.59	275.00	475.00	349.41
New cost per tonne ($/t)	160.98	160.98	160.98	160.98	160.98
Cost reduction from improvement ($/t)	4.02	4.02	4.02	4.02	4.02
Total value of ICRISAT contribution ($000)	*1330*	*3348*	*6*	*8*	*4692*

a: Values are in 1996 Australian dollars
b: Average of ten years to 1996-97

The first commercial hybrids using ICRISAT resistance would be released in time for 1998-99 plantings. The total benefits likely to be received depend on the adoption of the varieties with

ICRISAT's midge-resistant lines, and the length of time that ICRISAT's contribution will provide benefits over those that would have been obtained without ICRISAT's contribution. The following adoption assumptions were made:

(a) Adoption begins in 1999;
(b) It takes 5 years for adoption to reach its peak, increasing linearly;
(c) Adoption stays at the peak level for a total of 20 years;
(d) Newer forms will replace the resistance after that time.

On the basis of these assumptions, the future gross benefits of the cost reduction due to ICRISAT midge resistant lines available through ICSV 745 and other lines are estimated as shown in Table 2.2. The discounted gross benefits, in 1996 values, are estimated to reach $35.4 million over the twenty-five year period, averaging $1.48 million per year.

Table 2.2: Estimated Benefits for Australia from Cost Reduction in Sorghum Production

Year	**Gross benefits[a] ($ million)**				
	New South Wales	**Queensland**	**Victoria**	**Western Australia**	**Australia**
1997-98	0.00	0.00	0.00	0.00	0.00
1998-99	0.27	0.67	0.00	0.00	0.92
1999-00	0.53	1.34	0.00	0.00	1.84
2000-01	0.80	2.01	0.00	0.00	2.76
2001-02	1.06	2.68	0.00	0.01	3.68
2002-03	1.33	3.35	0.01	0.01	4.68
2003-04	1.33	3.35	0.01	0.01	4.68
2004-05	1.33	3.35	0.01	0.01	4.68
2005-06	1.33	3.35	0.01	0.01	4.68
2006-07	1.33	3.35	0.01	0.01	4.68
2007-08	1.33	3.35	0.01	0.01	4.68
2008-09	1.33	3.35	0.01	0.01	4.68
2009-10	1.33	3.35	0.01	0.01	4.68
2010-11	1.33	3.35	0.01	0.01	4.68
2011-12	1.33	3.35	0.01	0.01	4.68
2012-13	1.33	3.35	0.01	0.01	4.68
2013-14	1.33	3.35	0.01	0.01	4.68
2014-15	1.33	3.35	0.01	0.01	4.68
2015-16	1.33	3.35	0.01	0.01	4.68
2016-17	1.33	3.35	0.01	0.01	4.68
2017-18	1.33	3.35	0.01	0.01	4.68
2018-19	1.33	3.35	0.01	0.01	4.68
2019-20	1.33	3.35	0.01	0.01	4.68
2020-21	1.33	3.35	0.01	0.01	4.68
2021-22	1.33	3.35	0.01	0.01	4.68
Discounted[b] total	***10.04***	***25.29***	***0.05***	***0.06***	***35.44***

Discounted[b] annual mean	*0.42*	*1.05*	*0.00*	*0.00*	*1.48*

a: In constant 1996 Australian dollars.

b: Discounted to 1996 values at real discount rate of 8% per annum

3. Impact in Australia of ICRISAT's Chickpea Research

3.1 ICRISAT's Research on Chickpeas

Chickpeas are grown largely for human consumption, although in some countries the dominant use is for livestock feed. Both of the main seed types (desi and kabuli) are grown in Australia, although desi is predominant. Chickpea is agronomically suited to low-rainfall and rainfed areas. Almost three-quarters of the total world's area planted is in India, with Turkey the next most important producer. International trade is limited, with only approximately 350,000 tonnes being traded internationally (Lazenby *et al.* 1994).

ICRISAT has three main research domains, related to latitude:

1. Hot, dry environments, winter-sown (near equator);
2. Cooler, dry environments, winter-sown (25-30º latitude)
3. West Asia and North Africa (30º plus latitude)

Australian production falls largely within the second research domain.

ICRISAT has distributed international nurseries widely, notably the International Chickpea Screening Nursery and the International Chickpea Cooperative Trial. ICRISAT outputs have been finished varieties, intermediate lines and segregating materials for breeders to develop further. This has led to some difficulties in identifying and acknowledging ICRISAT's contribution, notably in India.

ICRISAT has been developing cold tolerant genotypes under the Chickpea Project for dry and cool environments since 1980, aiming for a combination of cold tolerance and early flowering to find broad adaptation, breaking the latitudinal barriers of adaptation.

3.2 Australian Chickpea Industry

Production of chickpeas grew rapidly in Australia during the 1980s, and it is now a significant crop in Victoria (the leading producer), NSW, Queensland, WA and SA. Production was concentrated in Queensland and NSW in the 1980s (Appendix Table A.2), but since that time the relative importance of the more temperate regions of Victoria and WA has increased, with particularly rapid growth in WA in recent years.

Australia has exported most of its chickpea production, with exports averaging 177,000 tonnes in the five years to 1996-97 (compared to average production of 195,000 tonnes), valued at $67 million (ABARE 1997). Exports have been made to 38 countries, including India (Ryan 1996). Local consumption of chickpeas is confined to specialty foods and stockfeed (Singh 1993).

Although higher commercial yields have been achieved, Australian crop yields have averaged 1.01 t/ha over the past five years. Australia is the world's fifth largest producer of chickpeas, and the only country other than Turkey with average yields more than 1 tonne per hectare (Singh 1993). However, management strategies developed to reduce the damaging effects of waterlogging, weeds and *Helicoverpa*, coupled with the recent release of *Phytophthora*- resistant varieties, provide grounds for predicting increased average yields (Lazenby *et al.* 1994).

When chickpea was first introduced in Australia, very few production problems were evident except those associated with the development of cultivars and production technologies. But, as cultivation spread, many problems surfaced (Singh 1993). Some of the more serious problems include diseases (*Phytophthora* root rot and *Botrytis* grey mould), viruses (especially luteo viruses), insects (*Helicoverpa armigera* and *Helicoverpa peltigerea*), nematodes (*Pratelechus* spp.), waterlogging, frost injury, seed weathering and lack of appropriate herbicides to control broadleaf weeds within the crop (Singh 1993).

3.3 Australian Chickpea Improvement Program

Chickpea research in Australia began in earnest in the early 1970s. In 1974, a full-time chickpea breeder was appointed at the Agricultural Research Institute, Wagga Wagga, New South Wales. Subsequently, research and evaluation programs were begun in other States, although not until the late 1980s in Western Australia.

The research is now spread throughout Australia. The total breeder resources were estimated at 1.5 person-years in 1992 (Clements *et al.* 1992), with total funds of $393,000 per year. The National Chickpea Breeding Program is now based at Tamworth, New South Wales, with breeding also carried out at Hermitage, Queensland. Mr E.J. Knights, who is the coordinator of the National Chickpea Breeding Program, is the only scientist working on chickpeas on a full-time basis.

The largest commitment of research resources is by the State Departments of Agriculture, with other significant contributions coming from the Universities of Queensland and Western Australia (WA), Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Grains Research and Development Corporation (GRDC) (Singh 1993).

Australia, with its relatively new and growing industry, has had irregular demand for the ICRISAT chickpea nurseries. Characteristics that are important to Australia are: (a) drought tolerance; (b) cold tolerance; (c) *phytophthora* resistance; (d) virus resistance; and possibly (e) soil-borne diseases.

In WA, the Centre for Legumes in Mediterranean Agriculture (CLIMA) recently has been evaluating ICRISAT cold-tolerant lines (low temperatures around flowering), which were released as Sona (ICCV 88202) and Heera (ICC 14880) in July 1997. Cold temperatures in spring in southern and western Australia can delay flowering and pod-set, and reduce yields without such tolerance.

In the 1970s, Australia had obtained C235 (a desi chickpea) via the Indian Agricultural Research Institute, New Delhi. It was bred in the Punjab, and had: (a) high yield, (b) wide adaptation, and (c) tolerance to *ascochyta* blight. It was released in Queensland as *Tyson* by the Division of Tropical Crops and Pastures, CSIRO, in 1978. The Queensland Department of Primary Industries subsequently released an improved version of *Tyson*, on the basis of high yield, frost tolerance, desirable agronomic characters, and market acceptability (Singh 1993).

Subsequently, several other chickpea varieties have been released in Australia (Table 3.1) without direct ICRISAT germplasm. The desi varieties Amethyst, Dooen and Semsen were released in the 1980s, along with five kabuli varieties. All varieties released in the 1990s have been desi types. Following Barwon and Norwin, Desavic (an introduction from India) was released jointly by South Australia and Victoria in 1993. Only in WA in 1997 have the first varieties (Sona and Heera) been released with direct ICRISAT germplasm.

Table 3.1: Chickpea Varieties Released in Australia with Indian Germplasm

Variety	Origin	Year	State of release	Comments
Desi Types				
Tyson	India	1978	Queensland	*Helicoverpa* tolerance; Indian line C235
Amethyst	Aust.	1988	NSW	Tall, lodging tolerance
Dooen	USSR	1988	Victoria	Large-seeded desi
Semsen	Aust.	1989	Queensland	Very large-seeded desi
Barwon	Aust.	1991	NSW/Qld	*Phytophthora* resistance
Norwin	Aust.	1992	Queensland	*Phytophthora* resistance
Desavic	India	1993	SA/Victoria	Tall, lodging tolerance; Line ICC 1166
Lasseter	Iran	1996	Victoria	Very large, light tan-coloured seed
Sona	ICRISAT	1997	WA	Very early maturing, yellow seeds
Heera	ICRISAT	1997	WA	Very early maturing, yellow seeds
Kabuli Types				
Opal	USSR	1980	NSW	High yield potential
Macareena	Mexico	1984	WA	Very large seeds
Garnet	Turkey	1989	NSW	Moderately large seeds
Kaniva	Spain	1989	Victoria	Moderately large seeds
Narayen	USSR	1989	Queensland	

Source: S.C. Sethi, personal communication, 1997.

3.4 Use of ICRISAT Chickpea Material in Australia

3.4.1 Use of ICRISAT material in Australian crosses

ICRISAT material has been brought into Australia over several years, and has been extensively tested for various attributes. In recent years, ICRISAT material has been widely used in Australian chickpea crosses carried out by the National Chickpea Breeding Program. In 1994 and 1995, 20% of desi crosses were made using at least one ICRISAT line, and a further 78% were made using at least one line with ICRISAT background (see Table 3.2). For kabuli crosses, the percentages were much lower: 0% with ICRISAT lines, and 32% with at least one line with ICRISAT background. It is evident from these figures that ICRISAT material has a pervasive influence on desi chickpea improvement in Australia.

Table 3.2: Use of ICRISAT Material in Australian Chickpea Crosses, 1994, 1995

	Classification[a]							
	A	**B**	**C**	**D**	**E**	**F**	**Total**	
1995 Desi								
North-East Australia								
- *Phytophthora* resistance/yield/erect habit	0	0	0	35	0	0	35	
- *Phytophthora* resistance/virus resistance	0	0	0	8	19	1	28	
- *Phytophthora* resistance/*Helicoverpa* resistance	0	1	0	5	0	0	6	
Victoria/South Australia	0	1	1	4	3	1	10	
Western Australia	1	5	7	0	0	0	13	
- Total Desi	1	7	8	52	22	2	92	
1995 Kabuli								
Large seed/yield/erectness	0	0	0	0	0	22	22	
Large seed/*phytophthora* resistance/erect habit	0	0	0	5	10	0	15	
Large seed/virus resistance/erectness	0	0	0	0	0	6	6	
Large seed/*phytophthora* & virus resistance/erect habit		0	0	0	1	2	1	4
Large seed/earliness/erectness	0	0	0	0	0	8	8	
- Total Kabuli	0	0	0	6	12	37	55	
1994 Desi								
North-East Australia								
- *Phytophthora* resistance/yield/erect habit	0	0	0	34	6	0	40	
- *Phytophthora* resistance	0	0	0	28	0	0	28	
- *Phytophthora* resistance/virus resistance	0	0	0	13	1	0	14	
- *Phytophthora* resistance/*Helicoverpa* resistance	0	10	0	4	0	0	14	
Victoria/South Australia	0	2	2	4	4	0	12	
Western Australia	0	4	9	2	2	3	20	
- Total Desi	0	16	11	85	13	3	128	
1994 Kabuli								
Large seed/yield/erect habit	0	0	0	0	0	16	16	
Large seed/*phytophthora* resistance	0	0	0	0	11	10	21	
Phytophthora resistance/virus resistance	0	0	0	1	5	2	8	
Large seed/earliness	0	0	0	0	0	10	10	
- Total Kabuli	0	0	0	1	16	38	55	
1994 Additional	0	0	0	14	0	0	14	

a: Classification as follows:

- A ICRISAT line x ICRISAT line
- B ICRISAT line x ICRISAT background
- C ICRISAT line x Other
- D ICRISAT background x ICRISAT background
- E ICRISAT background x Other
- F Other x Other

Source: Data provided by E.J. Knights (personal communication, February 1996)

The main ICRISAT lines involved in that material were ICC 2828 and ICC 2903 (*phytophthora* resistance), ICC 506 (*Helicoverpa* resistance), CTS 60543, CTS 11308, ICCV 88501 and ICCV 88502 (cold tolerance at flowering), and some miscellaneous lines conferring earliness or other drought avoiding attributes (E.J. Knights, personal communication, February 1996).

3.4.2 Performance of ICRISAT material in yield trials

A detailed examination was made of the relative yield performance of ICRISAT lines and materials with ICRISAT background compared to other material in the Australian Chickpea Breeding Program. It is apparent (Table 3.3) that there is no inherently different yield performance for the ICRISAT material, as there are no significant differences between ICRISAT material and current varieties or non-ICRISAT materials. It is possible, that the ICRISAT material could confer some yield stability through the introduction of tolerance to environmental stresses. Only in WA are there significant yield advances in ICRISAT lines over current varieties, and in that case there are other non-ICRISAT lines that have similar yields.

Table 3.3: Relative Yields in Chickpea Yield Trials, 1994
(Mean yields as percentage of Tyson)

Cultivars/Lines	**Southern NSW**	**Central NSW**	**Northern NSW**	**Southern Qld**	**Central Qld**	**Victoria**	**South Aust.**	**Western Aust.**
Cultivars:								
- Tyson	100	100	100	100	100	100	100	100
- Amethyst	139	127	107	102	104	na	95	na
- Barwon	120	81	104	88	97	na	96	na
- Norwin	88	90	99	92	na	88	93	na
- Dooen	na	na	na	na	na	94	100	na
- Desavic	na	na	na	na	98	91	108	na
ICRISAT lines	na	na	na	na	na	94	na	121
ICRISAT background	100	95	103	89	100	98	97	112
Non-ICRISAT	na	79	107	na	102	97	89	119

na Not available
Source: Data provided by E.J. Knights (personal communication, February 1996)

3.5 ICRISAT's Impact on Australian Chickpea Production

In assessing the impact of ICRISAT on Australian chickpea production, there has been no direct contribution in the past, since no ICRISAT germplasm has been used commercially in Australia to date. Although neither of the two varieties developed from Indian material (*Tyson* and *Desavic*) grown before 1997 were developed by ICRISAT, ICRISAT nurseries played a significant role in their arrival in Australia.

However, there are likely to be important impacts in the future, both through the varieties released in WA in 1997 and through the ICRISAT germplasm currently in use throughout the breeding program. The impact of ICRISAT chickpea research has been identified as likely to be different in Western Australia (WA) from the rest of Australia. As a result, the WA impact is assessed separately in this analysis.

3.5.1 ICRISAT's impact in Western Australia

In WA, two ICRISAT varieties, Heera and Sona, were released in July 1997. They are seen as having a significant impact on the chickpea industry in WA. They have significant levels of cold tolerance, and are expected to yield an average of 10% higher than alternative varieties that will be available over the next 5 years (S. Loss, Agriculture WA, personal communication). Other (non-ICRISAT) lines with similar yields are likely to be available in the future, but not for another 5-10 years. These two new varieties may also achieve a higher price than Tyson, the variety they will replace, because of improved quality, although that is not clear at this stage. The result is that the area sown to chickpeas in WA is expected to increase strongly over the next 10 years.

In an analysis of the impact of these new varieties in WA, it is difficult to assess the gains that might be achieved if there is a considerable expansion in the area sown to chickpeas. The benefits of such an expansion depend critically on what enterprises are replaced on the farms where chickpeas are grown, and the difference in the returns between the new crops and those replaced. That is very difficult to assess in a broad study such as this one. As a conservative assumption, the area sown to chickpeas is assumed to double in the next five years, and the yield increase due to ICRISAT is measured on that area. Since the price used in the analysis ($431 per tonne) is above the current price of Tyson in WA, no additional value is used to account for differences in quality.

Therefore, in the analysis of the impact in WA, the following assumptions are used: (a) area of chickpeas in WA will approximately double to 100,000 ha by 2002; and (b) yields of chickpeas in WA will increase by 10% as a result of the new varieties. No account is taken of any possible quality differences in the new varieties.

3.5.2 ICRISAT's impact in the rest of Australia

In the other States, there are no such clearly-identifiable benefits from the use of ICRISAT materials. However, material either developed from or incorporating ICRISAT background is prevalent throughout the breeding materials currently in use in Australia. Therefore, it is likely that there will be a measurable impact in the near future. There is no simple, unambiguous means by which the future yield impact of the ICRISAT material on the rest of Australia can be measured.

One means of estimating the future impact of ICRISAT germplasm on yield improvement in the rest of Australia is through estimating the proportion of ICRISAT's contribution to the germplasm used in the current breeding program. In deriving that estimate, the following rules for allocating weights to the lines used in the breeding program were used:

(a) 100% weighting for ICRISAT lines
(b) 50% weighting for lines with some ICRISAT background

(c) zero weighting for non-ICRISAT lines.

On that basis, the weight given to each cross used in the program was as follows:

(a)	ICRISAT line x ICRISAT line	1.00
(b)	ICRISAT line x ICRISAT background	0.75
(c)	ICRISAT line x Other	0.50
(d)	ICRISAT background x ICRISAT background	0.50
(e)	ICRISAT background x Other	0.25
(f)	Other x Other	0.00

According to those criteria, the weighted contribution of ICRISAT to the germplasm used in the program was estimated (Table 3.4) as 45% for desi chickpeas and 11% for kabuli chickpeas, based on 1995 crosses. The weighted average of ICRISAT's contribution to the two types was 41.6%.

Table 3.4: Calculation of Contribution of ICRISAT to Germplasm Used in Australian Chickpea Breeding Program, 1995

Cross	Weight	No. of crosses		Weighted value	
		Desi	Kabuli	Desi	Kabuli
ICRISAT line x ICRISAT line	1.00	1	0	1.0	0.0
ICRISAT line x ICRISAT background	0.75	7	0	5.3	0.0
ICRISAT line x Other	0.50	8	0	4.0	0.0
ICRISAT background x ICRISAT background	0.50	52	6	26.0	3.0
ICRISAT background x Other	0.25	22	12	5.5	3.0
Other x Other	0.00	2	37	0.0	0.0
- Total		*92*	*55*	*41.8*	*6.0*
Weighted average[a] (%)				***45%***	***11%***

a: Weighted value as percentage of total number of crosses

Future progress in the Australian chickpea breeding program was then estimated, on the basis of yield increases of approximately 1.0% per year, or 5.0% over the next five years. Given the 41.6% contribution of ICRISAT, the estimated yield gain due to ICRISAT was 2.08% for the rest of Australia, considerably lower than the 10.0% estimated for WA.

3.5.3 Overall impact of ICRISAT for chickpeas

For WA, the 10.0% yield increase due to ICRISAT is equivalent to a cost reduction of $39.18 per tonne (Table 3.5). For the other States, the ICRISAT impact of a yield increase of 2.08% is equivalent to a cost reduction of $8.78 per tonne. These are equivalent to an average yield increase of 4.96%, for Australia as a whole, or a production cost reduction of $20.37 per tonne. On the basis of the projected area, yield and production data, the total benefits attributable to ICRISAT, in terms of a cost reduction for chickpeas, are $5.21 million per year. WA is the main beneficiary of these benefits, with Victoria the next most significant. The other three producing States receive small benefits.

Table 3.5: Estimating ICRISAT's Contribution to Chickpea Improvement in Australia

	NSW	Qld	Vic	SA	WA	Australia
Base Data[a]						
Average chickpea area (000 ha)	29	22	113	11	100	275
Average yields (t/ha)	0.90	0.68	1.10	1.18	0.93	0.99
Average production (000 t)	26	15	124	13	93	271
Yield impact:						
Yield increase over 5 years (%)	5.0	5.0	5.0	5.0	10.0	6.82
Proportion of contribution by ICRISAT	42%	42%	42%	42%	100%	73%
Overall yield impact (%)	2.08	2.08	2.08	2.08	10.00	4.96
New yield (t/ha)	0.92	0.70	1.12	1.21	1.02	1.03
Cost reduction[b]**:**						
Price/Total cost ($/t)	431.00	431.00	431.00	431.00	431.00	431.00
Gross income/Total cost per ha ($/ha)	386.41	293.86	472.96	509.36	400.83	424.73
New cost per tonne ($/t)	422.22	422.22	422.22	422.22	391.82	410.63
Cost reduction from improvement ($/t)	8.78	8.78	8.78	8.78	39.18	20.37
Total value of ICRISAT contribution[b] *($000)*	*228*	*132*	*1089*	*114*	*3644*	*5207*

a: Average of five years to 1996-97 for all States except WA; for WA, area projected at 100,000 ha, yields based on five-year average
b: Values are in 1996 Australian dollars

The estimates derived in Table 3.5 are the annual benefits at full adoption of the varieties. The flow of those benefits over time, and the total benefits likely to be received, depend on the rate of adoption by farmers of those varieties with ICRISAT's germplasm. The following adoption assumptions were made:

(a) Adoption begins in 1999
(b) These yield increases will relate to 100% of the area of chickpeas;
(c) Varieties take five years to reach peak adoption, increasing linearly;
(d) Adoption stays at the peak level for a total of 20 years.

On the basis of these assumptions, the future gross benefits of the cost reduction ICRISAT's germplasm are estimated as shown in Table 3.6. The discounted gross benefits, in 1996 values, are estimated to reach $39.3 million over the twenty-five year period, averaging $1.64 million per year.

Table 3.6: Estimated Benefits for Australia from Cost Reduction in Chickpea Production

Year	Gross benefits[a] ($ million)					
	NSW	Queensland	Victoria	SA	WA	Australia
1997-98	0.00	0.00	0.00	0.00	0.00	0.00
1998-99	0.05	0.03	0.22	0.02	0.73	1.04
1999-00	0.09	0.05	0.44	0.05	1.46	2.08
2000-01	0.14	0.08	0.65	0.07	2.19	3.12
2001-02	0.18	0.11	0.87	0.09	2.92	4.17
2002-03	0.23	0.13	1.09	0.11	3.64	5.21
2003-04	0.23	0.13	1.09	0.11	3.64	5.21
2004-05	0.23	0.13	1.09	0.11	3.64	5.21
2005-06	0.23	0.13	1.09	0.11	3.64	5.21
2006-07	0.23	0.13	1.09	0.11	3.64	5.21
2007-08	0.23	0.13	1.09	0.11	3.64	5.21
2008-09	0.23	0.13	1.09	0.11	3.64	5.21
2009-10	0.23	0.13	1.09	0.11	3.64	5.21
2010-11	0.23	0.13	1.09	0.11	3.64	5.21
2011-12	0.23	0.13	1.09	0.11	3.64	5.21
2012-13	0.23	0.13	1.09	0.11	3.64	5.21
2013-14	0.23	0.13	1.09	0.11	3.64	5.21
2014-15	0.23	0.13	1.09	0.11	3.64	5.21
2015-16	0.23	0.13	1.09	0.11	3.64	5.21
2016-17	0.23	0.13	1.09	0.11	3.64	5.21
2017-18	0.23	0.13	1.09	0.11	3.64	5.21
2018-19	0.23	0.13	1.09	0.11	3.64	5.21
2019-20	0.23	0.13	1.09	0.11	3.64	5.21
2020-21	0.23	0.13	1.09	0.11	3.64	5.21
2021-22	0.23	0.13	1.09	0.11	3.64	5.21
Discounted[b] total	***1.72***	***0.99***	***8.22***	***0.86***	***27.52***	***39.33***
Discounted[b] annual mean	*0.07*	*0.04*	*0.34*	*0.04*	*1.15*	*1.64*

a: In constant 1996 Australian dollars
b: Discounted to 1996 values at real discount rate of 8% per annum

As for sorghum, this is only a simplified analysis and provides only a partial measure of the full impact of ICRISAT on Australian chickpea industry. Other effects are likely to be felt through the impact on prices of ICRISAT's research. In Section 8, a more complete analysis of the full impacts on Australia is carried out.

4. Impact in Australia of ICRISAT's Pigeonpea Research

Pigeonpea is well suited to dry areas. Pigeonpea is generally grown on very marginal land where other crops are risky. Its features are: (a) perennial growth habit; (b) legume (providing N fixation); (c) stems used for fuel; and (d) deep rooting, providing drought resistance. However, pigeonpea is frost sensitive.

ICRISAT has had two targets in pigeonpea research: (a) Long and medium duration (traditional); and (b) Short and extra-short duration (newly developed).

Globally, India is the dominant producer. Myanmar has developed a pigeonpea industry, based largely on export to India. Nepal is also an important producer. In East Africa, Kenya and Malawi produce pigeonpea for the local Indian population as well as indigenous Africans, and split pigeonpeas for export to Asia, Europe and North America. In the Caribbean, pigeonpeas are used as a fresh vegetable for local human consumption, for animal feed, and for the green peas that are consumed locally or exported as canned peas to North America. Market channels for pigeonpea are also established in Eastern Africa and the Caribbean.

The grain can be used as a stockfeed (source of protein), and the by-product of splitting pigeonpea for dhal (seed coats, broken seeds) is valuable as animal feed. The leaves are deficient in sulphur and are not favoured for grazing or feeding

Insect (especially pod-borer) control is very important for pigeonpea production. Some genetic resistance is available, but it is limited. Natural predators exist (wasp, spider, NPV virus), but integrated pest management is vital, and includes avoidance by selecting appropriate maturity.

Pigeonpea is well adapted to Queensland environments. Between 1977 and 1986, there was a strong interactive research program on pigeonpeas between ICRISAT and University of Queensland, as part of an exploratory push for producing tropical crops for export, particularly for Asian immigrants in developed countries (eg UK).

Materials were introduced from ICRISAT, but different plant types needed to be developed for Australia. The characteristics sought for Australian conditions were: (a) short plant height; (b) determinate (for mechanical harvesting); and (c) short duration (110-130 days to maturity). This research provided a stimulus to ICRISAT to consider different plant types more closely.

After 1986, ACIAR provided support when ICRISAT core funding support was withdrawn (from 1986-1989). Three varieties were released in Australia in the 1980s: Hunt, Quantum and Quest; all had high yield potential. Mega was released in Indonesia from this material. Currently, testing is being carried out for pigeonpea in more southern areas of Australia, by Sydney University and the Victorian Institute for Dryland Agriculture at Horsham.

Australia found some niche markets in the early 1980s, but production began to meet some problems: (a) pod-borer insects, (b) droughts, (c) soil problems (iron deficiency), (d) difficult crop to manage, and (e) dehulling. As a result, they could not meet their commitments to niche markets.

As there was no domestic market, production was found to be uneconomic, despite a potential for export to India.

There still is enormous potential for production in Australia, but considerable industry infrastructure is required (as for cotton). Certainty of supply is needed, and integrated pest management and control of insecticides to prevent pod-borers developing resistance to the insecticides (1-2 sprays) is vital. Potential markets for Australia include:

(a) Export of whole seed to India (which has its own processing industry);
(b) Export of split peas to other markets;
(c) Use as source of protein in animal feed (*cf*. soybean).

Material from Australia has proven useful elsewhere: (a) the first male-sterile material used to develop hybrids was found in Australia; (b) an ACIAR program in South-East Asia led to the testing in Indonesia of short-duration material developed in Australia, and the variety Mega was developed from this.

Pigeonpea is a very minor crop in Australia at present (Appendix Table A.3). In recent years, the area sown to pigeonpeas has averaged less than 500 ha per year, with production of less than 100 tonnes, with production predominantly in New South Wales and Queensland. In the late 1980s, more substantial areas were sown, but the area sown and production has declined markedly since that time.

5. Impact in Australia of ICRISAT's Groundnut Research

The groundnut plant is drought hardy, and has strong survival mechanisms. However, it needs moisture to provide good pod production and needs calcium directly from soil for pods. Because it is a high value crop, it is more profitable for dry areas than other equal-yielding crops (eg sorghum).

Groundnuts are used for two major purposes: (a) crushed for oil (India, Nepal, Myanmar); and (b) other than oil: confectionery (bold, large seeded).

ICRISAT's research on groundnut has the following objectives:

(a) Improve and stabilise productivity of groundnut in major production systems;
(b) Develop environment and farmer friendly groundnut stress alleviation strategies;
(c) Generate and enhance knowledge of science and technology of groundnut; and
(d) Share knowledge and skills with national agricultural research systems.

ICRISAT is breeding for both high oil (where crushed) and low oil (for confectionery). Important characteristics being sought include: (a) early maturity; (b) leaf spot and rust resistance; (c) drought tolerance; and (d) regional diseases (bacterial wilt, peanut stripe and peanut bud necrosis in Asia; and rosette in Africa). Genetic improvement has been achieved in the ICRISAT program, and on-farm improvements have been realised in India and South-East Asia. This improvement has been translated to a limited impact in Africa.

The Australian peanut industry is relatively small, with recent average production of 41,000 tonnes from 24,000 ha, at average yields of 1.7 t/ha (Appendix Table A.4). The industry is based almost exclusively in Queensland. The only Australian peanut breeding program is run by the QDPI at Kingaroy in Queensland.

Australia has long had close interaction with ICRISAT in groundnut research. An ACIAR-funded project on bacterial wilt has led to benefits for Indonesia. During 1991-92, there was cooperative work on groundnut in acid soils in Indonesia, which resulted in the identification of genotypes with superior performance in acid soils. An ACIAR-funded collaborative project on "Selection for water-use efficiency", involving ACIAR, QDPI, ICRISAT and the Indian Council for Agricultural Research as partners, operated from 1993 to 1996. In that project, a range of groundnut genotypes with high expression of physiological traits contributing to drought tolerance have been developed to assist selection for these traits using simple tools; about 13 selected genotypes with drought tolerant traits have been sent to QDPI at Kingaroy for use in the breeding program. In addition, based on the information generated on selection for water-use efficiency, the second phase of the project, entitled "Development of drought-resistant peanuts, using novel selection methods in India and Australia", was launched in June 1997 by ACIAR.

Although ICRISAT materials have been sent regularly to the Australian breeding program, no commercial varieties with those materials have been released by QDPI to date. Australia has obtained groundnut germplasm with various desirable characteristics such as confectionery types (large-seeded), early maturity, and aflatoxin resistance.

6. Impact in Australia of ICRISAT's Millet Research

The emphasis in ICRISAT millet research is on pearl millet, and less so on finger millets. The main production areas for pearl millet are South Asia (India), Africa, South Korea (forage only). ICRISAT's mandate is for grain types, and dual-purpose types (and more recently some funding has been provided for research on forage types). Pearl millet has a high degree of acid soil tolerance. However, pearl millet has only moderate drought tolerance, and can avoid droughts because of a very short growing season.

ICRISAT, in partnership with national agricultural research systems in Asia, has been successful in getting improved pearl millet materials to farmers, mainly because of high yield combined with downy mildew resistance. The yield advances initially came through hybrids, but open-pollinated varieties provided a broader base for resistance. Recently, the diversity on downy mildew resistance of hybrid parents has been increased, as well as the yield of open-pollinated varieties.

The latest ICRISAT material has: (a) large round seed, with ease of dehulling; (b) high yield; (c) early maturity; and (d) high tillering.

Hybrids are important in India (perhaps 30-40% of area). Quality seed is important, and hybrids are a way of farmers getting quality assurance for seed. However, there appears to be no real yield advantage in hybrids.

There was once a public breeding program for pearl millet in Australia, but it is now closed. Currently there is little pearl millet grown in Australia; what there is at present is with Pacific Seeds program on forage millet. The impact of ICRISAT through that material is difficult to identify, but is likely to be small. In recent years, the area sown to millets for grain has averaged 32,000 ha, while production has averaged 31,000 tonnes per year, with production predominantly in Queensland (Appendix Table A.5).

To develop grain millets for Australia, researchers believe that they would need to alter plant architecture to enable mechanical harvesting (short stature). Dwarf pearl millets are available in forage varieties.

There have also been impacts from Australia to ICRISAT: A mutant plant was identified in the Australian forage variety Katherine with a gene for photoperiod insensitive early flowering. This gene has subsequently been used in ICRISAT's breeding programs.

7. Impact in Australia of ICRISAT's Resource Management Research

7.1 Resource Management Research at ICRISAT

ICRISAT has several projects in the resource management area, which aim to improve the sustainability of production in a range of environments. During the period 1994 to 1996, four projects were defined to target the following:

(a) Strategies for enhanced and sustainable productivity in rainfed short-season millet-legume-based production systems;
(b) Strategies for enhanced and sustainable productivity in short- to intermediate-season rainfed millet-sorghum-legume based production systems;
(c) Strategies for enhanced and sustainable productivity in low- to intermediate-rainfall production systems in the SAT; and;
(d) Legume-based technologies for rice and/or wheat production systems in South and South-East Asia.

ICRISAT turned its focus to four systems projects in 1996 (Bantilan *et al.* 1997). These are:

(a) *Desert margin systems:* The objectives of this project are to: (i) identify opportunities where research is likely to contribute to sustainable improvements in the driest farming systems of the SAT; (ii) apply models to systems research to improve research efficiency and outcomes; (iii) develop strategies to enhance the availability and utilisation of water and nutrients; (iv) test and adapt IPM components to fit diverse SAT farming systems; (v) develop participatory methodologies for technology delivery; (vi) facilitate and catalyse technology transfer; and (vii) assess impact, identify bottlenecks and improve systems understanding.
(b) *Dry savanna systems:* This project involves: (i) characterisation and systems modelling to identify constraints and research opportunities; (ii) development of improved soil, water, nutrient and land management systems for increased productivity and sustainability; (iii) special focus on improving sorghum- and groundnut-based production systems on sandy soils; and (iv) integration of improved germplasm and IPM components into the production system context.
(c) *Semi-arid watershed systems:* The objective of this project is development and evaluation of strategies for sustainable improvement of seasonally moist valley bottom and alluvial lowland soils of the SAT, including post-rainy-season cropping on stored moisture and determination of socioeconomic constraints to crop intensification.
(d) *Diversifying rice-wheat systems:* This project aims to: (i) improve the productivity, sustainability and diversity of irrigated rice-wheat systems through the incorporation of appropriate legume-based technologies; and (ii) demonstrate the value of inter-institutional collaboration among a large set of international and local agencies to solve complex system problems.

7.2 Relationship between Australia and ICRISAT for Resource Management

In Resource Management, there are similarities in soils, climate between Australia and developing country SAT, but technologies recommended for farmers in developing countries are not necessarily relevant to Australia. Examples of issues that highlight the inapplicability of ICRISAT resource management to Australia include: (a) the importance of farm-yard manure in the sorghum production system, and (b) the cost of harvest labour versus mechanised harvesting.

However, techniques and basic research (such as physiology) - in which ICRISAT has a comparative advantage - can have important benefits for Australia.

A Queensland Department of Primary Industries project ran for approximately 8 years from 1986 (Ryan 1994). Its aim was to adapt the Queensland PERFECT model (erosion-productivity model) to the alfisol soils. It has led to the development of the INPERFECT (Indian PERFECT) model. The project is now moving from its strategic/basic phase to a more applied phase, with the development of a new project. The INPERFECT model developed for alfisols is directly applicable to the soils of Queensland, and so benefits will flow back to Australia.

A project with the Agricultural Production Systems Research Unit (APSRU) at Toowoomba, Queensland, funded by ACIAR as part of Restricted Core Funding, is also operating at ICRISAT. It has links with the Rural Extension Unit, Gatton, and the Communications Institute of Australia at University of Queensland. The project aims to use Australian technologies to assist ICRISAT. However, there are also benefits to Australia through developments to the APSIM (Agricultural Production Systems Simulation Model) model, such as: (a) incorporation of P-deficiency into models (Ryan 1994); and (b) treatment of farm manure (relevant for sewage sludge). In addition, some parts of the APSIM model are based on work that was originally carried out at ICRISAT.

While these impacts on Australia can be important, no attempt is made in this report to put an economic value on them. It would require a more detailed study than is possible in this project to identify the benefits to Australia of ICRISAT’s resource management research, since the benefits can only be identified with intensive economic evaluations. To that extent, the results obtained in this study will understate the total benefits to Australia derived from collaboration with ICRISAT.

8. Economic Analysis of Impacts of Sorghum and Chickpea Research

8.1 Economic Approach

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

In the analysis in this study, the spillover effects of research at ICRISAT on the production of mandate crops in Australia are identified. An attempt is made to quantify the extent of those spillover effects from the ICRISAT program, largely through their effect on Australian yields. A genetic improvement in yield means an increase in productivity, in the sense that there is higher output for each level of input. In economic terms, the yield-increasing effects of a new variety result in a shift of the supply curve (Lindner and Jarrett 1978; Norton and Davis 1981; Edwards and Freebairn 1984).

Following Edwards and Freebairn (1984), the increase in productivity is defined as a parallel vertical shift in the supply curve through a lowering of the production costs per tonne. If the cost of growing the marginal hectare is E ($/ha) and the yield is Y (t/ha), the average cost of production is E/Y per tonne. If the yield increases by the proportion a with no increase in costs per hectare, then the cost per tonne falls to $E/[Y(1+a)]$, and the proportional fall in costs is $a/(1+a)$ dollars per tonne. Thus a costless (in terms perceived directly by farmers) yield increase of 5.00% is equivalent to a cost reduction of 4.76%, or $7.14 at an average total cost of $150 per tonne.

If it is assumed that new varieties do not interact with changes in other inputs (see Brennan 1989, Brennan and Fox 1995), the economic benefits can be estimated directly from these cost reductions.

The shifts in world supply attributed to research emanating from ICRISAT are likely to have had an impact on the world price for the relevant crops. It is likely, therefore, that the increased supply resulting from the increased productivity obtained through ICRISAT has affected the prices received for Australia's production of the mandate crops. The analysis in this study is based on estimates of supply and demand elasticities from ICRISAT studies. Since the markets are less than perfectly elastic, the increased supply in other countries will have reduced the price, so that the gains indicated by this analysis are lower than if the assumption of perfect elasticity (as in Brennan and Fox 1995) had been maintained. As a result, these price effects are likely to have produced reductions in welfare for Australian producers of those crops, at the same time as producing benefits for Australian consumers.

Thus, the approach used in this study is a modified version of that used in the Brennan and Fox (1995) study of the impact of the International Maize and Wheat Improvement Center (CIMMYT) on Australian wheat production. For the analysis of CIMMYT wheat in Australia, the supply shift was for a large export industry, for which the assumption of an elastic demand curve was reasonable. In addition, the nature of the impact was that the development of the semi-dwarf wheats resulted in a large, one-off shift in the supply curve for wheat. However, for the ICRISAT crops, all are smaller industries in Australia than wheat, and many are likely to have less elastic demand. Other features are that it is more difficult to identify the technological impacts, and that for some crops it is more a matter of potential impacts than actually realised impacts.

8.2 Spillover Framework Used

The framework used in this analysis is based on Edwards and Freebairn (1984). The world markets for each crop are disaggregated into two regions, namely Australia and Rest of World (ROW). Australia is further sub-divided into States.

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

(a) Elasticities of demand and supply are the same throughout Australia;
(b) All countries other than Australia are grouped into Rest of World;
(c) The total production costs per tonne equal the equilibrium price (GRDC 1992);
(d) All supply and demand curves are linear;
(e) All shifts in supply are defined as vertical shifts (ie, cost reductions).

The framework used is illustrated in Figure 8.1. ICRISAT research leads to a shift in supply curves for each region. The shifts are greatest in the Rest of the World (the “target” region), with spillovers impacting on Australia. For simplicity in this analysis, the impact on developed countries other than Australia is ignored. The resultant welfare gains are measured as changes in producer and consumer surpluses for each region.

8.3 Empirical Analysis of Sorghum Impact

The genetic materials identified in the earlier analysis of the impact of ICRISAT research in Australia (Section 2) are expected to have their research impact over the five years starting in 1998-99, with their commercial impact on farms extending well past that time. In this analysis, an attempt is made to quantify the impacts of the known research materials and their effect on hybrids and varieties released over the next five years. Beyond that time, there are likely to be further research impacts that are too difficult to estimate at this time. As a result, the impacts measured are those expected to occur through hybrids/varieties released in the next five years.

Estimates of the global impact of ICRISAT’s sorghum research (Table 8.1) are that yields will be increased by 14.7% as a result of current research. However, some of those gains are likely to be achieved well into the future, and it is estimated that the yields will increase by 10.2% over the next five years. Thus, the yield gains in the Rest of World will be 10.2% over that period, compared to 2.5% for Australia in the same period (Section 2).

Figure 8.1: Spillover Framework Used in Analysis

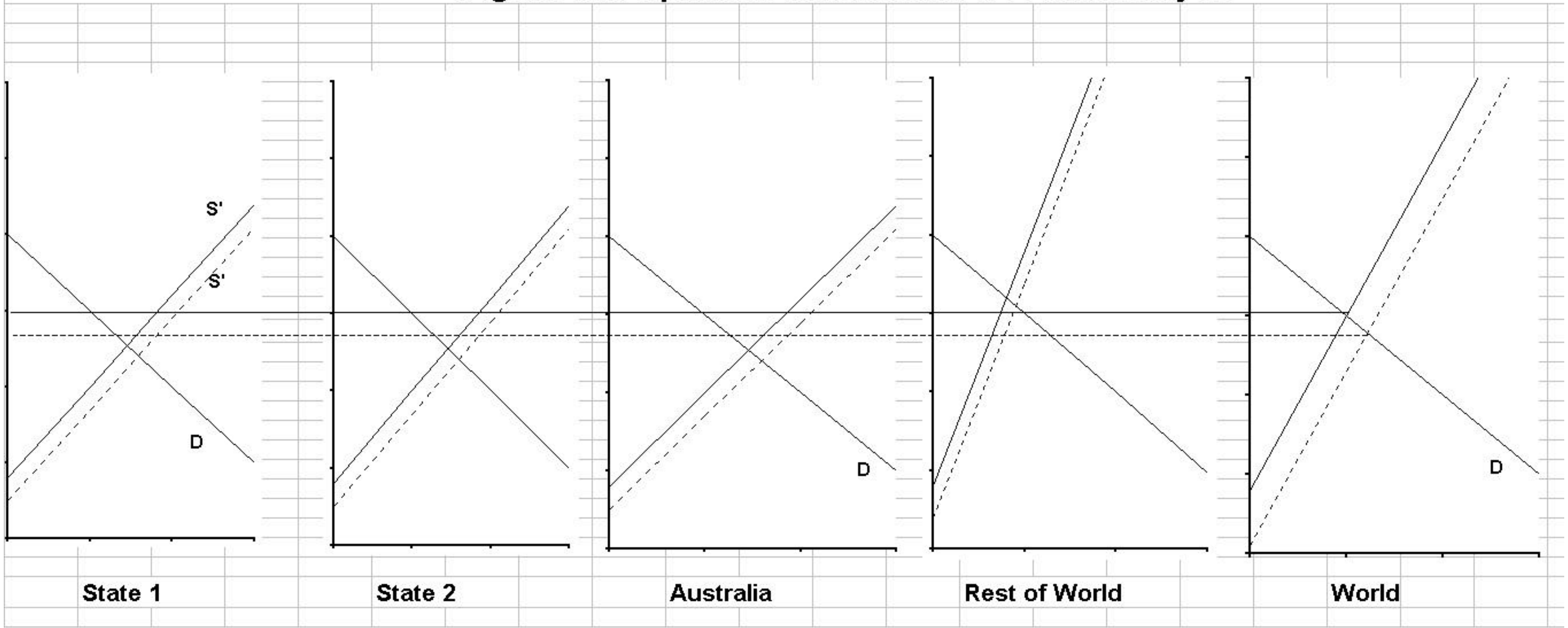

Table 8.1: Estimated ICRISAT Impact on World Sorghum Production by 2002

Research Area	Area affected (m. ha)	Expected yield increase (%)	Achievable by 2002 (%)
Grain, stover and forage yield breeding	45.02	1.0	1.0
Grain mould resistance and management	15.56	5.0	5.0
Anthracnose resistance	14.77	4.0	4.0
Foliar disease resistance	5.69	8.6	5.0
Head bug resistance and management	9.32	6.1	6.1
Midge resistance and management	15.95	10.0	7.0
Shoot fly resistance and management	6.90	5.0	5.0
Stem borer resistance and management	30.74	3.0	0.0
Low temperature resistance for highlands	0.80	1.0	1.0
Drought resistance breeding	7.66	5.3	0.0
Acid soil tolerance	0.81	8.0	8.0
Striga resistance and management	7.71	5.0	5.0
Gains from ICRISAT research	*45.02*	*14.7%*	*10.2%*

Source: ICRISAT

In assessing the impact of ICRISAT spillovers to Australia in sorghum research, the following data were used in the analysis:

(a) World sorghum price $165/t;
(b) Supply elasticity 0.3, demand elasticity -3.4 for Australia (Singh and Brennan 1998);
(c) Supply elasticity 0.2, demand elasticity -0.3 for Rest of World[1];
(d) World sorghum production 58.358 Mt;
(e) ICRISAT research will have increased sorghum yields by 10.2% in Rest of World by 2002, equivalent to a cost reduction of $15.27/t;
(f) Australian sorghum area 551,000 ha, yields 2.12 t/ha, production 1.166 Mt.;
(g) ICRISAT research will have increased Australian sorghum yields by 2.5%, equivalent to a cost reduction of $4.02/t (Section 2), by 2002.

The direct research impacts are a cost reduction in the Rest of World of $15.27/t, and spillover benefits of a cost reduction of $4.02/t for Australia. While these cost reductions result in savings for producers, who increase production, the resultant increased quantities produced lead to a fall in price of $5.52/t, or 3.35%. That leads to substantial benefits for consumers of these grains (that is, the livestock sector), while producers simultaneously face both yield increases and price falls. The net position of producers depends on the balance between the yield gains and the price fall.

[1] These elasticities are likely to vary considerably between countries.

Using these data in the analytical framework provides the results shown in Table 8.2. For Rest of World producers, there is a large welfare gain of $559 million per year, with the yield increase more than offsetting the lower price. For Rest of World consumers, there are significant gains from the lower prices ($324 million per year). For Australia, the impacts are relatively small compared to these overall benefits from ICRISAT. The cost reduction (Section 2) provides benefits of approximately $4.7 million. However, the price reduction has a significant impact on the magnitude and distribution of those benefits. The net effects are a reduction in welfare for producers of $1.7 million per year, which results from a gain of $4.7 million from the higher yields associated with ICRISAT research, but a reduction of $6.4 million because the world price has fallen 3.4% from the same research. Australian sorghum consumers (that is, the livestock sector) gains $5.3 million from the lower prices, so that overall there is a net gain to Australia of $3.6 million.

Table 8.2: Annual Welfare Gains[a] from ICRISAT's Sorghum Research (at full adoption)

	Australia ($m)	Rest of World ($m)	World ($m)
Sorghum Producers			
- Price effect	-6.4	-312.6	-319.0
- Yield effect	4.7	873.4	878.2
- Net effect	-1.7	560.8	559.1
Sorghum Consumers	5.3[b]	318.9	324.2
Total	3.6	879.7	883.3

a: In 1996 Australian dollars
b: Livestock sector

These are the annual benefits that are expected at full adoption of the higher-yielding genotypes. On the basis that it would take five years for the research benefits to be fully adopted, with the first year of adoption being 1998, full benefits would not be achieved until 2002. The genotypes are assumed to have a productive life of a further 20 years beyond 2002 before being replaced or outmoded.

On the basis of these adoption parameters, the annual flow of benefits has been estimated over the period 1999 to 2022. When the annual benefits are discounted (at 8% per annum) over that period, there is an estimated net gain to Australia (in 1996 discounted dollars) of $27.3 million, at an average of $1.14 million per year. Australian producers suffer a reduction in welfare averaging $0.55 million per year (despite an increase in yields), while Australian feed grains consumers gain an average of $1.69 million per year from the lower prices. In Rest of World, both producers and consumers reap substantial benefits from ICRISAT's sorghum research, averaging $177 million and $100 million, respectively, per year in discounted 1996 dollars.

To examine the extent to which the chosen values for the parameters of the analysis for sorghum have an impact on the findings of the study, the sensitivity of the results (measured as the aggregate gains for Australia) was examined (Table 8.3). Each selected parameter was varied by ±20%, and the effect on the gains for Australia estimated.

Table 8.3: Sensitivity of Results for Sorghum to Changes in Parameters [a]

Parameter	Value	Aggregate Gain for Australia ($m)
Yield increase in Rest of World by 2002	**10.20%**	**1.14**
	8.16%	1.19
	12.24%	1.10
Yield increase in Australia by 2002	**2.5%**	**1.14**
	2.0%	0.85
	3.0%	1.42
Price ($/t)	**$165**	**1.14**
	$132	0.91
	$198	1.37
Elasticity of demand - ROW	**-0.30**	**1.14**
	-0.24	1.11
	-0.36	1.16
Elasticity of demand - Australia	**-3.40**	**1.14**
	-2.72	1.12
	-4.08	1.16
Elasticity of supply - ROW	**0.20**	**1.14**
	0.16	1.17
	0.24	1.11
Elasticity of supply - Australia	**0.30**	**1.14**
	0.24	1.14
	0.36	1.14
Years to peak adoption	**5**	**1.14**
	4	1.22
	6	1.06

a: Selected parameter values varied by +20% and -20% from values used in estimates

The aggregate results are clearly sensitive to the value of several of the parameters that have been used in the analysis. In addition, the relative gains of Australian sorghum producers and consumers vary with the values used. It is possible to identify "break-even" points, the values at which Australian producers have net gains rather than net losses from ICRISAT. These are:

- (a) Yield gains in Rest of World are 7.2% or less;
- (b) Yield gains in Australia are 3.5% or more;
- (c) Elasticity of demand in Rest of World larger (more negative) than -0.5;
- (d) Elasticity of demand for Australia larger (more negative) than -16.4;
- (e) Elasticity of supply for rest of World less than 0.1;
- (f) Elasticity of supply in Australia more than 44.7.

The other parameters tend to shift the total benefits in unison, without changing the relativity between producers and consumers to any great extent.

8.4 Empirical Analysis of Chickpea Impact

A similar assessment of the impact of ICRISAT spillovers to Australia in chickpea research was made, with the analysis based on impacts expected to occur through hybrids/varieties released in the next five years.

Estimates of the global impact of ICRISAT's chickpea research (Table 8.4) are that yields will be increased by 60.2% as a result of current research. However, some of those gains are likely to be achieved well into the future, and it is estimated that the yields will increase by 21.4% over the next five years. Thus, the yield gains in Rest of World will be 21.4% over that period, compared to 4.96% for Australia in the same period (Section 3).

Table 8.4: Estimated ICRISAT Impact on World Chickpea Production by 2002

Research Area	Area affected (m. ha)	Expected yield increase (%)	Achievable by 2002 (%)
Grain yield breeding	8.15	7.0	0.0
Ascochyta blight resistance	5.80	10.0	0.0
Botrytis grey mould resistance	1.77	3.0	3.0
Root rot resistance, biocontrol and management	8.02	2.0	2.0
Wilt resistance	8.02	7.0	7.0
Stunt virus diagnostics and resistance	7.78	0.5	0.5
Cold tolerance breeding	1.35	5.0	5.0
Drought and heat resistance	7.68	10.0	10.0
Helicoverpa IPM	8.02	25.0	0.0
Nematode resistance and management	4.88	2.0	2.0
Gains from ICRISAT research	*8.15*	*60.2%*	*21.4%*

Source: ICRISAT

In assessing the impact of ICRISAT chickpea research, the following data were used in the analysis:

(a) World chickpea price $431/t;
(b) Supply elasticity 0.5, demand elasticity -3.0 for Australia (based on Singh and Brennan 1998);
(c) Supply elasticity 0.4, demand elasticity -0.6 for Rest of World[2];
(d) World chickpea production 8.2 Mt;
(e) ICRISAT research will have increased chickpea yields by 21.4% in Rest of World (Table 8.4), equivalent to cost reduction of $75.96/t, by 2002;
(f) Australian chickpea area 275,000 ha, yields 0.99 t/ha, production 271,000 t;
(g) ICRISAT research will have increased Australian chickpea yields by 4.96%, equivalent to a cost reduction of $20.37/t (Section 3), by 2002.

The direct research impacts are a cost reduction in the Rest of World of $75.96/t, and spillover benefits of a cost reduction of $20.37/t for Australia. The large yield increases from ICRISAT research worldwide lead to benefits of $603 million per year to producers. These benefits are partially offset (to the value of $227 million) by the effect of a price fall of $28.89/t (or 6.70%). That price fall leads to large benefits for chickpea consumers (that is, largely the livestock sector), which are estimated at $241 million (Table 8.5). The net impact is a gain of $617 million worldwide. The impact of the cost reduction for Australia (Section 3) is $5.2 million. However, the price reduction has a significant impact on the magnitude and distribution of the net benefits to Australia. The net effects are a reduction in welfare for producers of $2.6 million per year, which results from the gain of $5.2 million from the higher yields associated with ICRISAT research, but a reduction of $7.8 million because the world price has fallen 6.70% because of the same research. Australian chickpea consumers (again, mainly the livestock sector) gain $3.8 million from the lower prices, so that overall there is a net gain to the Australia chickpea industry of $1.2 million per year.

Table 8.5: Annual Welfare Gains[a] from ICRISAT's Chickpea Research (at full adoption)

	Australia ($m)	Rest of World ($m)	World ($m)
Chickpea Producers			
- Price effect	-7.8	-219.6	-227.4
- Yield effect	5.2	598.7	603.9
- Net effect	-2.6	379.1	376.5
Chickpea Consumers	3.8[b]	236.7	240.5
Total	1.2	615.8	617.0

[2] As for sorghum (Footnote 1), these elasticities are likely to vary considerably between countries.

a: In 1996 Australian dollars
b: Livestock sector

These are the annual benefits that are expected at full adoption of the higher-yielding genotypes. On the basis that it would take five years for the research benefits to be fully adopted, with the first year of adoption being 1999, full benefits would not be achieved until 2003. The genotypes are assumed to have a productive life of a 20 years to 2002 before being replaced or outmoded.

On the basis of these adoption parameters, there is an annual flow of benefits for chickpeas over the period 1999 to 2022. When the annual benefits are discounted (at 8% per annum), the value of the net spillover benefits over the period considered are found to be small but positive for Australia. In the 25 years from 1998, there is an estimated net gain to Australia (in 1996 discounted dollars) of $9.1 million, at an average of $0.38 million per year. Australian producers have a reduction in welfare of an average of $0.81 million per year, despite an increase in yields, because of the price fall from the larger yield gain in the rest of the world. Australian consumers gain an average of $1.19 million per year from the lower prices. In Rest of World, both producers and consumers reap substantial benefits from ICRISAT's chickpea research, averaging $119 million and $75 million, respectively, per year in discounted 1996 dollars.

To examine the extent to which the chosen values for the parameters of the analysis for chickpeas have an impact on the findings of the study, the sensitivity of the results (measured as the aggregate gains for Australia) was examined (Table 8.6). Each selected parameter was varied by ±20%, and the effect on the gains for Australia estimated.

As for sorghum, the aggregate results obtained are sensitive to the value of several of the parameters that have been used in the analysis. In addition, the relative gains of Australian chickpea producers and consumers vary with the values used. It is possible to identify "break-even" points, the values at which Australian producers have net gains in welfare rather than net reductions from ICRISAT. These are:

(a) Yield gains in Rest of World are 13.3% or less;
(b) Yield gains in Western Australia are 18.2% or more;
(c) Yield gains in the Rest of Australia are 13.9% or more;
(d) Elasticity of demand in Rest of World larger (more negative) than -1.1;
(e) Elasticity of demand for Australia larger (more negative) than -38.2;
(f) Elasticity of supply for rest of World less than 0.2;
(g) Elasticity of supply in Australia more than 23.8.

The other parameters tend to shift the total benefits in unison, without changing the relativity between producers and consumers to any great extent.

Table 8.6: Sensitivity of Results for Chickpea to Changes in Parameters [a]

Parameter	Value	Aggregate Gain for Australia ($m)
Yield increase in Rest of World by 2002	**21.40%**	**0.38**
	17.12%	0.58
	25.68%	0.20
Yield increase in WA by 2002	**10.0%**	**0.38**
	8.0%	0.17
	12.0%	0.59
Yield increase in Rest of Australia by 2002	**2.08%**	**0.38**
	1.66%	0.29
	2.50%	0.47
Price ($/t)	**$431**	**0.38**
	$345	0.30
	$517	0.46
Elasticity of demand - ROW	**-0.60**	**0.38**
	-0.48	0.24
	-0.72	0.50
Elasticity of demand - Australia	**-3.00**	**0.38**
	-2.40	0.35
	-3.60	0.41
Elasticity of supply - ROW	**0.40**	**0.38**
	0.32	0.53
	0.48	0.26
Elasticity of supply - Australia	**0.50**	**0.38**
	0.40	0.38
	0.60	0.38
Years to peak adoption	**5**	**0.38**
	4	0.41
	6	0.36

a: Selected parameter values varied by +20% and -20% from values used in estimates

8.5 Aggregate Results

The aggregate benefits over the period to 2022 are summarised in Table 8.7. Overall, Australia benefits from the activities of ICRISAT by an average of $1.52 million per year, or $36.4 million over the period to 2022. There is a net transfer of welfare from the producers of each grain to the consumers (that is, the livestock sector) in Australia, but the net effect is a significant gain for Australia.

Table 8.7: Net Welfare Gains [a] for Australia from ICRISAT

(Average annual benefits for 1999 to 2022)

	Sorghum ($m)	Chickpeas ($m)	Total ($m)
Producers	-0.55	-0.81	-1.36
Consumers[b]	1.69	1.19	2.88
- Total	*1.14*	*0.38*	*1.52*

a: Discounted to 1996 Australian dollars at 8% per annum

b: Livestock sector

9. Implications and Conclusions

There are several implications of the findings of this study:

(a) International Centres such as ICRISAT remain a source of materials for potential yield gains for Australian crops, even those crops grown in systems and environments significantly different from those targeted by the international centres.

(b) Australian producers will be affected by the price implications of the successful research that is undertaken by the international centres such as ICRISAT, whether or not they take advantage of the possible yield gains spilling over.

(c) Consumers, which for many grains in developed countries means livestock industries, are likely to be significant benefactors of any research advances in the grains industries.

(d) Australia's gains are likely to be greatest for those industries where there are significant links between Australian researchers and the researchers and programs being undertaken in the international research centres. As a result, personnel interchange and overseas visits by Australian researchers to those centres are likely to have enormous pay-offs for Australian grains industries, since they are a principal means of developing those links. The subsequent reduced time lags for the exchange of research information are also likely to result in increasing the impacts.

(e) Australian researchers need to maintain their vigilance over international agricultural research developments. Only where Australian researchers can keep abreast of developments in other parts of the world can the benefits for Australian producers be maintained. Producers continually face the long-term decline in real prices that results from the ongoing success of the agricultural scientists around the world, in both national and international research, to increase yield levels for so many significant crops. The long-term decline in real prices will occur whether or not Australia contributes to the international agricultural research system, and Australia's best opportunity to glean spillover benefits from the system lies in being part of the system through financial support.

Those declines in prices can lead to significant benefits for Australian consumers of grains, whether in consuming grain products directly or in consuming livestock products that use the lower-priced feed grains. In previous studies, those benefits to consumers in developed countries such as Australia have not been recognised, although they have been found in this study to be significant in some industries. The findings of this study mean that the importance of the price effects needs to be recognised in evaluating the economic benefits spilling over from international agricultural research.

In conclusion, this study has produced significant findings at two levels. The first level has been the identification of anticipated spillover benefits in terms of cost reduction for producers in two of the ICRISAT mandate crops, namely sorghum and chickpeas. Those cost reductions are expected to result from yield increases attributable to germplasm developed at ICRISAT or enhanced by being coordinated by ICRISAT and incorporated into genotypes that will be grown in Australia. The second level at which significant findings have emerged for the first time is in the incorporation of the price effects of international agricultural research for these crops. In these two export-oriented Australian industries, the price effects were found to be significant, with a shift in welfare between the Australian producers of those grains and the Australian consumers of them in the livestock sector.

Recognition of these factors can assist in leading to better-informed decision-making for research resource allocation and is likely to lead to a more efficient, and more cooperative, research system worldwide. That improved system will deliver expected improvements in the efficiency of production and in the delivery of appropriate food cheaply to the consumers most in need of it.

Overall, Australia has received small but significant benefits from ICRISAT's research, at an average of $1.52 million per year. Those benefits are well in excess of Australia's financial contribution to ICRISAT.

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Appendix A:
Australian Production of ICRISAT Mandate Crops

Table A.1: Area, Production, Yield of Sorghum by State, 1987-1996

Year	NSW	Vic.	Qld	WA	Australia
Area (000 ha)					
1987-88	175	0	565	0	740
1988-89	152	1	468	1	622
1989-90	138	0	238	0	376
1990-91	84	0	291	1	376
1991-92	147	0	420	0	567
1992-93	118	0	308	0	426
1993-94	99	0	399	0	498
1994-95	161	6	519	0	686
1995-96	150	1	500	1	652
1996-97	126	1	435	2	564
Mean (10 yrs)	*135*	*1*	*414*	*1*	*551*
Yield (t/ha)					
1987-88	2.35	-	2.15	-	2.19
1988-89	1.98	1.00	2.00	1.00	1.99
1989-90	2.60	-	2.43	-	2.49
1990-91	2.23	-	1.92	2.00	1.99
1991-92	2.71	-	2.49	-	2.54
1992-93	1.94	-	1.02	-	1.28
1993-94	2.30	-	2.14	-	2.17
1994-95	2.16	1.33	1.76	-	1.86
1995-96	3.00	2.00	2.20	3.00	2.38
1996-97	3.13	2.00	1.86	3.00	2.15
Mean (10 yrs)	*2.45*	*1.67*	*2.01*	*2.88*	*2.12*
Production (000 t)					
1987-88	412	0	1213	0	1625
1988-89	301	1	934	1	1237
1989-90	359	1	578	1	939
1990-91	187	1	558	2	748
1991-92	398	0	1045	0	1444
1992-93	229	0	315	2	546
1993-94	228	0	852	2	1082
1994-95	347	8	916	2	1273
1995-96	450	2	1100	3	1555
1996-97	395	2	809	6	1212
Mean (10 yrs)	*330*	*2*	*832*	*2*	*1166*

Source: ABARE, **Australian Commodity Statistics 1997** (and previous issues), and ABARE (1997).

Table A.2: Area, Production, Yield of Chickpea by State, 1987-1996

Year	NSW	Vic.	Qld	WA	SA	Australia
Area (000 ha)						
1987-88	21	9	20	0	5	55
1988-89	21	11	29	0	6	68
1989-90	22	25	41	0	6	93
1990-91	40	58	72	1	8	178
1991-92	85	90	58	1	16	250
1992-93	28	78	33	1	12	152
1993-94	26	100	7	3	9	147
1994-95	20	144	19	13	13	209
1995-96	35	101	30	30	11	207
1996-97	34	144	20	45	12	255
Mean (5 yrs)	*29*	*113*	*22*	*19*	*11*	*194*
Yield (t/ha)						
1987-88	1.12	1.02	0.84	1.25	0.96	0.99
1988-89	1.21	1.27	1.41	2.33	0.82	1.28
1989-90	0.96	1.56	1.03	2.67	1.29	1.18
1990-91	1.43	0.63	1.21	2.00	1.22	1.08
1991-92	0.62	1.26	0.63	2.40	1.21	0.89
1992-93	0.88	1.63	0.44	1.60	0.76	1.17
1993-94	1.08	1.46	0.57	1.00	1.14	1.31
1994-95	0.38	0.26	0.41	0.60	0.61	0.33
1995-96	1.14	1.68	0.27	0.83	1.36	1.25
1996-97	0.88	0.97	2.00	1.07	1.67	1.09
Mean (5 yrs)	*0.91*	*1.10*	*0.68*	*0.93*	*1.09*	*1.01*
Production (000 t)						
1987-88	23	9	17	1	5	54
1988-89	26	15	40	1	5	86
1989-90	21	38	42	1	8	109
1990-91	57	36	88	1	10	192
1991-92	53	113	37	1	20	223
1992-93	25	128	14	2	9	177
1993-94	29	146	4	3	11	193
1994-95	8	38	8	8	8	69
1995-96	40	170	8	25	15	258
1996-97	30	140	40	48	20	278
Mean (5 yrs)	*26*	*124*	*15*	*17*	*13*	*195*

Source: ABARE, **Australian Commodity Statistics 1997** (and previous issues), and ABARE (1997).

Table A.3: Area, Production, Yield of Pigeonpea by State, 1987-1996

Year	NSW	Vic.	Qld	Australia
Area (ha)				
1987-88	2263	30	682	975
1988-89	96	0	260	356
1989-90	0	0	236	236
1990-91	0	0	580	580
1991-92	67	0	840	907
1992-93	48	0	268	316
1993-94	64	0	106	170
1994-95	na	na	na	na
1995-96	na	na	na	na
1996-97	na	na	na	na
Mean (5 yrs)	*56*	*0*	*187*	*243*
Yield (t/ha)				
1987-88	0.57	0.80	0.43	0.54
1988-89	0.55	-	0.42	0.46
1989-90	-	-	0.50	0.50
1990-91	-	-	0.35	0.35
1991-92	0.92	-	0.11	0.17
1992-93	0.52	-	0.14	0.20
1993-94	0.66	-	0.26	0.41
1994-95	na	na	na	na
1995-96	na	na	na	na
1996-97	na	na	na	na
Mean (5 yrs)	*0.60*	-	*0.17*	*0.27*
Production (tonnes)				
1987-88	1286	24	291	601
1988-89	52	0	110	163
1989-90	0	0	118	118
1990-91	0	0	206	206
1991-92	62	0	96	157
1992-93	25	0	37	62
1993-94	42	0	28	70
1994-95	na	na	na	na
1995-96	na	na	na	na
1996-97	na	na	na	na
Mean (5 yrs)	*34*	*0*	*33*	*66*

na Not available

Source: Australian Bureau of Statistics (Unpublished data).

Table A.4: Area, Production, Yield of Groundnut/Peanut by State, 1987-1996

Year	NSW	Qld	WA	Australia
Area (000 ha)				
1987-88	0.5	31.0	0.2	31.7
1988-89	0.2	22.0	0.2	22.4
1989-90	0.2	18.1	0.0	18.3
1990-91	0.3	17.8	0.1	18.2
1991-92	0.3	20.5	0.1	20.9
1992-93	0.7	21.9	0.1	22.7
1993-94	0.7	21.1	0.0	21.8
1994-95	0.2	12.9	0.1	13.2
1995-96	0.8	19.8	0.0	20.6
1996-97	1.0	28.0	0.1	29.1
Mean (5 yrs)	*0.7*	*20.7*	*0.1*	*21.5*
Yield (t/ha)				
1987-88	2.20	1.15	1.50	1.17
1988-89	3.50	1.09	1.50	1.11
1989-90	3.00	0.99	-	1.02
1990-91	2.67	1.48	2.00	1.50
1991-92	2.00	1.86	2.00	1.86
1992-93	1.71	1.42	1.00	1.42
1993-94	2.00	2.07	-	2.06
1994-95	4.00	1.74	1.00	1.77
1995-96	1.00	1.90	-	1.86
1996-97	2.50	1.55	2.00	1.58
Mean (5 yrs)	*1.97*	*1.72*	*1.33*	*1.72*
Production (000 t)				
1987-88	1.1	35.7	0.3	37.1
1988-89	0.7	23.9	0.3	24.9
1989-90	0.6	17.9	0.1	18.6
1990-91	0.8	26.3	0.2	27.3
1991-92	0.6	38.1	0.2	38.9
1992-93	1.2	31.0	0.1	32.3
1993-94	1.4	43.6	0.0	45.0
1994-95	0.8	22.5	0.1	23.4
1995-96	0.8	37.6	0.0	38.4
1996-97	2.5	43.4	0.2	46.1
Mean (5 yrs)	*1.3*	*35.6*	*0.1*	*37.0*

Source: ABARE, **Australian Commodity Statistics 1997** (and previous issues), and ABARE (1997).

Table A.5: Area, Production, Yield of Millet by State, 1987-1996

Year	NSW	Vic.	Qld	WA	Australia
Area (000 ha)					
1987-88	2.2	1.4	35.2	0.0	38.9
1988-89	1.3	1.0	23.4	0.0	25.8
1989-90	2.3	1.8	30.0	0.3	34.4
1990-91	2.3	1.3	28.6	0.0	32.3
1991-92	2.6	0.9	30.9	0.0	34.3
1992-93	3.0	0.8	18.0	0.0	21.8
1993-94	3.5	1.4	32.4	0.0	37.4
1994-95	7.2	1.7	34.8	0.0	43.7
1995-96	3.4	1.0	18.6	0.0	23.0
1996-97	na	na	na	na	na
Mean (5 yrs)	*4.3*	*1.2*	*25.9*	*0.0*	*31.5*
Yield (t/ha)					
1987-88	1.82	1.55	1.11	1.00	1.16
1988-89	1.60	1.55	0.72	2.00	0.80
1989-90	1.79	1.62	1.06	1.60	1.14
1990-91	1.44	1.59	0.55	-	0.66
1991-92	1.60	1.90	1.21	-	1.25
1992-93	2.02	2.01	0.37	-	0.65
1993-94	1.63	1.47	0.90	-	0.99
1994-95	1.06	1.58	0.96	-	1.00
1995-96	1.47	1.74	1.24	-	1.30
1996-97	na	na	na	na	na
Mean (5 yrs)	*1.43*	*1.65*	*0.89*	-	*0.99*
Production (000 t)					
1987-88	4.0	2.1	39.1	0.0	45.2
1988-89	2.1	1.6	16.8	0.0	20.5
1989-90	4.2	3.0	31.7	0.0	39.3
1990-91	3.3	2.1	15.8	0.0	21.3
1991-92	4.1	1.7	37.3	0.0	43.0
1992-93	6.0	1.6	6.6	0.0	14.2
1993-94	5.8	2.0	29.1	0.0	37.0
1994-95	7.7	2.6	33.2	0.0	43.6
1995-96	5.0	1.8	23.1	0.0	29.8
1996-97	na	na	na	na	na
Mean (5 yrs)	*6.1*	*2.0*	*23.0*	*0.0*	*31.2*

na Not available

Source: Australian Bureau of Statistics (Unpublished data).

Appendix B:
Survey of Australian Research Programs on Contributions from ICRISAT

B.1 Survey of Crop Improvement Programs

In late 1996, a survey was conducted of the crop improvement programs in Australia known to be working on ICRISAT's mandate crops. In all, twelve responses were received, with only one program known to be currently releasing varieties failing to supply a completed reply. A copy of the survey form is shown in Figure B.1.

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

The detailed results of the survey are summarised in the following section. It is apparent that ICRISAT material is currently being widely used for a number of the crops. The breadth of that reliance on ICRISAT as a source of breeding materials and methodologies varies widely between crops.

B.2 Results of Survey

B.2.1 Release of varieties/hybrids developed by ICRISAT

(a) Sorghum

No sorghum varieties or hybrids from ICRISAT had been released directly in Australia. The reason given was that cultivars developed by ICRISAT are not adapted to Australia, particularly with respect to later maturity and excessive height.

(b) Chickpea

Prior to 1997, the only direct release in Australia was Desavic (ICC 1166), released in Victoria and South Australia in 1993. In July 1997, Sona and Heera were released in Western Australia.

(c) Pigeonpea

The University of Queensland released Hunt, Quest and Quantum pigeonpea in the early 1980s; these were lines from ICRISAT. No other varieties direct from ICRISAT have been released in Australia.

(d) Groundnut

No ICRISAT varieties have been released.

(e) Pearl millet

No ICRISAT varieties have been released.

B.2.2 Release of varieties/hybrids with ICRISAT materials in their pedigree

(a) Sorghum

Two sorghum lines (out of 94 released from the public breeding program since 1989) each have PM 13654 in their pedigree (12.5% by pedigree in each). One of these lines has white grain and tan plant colour, derived from PM 13654. In addition, Monsoon sorghum for northern Australia was reported as originating from material sourced from ICRISAT, although details of the actual materials used and crossings involved were not available.

(b) Chickpea

The varieties Barwon (released in 1991) and Norwin (1992) had ICRISAT-derived parents in their pedigrees. Barwon was a cross between CPI 56564 and ICC 2903; and Norwin was a cross between CPI 56564 and ICC 2828.

(c) Pigeonpea

No varieties or hybrids with ICRISAT materials in their pedigrees have been released.

(d) Groundnut

No ICRISAT varieties have been released.

(e) Pearl millet

One late-maturing forage hybrid millet has one parent from ICRISAT.

B.2.3 Advanced lines with ICRISAT materials in their pedigree

(a) Sorghum

The public breeding program reported that PM 13654-derived material is at an advanced stage (two have already been released). One breeding organisation reported that there were no ICRISAT-derived materials in advanced lines for grain sorghum, but that for forage sorghum there were some late-maturity grain sorghums being used in pedigree crossing.

(b) Chickpea

A number of ICRISAT lines are contained in advanced stages of the Western Australian materials, including: CTS 60543-10W (ICRISAT selection), ICCX-840060 (extra early), ICCV 90008 (early duration), ICCV 88109 (mid duration), ICCV 89402 (long duration), ICCV 89443 (long duration), CTS 11308 and ICCV 88201.

(c) Pigeonpea

The extra-short duration type pigeonpeas currently being tested are all ICRISAT lines. The lines being tested are ICPL 85010, ICPL 85014, ICPL 88001, ICPL 88007, ICPL 88015, ICPL 88020, ICPL 90008 and ICPL 90011.

(d) Groundnut

No advanced lines in the program have ICRISAT materials in their pedigrees.

(e) Pearl millet

No advanced lines in the program have ICRISAT materials in their pedigrees.

B.2.4 ICRISAT materials being used in current crossing program

(a) Sorghum

The public sorghum breeding program is currently using PM 13654, ICSV 197 and ICSV 745. The latter two have been used to combine their (hopefully) different genes for midge resistance with those used in Australia. The stage of development varies from F_4 to F_2. Entomology and molecular marker research is being employed to test for differences in mechanisms and resistance genes. One breeding organisation reported that there were no ICRISAT materials being used in their crossing program for grain sorghum, but that for forage sorghum there were some late-maturity B-lines being used in single-cross steriles.

(b) Chickpea

For chickpeas, the ICRISAT lines being used in crosses include: ICC 1069 (botrytis resistance); CTS 60543 and CTS 11308 (cold tolerance at flowering); ICC 14880, ICCV 88201 and ICCV 88202 (high yield); ICC 4958 and ICC 14307 (drought avoidance); and ICC 506 (heliothis resistance). The WA improvement program is looking for wide adaptation, cold tolerance, resistance to botrytis greymould, and ascochyta blight.

(c) Pigeonpea

No ICRISAT lines are currently being used in crosses.

(d) Groundnut

The breeding program at Kingaroy is currently using CGS 14 (high yield), CS 22 (foliar disease resistance) and ICGV 86031 (water use efficiency) in its crossing program.

(e) Pearl millet

No ICRISAT lines are currently being used in crosses, although it is intended to introduce pearl millet inbred lines with high yield ability, maturity and stature suitable for grain in Australia.

B.2.5 ICRISAT outputs other than breeding lines that are being used

(a) Sorghum

For grain sorghum, midge screening techniques (after Sharma 1992) are being used.

(b) Chickpea

In addition to breeding lines, regular use is made of several nurseries such as for (a) cold tolerance, (b) ascochyta resistance, (c) helicoverpa resistance. ICRISAT Germplasm Catalogues and publications are also widely used. One program intends to use ICRISAT techniques for screening for cold tolerance.

(c) Pigeonpea

ICRISAT root rot nurseries for phytophthora and nematode resistance have been or are currently being assessed.

(d) Groundnut
Publications such as the International Arachis Newsletter and other ICRISAT publications.

(e) Pearl millet
One breeder mentioned that he would like to introduce some of ICRISAT's pearl millet land races. Use is currently being made of the following:
(i) High temperature screening of seedlings;
(ii) Technical papers on high temperature/physiology and on ICRISAT's range of crops.
In addition, ICRISAT outputs, including genetic material, have been used for work in countries other than Australia, especially parts of South-East Asia.

B.2.6 Regular contact with ICRISAT
(a) Sorghum
Sorghum researchers in Australia reported several visits to ICRISAT at Patancheru in recent years. In addition, there was regular written communication, particularly with Dr H.C. Sharma, who has been in Australia on sabbatical leave. Indigenous wild sorghums had been collected for, and sent to, ICRISAT.

(b) Chickpea
Chickpea researchers in Australia reported regular visits to ICRISAT, and other regular written and electronic contact with ICRISAT's chickpea scientists. In addition, visits to Australia by ICRISAT staff were seen as important means of contact. Currently ICRISAT is collaborating in a proposed ACIAR project on drought tolerance in chickpea (a joint ACIAR/CLIMA/India/ICRISAT proposal).

(c) Pigeonpea
Currently there is irregular contact only, although in the past it has been considerably greater.

(d) Groundnut
There is some contact with breeders, but no regular organised contact.

(e) Pearl millet
Breeders reported that they did not make regular visits, but maintained contact by mail, e-mail and phone regularly. ICRISAT scientists have visited Australia and collected wild relatives of pearl millet.

B.2.7 Other comments on impact of ICRISAT in Australia
(a) Sorghum
Breeders reported that ICRISAT is a very useful source of germplasm.

(b) Chickpea

ICRISAT germplasm was seen as becoming more important as chickpeas are moving into areas more akin with ICRISAT's target areas and with the threat of ascochyta blight emerging in Australia. ICRISAT is also increasing their efforts on large seeded kabulis that are of great interest to Australia. One breeder reported that he has strong interest in ICRISAT's expertise in quality evaluation, and expects links with ICRISAT to develop more in the next few years. Breeders reported good contacts with ICRISAT chickpea researchers. ICRISAT research and publications are valuable resources for breeders and genetic resource organisations in Australia.

(c) Pigeonpea
No further comments.

(d) Groundnut
ICRISAT provides good value in collaborative projects, particularly the ACIAR-funded water-use efficiency projects.

(e) Pearl millet
ICRISAT's continuity of work on pearl millet provides a useful resource for new germplasm for countries such as Australia, with a small or emerging industry. One breeder reported that, while ICRISAT's research is very relevant to northern Australia, there is inadequate real contact or appreciation of the depth of experience or relevance of ICRISAT in Australia, partly because of the differing agricultural systems involved. He suggested that there should be an increased interchange of staff in the training area, such as Australians working at ICRISAT for higher degrees but completing their work in Australia

Figure B.1: Copy of Survey Questionnaire

Survey of
Impact of ICRISAT on Australian Agricultural Production

1. Have you released varieties/hybrids that were developed by ICRISAT?
If so, please provide details.

2. Have you released varieties/hybrids that have ICRISAT materials in their pedigree? If so, please provide details.

3. Are there ICRISAT materials in your advanced lines? If so, please identify the ICRISAT materials, and provide details of the stage of the lines.

4. Are you currently using ICRISAT breeding material in your crossing program? f so, please specify the main lines that you are currently using and the characteristics you are seeking from them.

5. Are there ICRISAT outputs other than breeding lines that you have used or are using (eg, screening techniques, nurseries, etc)? Please list.

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

7. Any other comments on the impact of ICRISAT in Australia?

Please return the completed form, by 30 November 1996