An Economic Analysis of Investment in Cereal Rust Control

Background

The University of Sydney has maintained a cereal breeding program for rust resistance since before 1920. Breeding for disease resistance is a constant challenge as the resistance of older cereal varieties is overcome by the incursion of new rust pathotypes and the continuing evolution of existing strains.

The National Wheat Rust Control Program started in 1974 following the 1973 epidemic of stem rust in south east Australia, in response to a strong push to establish a program with a national focus. Leaf and stem rust had existed in Australia for a long time but in 1979 the first outbreak of stripe rust occurred. The workload for the Program increased by 30% as it then had three diseases with which to contend (Park, pers. comm., 2007).

In the mid-1980s the program was renamed the National Cereal Rust Control Program with the scope of effort broadened to include most cereal types rather than just wheat. The Australian Cereal Rust Control Program (ACRCP) commenced in 2003 (McIntosh, 2007) with national and international dimensions and addressing rust diseases in wheat, barley, triticale and rye. Funding for the Program has been from industry via GRDC and the University of Sydney. The program delivers both research and “services to industry” outputs. A fee for service model for rust testing in a privatised breeding environment is currently being developed. For a detailed history of breeding for rust resistance in Australia see Park (2007) and McIntosh (2007).

Cereal rust disease has imposed a large cost on the cereal industry throughout its history. For example, since 2003 stripe rust infections are estimated to have cost farmers between $40 and $90 m per annum in fungicides alone (Grains Week, 2006, media release). And this is without considering yield losses. The current analysis attempts to determine the impact of the cereal rust control program in terms of the benefits it has provided to the industry, impacts on the environment and to the community at large.

The Investment

Program Objectives

The program’s objectives are:
(i) to monitor and produce information on cereal rust pathogens throughout Australia
(ii) to identify and characterise new sources of rust resistance in cereals
(iii) to assist Australian cereal breeders to incorporate rust resistance into new cultivars

Recent Projects Funded by GRDC to meet Program Objectives

Table 1: Recent Rust Projects Funded by GRDC

Project Code and Title	Objective
US315:Australian Cereal Rust Control Program	(i) To carry out annual pathogenicity surveys of rust pathogens of wheat, barley oats, triticale and rye (ii) To screen and enhance germplasm (iii)To carry out genetic and cytogenetic studies of host resistance to cereal rusts
US00028: Adult plant resistance and pathogen variability in cereal rust: cereal host pathosystems	(i) To provide genetic information and improved germplasm for all cereal breeders that will increase the durability of resistance of cereal rusts in Australia so providing greater stability in production and reduce dependence on pesticides
CIM13: Adult plant resistance and introgression of new and novel genes	(i) To identify 3-5 slow rusting genes involved in adult plant resistance (APR) to leaf and stripe rusts as well as linked molecular markers for each gene (ii) To provide Australian wheat breeders with about 50 new wheat lines each year that have high levels of APR to leaf and stripe rusts for crossing into Australian wheats. (iii) To develop cultivars with new blocks of resistance genes to leaf rust, stem rust, BYDV and RLN in a recombined Agropyron alien chromosome segment
CSP00017: Molecular discovery	(i) To implement the use of markers to pyramid multiple effective stem rust resistance in wheat and cloned genes for transformation breeding (ii) To isolate Host and Rust genes involved in the disease process identified through functional genomics so that they can provide targets for developing novel strategies for disease resistance (iii)To implement the use of an effective Activation Tagging system in cereals and to isolate host promoters and genes whose pathogen specific induction causes reduction of pathogen growth and disease resistance

Investments

GRDC core funding for the past 5 years for the Program has just finished in June 2007. This was nearly $5 m over 5 years or about $1 m per annum. Since 1973 there has been a steady increase in real terms in the annual budget as new challenges have emerged (Park, pers comm., 2007).

The program has been supported strongly by the University of Sydney and with cash from GRDC. Also, NSW DPI contributes resources to the program through the long-term secondment of a senior scientist. The ACRCP is a collaborative program and GRDC has made other investments in the program though CIMMYT (International Maize and Wheat Improvement Centre) and CSIRO.

Estimates of the funding by institution for recent projects are shown in Tables 2 to 6

Table 2: Total Investment in Project US315 for Years ending June (nominal $)

Year	GRDC	University of Sydney	NSW DPI	Total
2003	880,405	2,963,678	90,860	3,934,943
2004	942,964	3,107,847	93,100	4,143,911
2005	1,002,455	3,332,364	95,500	4,430,319
2006	1,017,508	3,418,722	97,800	4,534,030
2007	1,050,318	3,582,429	100,300	4,733,047
Total	4,893,650	16,405,040	477,560	21,776,250

Source: Project proposal

Table 3: Total Investment in Project US00028 for Years ending June (nominal $)

Year	GRDC	University of Sydney	NSW DPI	Total
2005	204,800	594,700	14,800	814,300
2006	218,080	611,900	15,200	845,180
2007	208,460	632,400	15,600	856,460
Total	631,340	1,839,000	45,600	2,515,940

Source: Project proposal

Table 4: Total Investment in Project CIM13 for Years ending June (nominal $)

Year	GRDC	CIMMYT	Total
2003	366,000	300,000	666,000
2004	356,000	300,000	656,000
2005	356,000	300,000	656,000
2006	366,000	300,000	666,000
2007	356,000	300,000	656,000
Total	1,800,000	1,500,000	3,300,000

Source: Project proposal

Table 5: Total Investment in Project CSP00017 for Years ending June (nominal $)

Year	GRDC	CSIRO	Total
2003	513,063	872,100	1,385,163
2004	506,953	973,800	1,480,753
2005	542,139	1,015,900	1,558,039
2006	556,318	1,083,400	1,639,718
2007	558,847	1,130,000	1,688,047
Total	2,677,320	5,075,200	7,752,520

Source: Project proposal

Table 6: Total Investment in Core Activities (four projects) of the Program (Years ending June) (nominal $)

Year	GRDC	University of Sydney	NSW DPI	Other	Total
2003	1,759,468	2,963,678	90,860	1,172,100	5,986,106
2004	1,805,917	3,107,847	93,100	1,273,800	6,280,664
2005	2,105,394	3,927,064	110,300	1,315,900	7,458,658
2006	2,157,906	4,030,622	113,000	1,383,400	7,684,928
2007	2,173,625	4,214,829	115,900	1,430,000	7,934,354
Total	10,002,310	18,244,040	523,160	6,575,200	35,344,710

(a) Includes CIMMYT and CSIRO
Source: Additions of figures in Tables 2 to 5 above

For the four projects reported above, GRDC has contributed 28% of resources in nominal terms with the remaining support provided by the host organizations. Further funding of the ACRCP is gained from private contracts that enhance the program but are fully self-funded.

Table 7 summarises the total investment over the entire period.

Table 7: Total Investment in the Program for the Years ending June 1991 to June 2007 (nominal $)

Year	GRDC	University of Sydney (a)	NSW DPI (b)	Other	Total
1991	459,036	837,234	67,711	0	1,363,981
1992	486,636	887,616	68,997	0	1,443,249
1993	514,236	937,958	69,704	0	1,521,898
1994	540,336	985,563	70,990	0	1,596,890
1995	559,199	1,019,969	73,241	0	1,652,409
1996	650,000	1,185,589	76,328	0	1,911,916
1997	661,314	1,206,225	77,356	0	1,944,896
1998	702,599	1,281,528	77,807	0	2,061,934
1999	727,514	1,326,973	78,642	0	2,133,129
2000	753,295	1,373, 997	81,150	0	2,208,442
2001	750,814	1,369,472	86,037	0	2,206,323
2002	770,000	1,404,467	88,481	0	2,262,947
2003	1,759,468	2,963,678	90,860	1,172,100	5,986,106
2004	1,805,917	3,107,847	93,100	1,273,800	6,280,664
2005	2,105,394	3,927,064	110,300	1,315,900	7,458,658
2006	2,157,906	4,030,622	113,000	1,383,400	7,684,928
2007	2,173,625	4,214,829	115,900	1,430,000	7,934,354
Total	17,577,289	32,060,631	1,439,605	6,575,200	57,652,724

Source: GRDC, ACRCP

(a) Actual contributions for 2003 to 2007; earlier years based on ratio of University of Sydney to GRDC funding of 1.82 to 1.

(b) Actual contribution from 2003 to 2007; earlier years based on value of one scientist seconded to ACRCP.

Program Description

As reflected in its objectives, the ongoing activities of ACRCP (Park, 2007, in press) include annual pathogenicity surveys for all cereal rust pathogens in Australia, genetic research aimed at identifying and characterising new sources of resistance, and germplasm screening and enhancement service to all Australian cereal breeding groups.

The program is usually considered a pre-breeding program rather than a breeding program per se. The focus of the program is on improved germplasm and screening services. The investment has enhanced the varieties produced by the current cereal breeding program across Australia. The program covers:

- stem rust, leaf rust and stripe rust of wheat,
- leaf rust, stem rust and barley grass stripe rust of barley,
- crown rust and stem rust of oats,
- stem rust, leaf rust and stripe rust of triticale, and

- leaf rust and stem rust of cereal rye.

Wheat is the major cereal crop grown in Australia. Breeding is now privatised with 10 entities currently breeding wheat. The ACRCP works with all 10 wheat breeding programs, most of which have evolved from State wheat breeding programs. Currently a cost recovery process is being developed for the ACRCP due to the privatisation of wheat breeding. Recovery will be for those activities and services performed by the program where benefits will clearly be gained by the private sector. These include some of the testing of early and advanced material for the breeders, summer field testing and some germplasm enhancement including backcrossing and F2 selections (Anon, 2007). This change was introduced on July 1 2007 and therefore does not affect the costs of the ACRCP over the period of investment to June 2007.

Apart from the ACRCP and the cereal breeders, the CSIRO and the University of Adelaide have been involved in understanding and furthering knowledge associated with rust resistance in cereals. CIMMYT has also been involved with the ACRCP in terms of exchanging germplasm with rust resistance characteristics.

Outputs

The principal outputs from the investment made in the period from 2001 to 2007 include:

Contribution of Germplasm to New Resistant Cultivars

The ACRCP has identified sources of new resistance, and has developed a high level of understanding of the various genes involved. The program has undertaken field assessments of the level of protection that has resulted (Park, unpublished 2007). The approach has used biotechnology tools such as cytogenetics and molecular markers have been used to identify new genes. Molecular markers add precision to selection and make it easier to combine resistance genes (Park, 2007). Prospective genes have then been introduced to enhance a range of germplasm, some of which has been introduced into breeding programs. This is achieved by backcrossing the rust resistance into lines chosen in consultation with breeding program partners. There is actual data of new resistant cultivars being released and data is available on their resistance level and yield increases over previous cultivars.

The majority of cultivars released have been from the State based programs where the ACRCP's advanced breeding lines have been used. From the advanced breeding lines the breeders take 3 to 5 years to develop the rust resistant varieties to the stage of their release.

While the ACRCP has identified many different sources of rust resistance, two major sources (genes) of rust resistance have been deployed over the past 25 years. These genes have been incorporated into cultivars by both the ACRCP and breeders. The first resistance (leaf rust and stem rust; *Lr24/Sr24)* was first deployed in a cultivar released in 1983 and is still being utilised. The second resistance (leaf rust, stem rust and stripe rust; *Lr37/Sr38/Yr17*) was first deployed in a cultivar in 1998 or a little earlier and is still in a significant number of released and soon to be released cultivars. There have been at least

20 cultivars released that have been selected by breeders from back cross material generated by the ACRCP.

In the early stage of the program, single genes for resistance were used but from about 1970 onwards multiple genes have been used.

The ACRCP has also imported a great deal of wheat, barley, oat and triticale germplasm that was grown through quarantine, rust tested and then distributed to breeders along with rust response data. Some of this germplasm has been utilised by cereal breeders in their programs.

Germplasm Screening and Validation
Breeders submit germplasm to the ACRCP for screening of rust resistance. These lines are submitted from cereal breeders at different stages of their breeding cycle. For early generation material, the rust evaluations are used as a selection tool. For later generation material, the ACRCP validates whether lines are resistant or not, and based on this validation, the ACRCP is then responsible for making the final resistance rating for new varieties.

Pathogenicity Surveys
Pathogenicity surveys have been carried out since 1919 at University of Sydney (Park, 2007). These surveys are still a major function of the program and would not have occurred without a national centre. The surveys monitor and preserve new and existing pathotypes, pathogenic variability, the distribution of the various races of the pathogen, local mutations to virulence, and foreign incursions of exotic rust isolates.

The information produced from the surveys is used by cereal breeders and by cereal producers. Knowledge of genes in the fungus can lead to improved breeding designs. Also, the resistance building effort through new varieties strongly relies on the rust strains identified and characterised by the surveys.

Pathogens can overcome resistance slowly but sometimes this may occur quite quickly. The most common cause of development of virulence is through mutations in existing strains of the pathogen. Some producers are therefore growing cultivars that no longer have resistance and may face yield losses. The information from the surveys is therefore valuable as an input into extension services. Extension officers and producers can then make improved predictions of varietal resistance. This helps varietal selection and whether to use fungicides to manage the disease.

The surveys provide advance warnings to growers by identifying new strains before they reach levels that can cause significant economic damage. For example, the pathotype survey in 2004 showed that there was no evidence of change in the pathogen population and that in general the relative rankings of variety response to stripe rust have not altered appreciably (Wellings et al, 2004). Any changes in ratings as a result of an outbreak can have implications for sowing decisions for the following year.

Preparedness for Australia
The ACRCP plays a role in managing the biosecurity risk for new rust pathogens entering Australia. For example a relatively new wheat stem rust strain from Uganda (UG99) is expected to travel though the Middle-East and across Asia and may reach Australia. The ACRCP therefore has links to international breeding programs and is involved in screening varieties in Kenya and other locations under a global rust initiative. This type of cooperation ensures access to new resistant germplasm and assists to mitigate the potential impact of new rust types that may enter Australia.

Outcomes

The principal outcome of the investment has been the continued use of resistant varieties of cereals by grain producers. The resistant varieties have increased yields compared to yields that would have been obtained with less resistant varieties.

The proportion of area occupied by rust resistant wheat cultivars in the three GRDC agroecological zones was estimated for 2005/06 based on receivals data for the Australian Wheat Board (AWB). These are reported in Table 8 (Park, 2007, pers., comm.). To comply with AWB confidentiality requirements, the data are aggregated and no information is provided on the area occupied by individual cultivars.

Table 8: Areas of Rust Resistant Wheat Cultivars in 2005/06

		Area occupied (% of total)		
Rust disease	Resistance class	Northern	Southern	Western
Stripe rust	R to R/MR	18.82	6.63	0.87
	MR to MR/MS	74.92	46.92	6.45
	MS to MS/S	5.52	35.86	71.95
	S to VS	0.76	10.56	20.68
Leaf rust	R to R/MR	50.7	13.65	33.76
	MR to MR/MS	48.46	60.93	10.98
	MS to MS/S	0.69	21.31	40.95
	S to VS	0.14	4.1	14.26
Stem rust	R to R/MR	83.82	34.76	6.77
	MR to MR/MS	15.69	48.49	22.64
	MS to MS/S	0.48	14.22	62.21
	S to VS	0	2.51	8.34

Key: S=susceptible; VS=Very susceptible; MS=Moderately susceptible; MR=Moderately resistant; R= Resistant
Source: Park, unpublished data, 2007

Some general points are:
- Cultivars in the R to MR category would be unlikely to suffer yield losses
- Cultivars in the MR to MR/MS category could develop some disease with slight to low yield loss
- Cultivars in the MS to MS/S category could experience moderate yield losses
- Cultivars in the S to VS category could experience substantial yield losses

The table shows that for 2005/06 there is less resistance in the Western region. Also, the level of S to VS cultivars to all three rust diseases is in general low. This is a direct consequence of resistance breeding.

Twelve cultivars directly derived from the ACRCP backcross program were grown commercially in 2005/06. Eight of these cultivars were grown in the northern region, six grown in the southern region, and four grown in the western region (Park, pers.comm., 2007).

A second major outcome of the investment has been a reduction in the use of fungicides compared to the situation if resistant varieties were not available. Fungicides are used as pre-plant treatments mostly with susceptible varieties, as an insurance policy, and as foliar sprays if an outbreak occurs. When varieties that are resistant from the seedling stage are planted, fungicides are generally not applied. Fungicides are generally used with non-resistant varieties when an outbreak occurs and they may need to be used more than once.

Fungicidal control of cereal rust diseases have increased in recent years as they have become lower cost and there is improved application technology (Park, unpublished, 2007). The main fungicide group (triazoles) used in Australia has proven quite effective and there have been no signs of resistance to date in Australia. Also, alternate mode of action strobilurin fungicides are now becoming more widely available for use in the Australian grains industry. This gives industry scope for more effective control of a range of cereal foliar diseases including cereal rust (Rainbow, 2007). There is a tradeoff to make in terms of using less rust resistant varieties with more low-cost fungicide (Rainbow, 2007)

Among some producers there is a perception the yields may not be as high with rust resistance cultivars. There is some evidence of yield depression associated with some alien-derived resistances, although these are low and there are exceptions. There is no evidence of yield depression associated with non-alien derived rust resistance, and many cultivars carry these. The perception that rust resistant cultivars yield lower is essentially not correct, and is an oversimplification of the issue. Yield is a very complex trait and the presence of an alien derived rust resistance is not a recipe for lower yield. Cultivar Currawong is a high yielding cultivar that carries an alien derived stem rust resistance gene (*Sr26*), which has been shown in some genetic backgrounds to cause yield reductions (Park, pers. comm., 2007).

The policy of releasing only rust-resistant varieties in northern NSW and QLD has resulted in industry wide protection from the rust diseases in this region for the past 40 years (Park, pers comm., 2007).

A third outcome of the ACRCP predominantly derived from the rust surveys is that cereal producers are better informed about varietal/fungicide strategies and their risk management decisions are likely to be improved.

A fourth outcome of the ACRCP is a higher level of preparedness for new rust pathogens so that surveillance and response activities can be optimised at the national level.

Benefits

Industry productivity and profitability

The Australian grains industry has benefited from the investment in ACRCP from the higher yields that have been achieved due to the rust resistance of the varieties developed. However, some of the potential yield loss may have been recovered from the use of fungicides. Improved decisions regarding risk management in terms of the mix of varietal resistance and fungicide use would have increased the overall gross margins in high yielding situations due to the up-to-date information provided on varietal resistance and pathogen distribution and virulence by the ACRCP. However, the economics of fungicide application in low yielding situations (most wheat growing situations in Australia) do not allow profitable use of fungicides (Park, pers.comm., 2007). The use of resistant cultivars is also an important contributor to breaking the disease link from season to season, made by volunteer wheats during summer (the green bridge).

Impact on the environment

It can be concluded that if resistant varieties were not available, that more fungicides would have been used by the industry where it was economic to do so. Many fungicides do not persist in the environment and have low toxicity to mammals and birds but their toxicity to aquatic organisms varies with the chemical (AATSE, 2002). The most common fungicides used for rust are in the triazole group where pesticide movement ratings for such fungicides are considered moderate. There is no significant evidence that triazoles used in fungicides have any impacts on human health or the environment, despite the use of triazoles having expanded extensively world-wide.

As the use of resistant cultivars avoids the control of volunteer wheat plants during summer, there is the added benefit to the environment of reduced summer cultivation with improved soil moisture storage, reduced erosion and less export of contaminants to waterways.

Social Impacts

Social impacts include reduced anxiety of producers from reduced chemical use. In addition there is a higher capacity to cope with rust epidemics since resources such as crop sprayers are not over extended. The use of rust resistance cultivars has also contributed to greater stability in production and in rural communities as serious rust events can bankrupt cereal producers (e.g. 1973 stem rust epidemic). At a national level, rust resistance has contributed to a higher level of food security.

A summary of the principal types of benefits and related costs associated with the outcomes of the project is shown in Table 9.

Table 9: Categories of Benefits from the Investment in ACRCP

Benefits
Industry Productivity and Profitability • Overall reduction in frequency and severity of rust epidemics resulting in fewer growers affected and lower cost of control • High yield losses avoided using resistant varieties in the absence of fungicides • Some yield losses avoided using resistant varieties in the presence of fungicides • Reduced total cost to industry of fungicides and their application • Reduced need for oversummer control of rusts as volunteer wheats are resistant; susceptible wheat cultivars will lead to a susceptible 'green bridge" and greater likelihood of disease in the following year. • Improved gross margins for those growers who take a risk management approach to the varietal and fungicide mix based on information from the pathogen surveys.
Environmental • Higher soil moisture storage, less erosion, and reduced export of contaminants into waterways (due to reduced need for summer cultivation).
Social • Reduced farmer anxiety. • Greater capacity for growers to cope with rust epidemics. • Greater stability in production and rural communities. • Contribution to national food security.

Public versus Private Benefits

The benefits identified from the investment in the ACRCP are predominantly private benefits. Some of the benefits of the avoided yield losses and the associated higher production will be passed along supply chain to grain processors and other users of grain including consumers. As the grains industry is predominantly export orientated, benefits will be captured in the main by grain producers. However, given the importance of wheat as a food source in Australia, rust resistance has contributed to food security. There are examples from other countries where rust epidemics have threatened food security.

It is likely that some form of rust control program would have eventuated if GRDC had not supported the program over the years. Such a program would no doubt have been accommodated in the individual State breeding programs probably with considerable duplication and a less coordinated effort to identify and incorporate resistant germplasm. Also, a strong case can be made for a national approach to monitoring changing pathogenicity and the distribution of pathogen types. This is because the pathogens can spread and mutate quickly so that such information needs to be generated at a national level. A single strain of leaf rust, first detected in Victoria in 1984, took only 10 years to spread to all wheat growing regions of Australia and New Zealand (Park, pers.comm., 2007).

If GRDC did not receive funding (or received less funding) from the Commonwealth, the ACRCP projects probably still would have been funded at some significant level. Fungicides may have then played a larger role in disease control that would have lead to increased industry input costs and increased selection pressure for fungicide resistance.

Overall, it is postulated that the investment in rust resistance would have remained a high priority for GRDC and that the level of funding to the ACRCP probably would have remained unaltered in the event of a Commonwealth Government reduction in funding to GRDC. If the government contribution was removed altogether, there probably would have been some reduction in funding to the program.

Match with National Priorities

The Australian Government's national and rural R&D priorities are reproduced in Table 10.

Table 10: National and Rural R&D Research Priorities 2007-08

Australian Government	
National Research Priorities	**Rural Research Priorities**
1. An environmentally sustainable Australia 2. Promoting and maintaining good health 3. Frontier technologies for building and transforming Australian industries 4. Safeguarding Australia	1. Productivity and adding value 2. Supply chain and markets 3. Natural resource management 4. Climate variability and climate change 5. Biosecurity *Supporting the priorities:* 1. Innovation skills 2. Technology

The program has made a major contribution to Rural Research Priority 1 through its impact through higher cereal yield and lowered costs of protection.

The cereal rust breeding program makes a small contribution to National Research Priorities 1 and 2 from its impact on reducing fungicide use and in that regard can be aligned with natural resource management impacts such as higher water quality and associated biodiversity improvements (Rural Research Priority 3).

The investment has made a large contribution to National Research Priority 3 and has demonstrated innovation skills and new technologies (Supporting Rural Research priorities). Frontier technologies have been used in the identification of resistance genes. The ACRCP has been using increasingly doubled haploid technology, marker assisted selection, and Australian developed microarrays to assist in identifying and characterising new sources of rust resistance. The CSIRO component of one project also is using advanced molecular genetics to develop markers linked to resistance genes and also to understand the mechanism of resistance in the host and virulence of the pathogen to try to identify new strategies for genetic resistance. Both groups are leading the world in this area.

Protecting Australia from invasive pests and diseases (National Priority 4 and Rural Research Priority 5) is addressed by the ACRCP. This is in terms of preparedness for virulent rust pathogens likely to be introduced from overseas. In addition to monitoring the development of new strains of rust pathogens within Australia, the program also maintains a watch for incursions of diseases such as stripe rust of barley which would have a major impact if introduced.

Quantification of Benefits

Past economic analyses
Brennan and Murray (1988) used disease incidence and severity figures for a number of wheat diseases in Australia from Murray and Brown (1987) to estimate both the potential and actual yield losses for rust diseases of wheat. The difference between the potential costs (absence of controls such as breeding and pesticides) and the actual costs with control was taken as the value of controls. These values of control included those for stripe rust ($146m), leaf rust ($26m) and stem rust ($124 m) in 1986/87 dollar terms. These values of control were then subjectively allocated across three control mechanisms (cultural/rotational, pesticides and resistance). Resistance was estimated to contribute 95% of the value for stripe rust and 100% for leaf and stem rust. This resulted in the values of resistance breeding as $139m for stripe rust, $26m for leaf rust and $124 m for leaf rust, a total of $289 m per annum.

Brennan and Murray updated their incidence and severity estimates in 1998 (Brennan and Murray, 1998), but this time estimates were built up from estimates by cereal pathologists of losses and means of control for 23 regions, rather than from a state base in order to improve accuracy. Resulting estimates are shown in Table 11.

Table 11: Value of Disease Control for Rust in Wheat ($ m, 1998 terms)

Disease	Stem Rust	Stripe Rust	Leaf Rust
Potential cost	101	181	99
Present cost	2	11	9
Value of control	99	170	90
Contribution (%) from			
Resistance	100	95	95
Cultural / Rotational	0	0	0
Pesticides	0	5	5

Contribution ($m) from			
Resistance	99	161	85
Cultural / Rotational	0	0	0
Pesticides	0	8	4

The total contribution from resistance for all three forms of rust was therefore estimated at $345 m per annum (1998 $ terms).

Another estimate of the value of resistance breeding is in Hills et al (1999) who estimated that stem rust and leaf rust epidemics in wheat crops in WA in 1999 cost the grains industry about $50 million (cited by Park, unpublished, 2007).

Counterfactual

The nationally coordinated approach to genetic rust control was recognised as being required from the 1973 outbreak/epidemic in stem rust, estimated to have cost the grains industry some $300 million. What would have happened if the ACRCP had not been supported by GRDC and its predecessors?

First, rust is considered a social disease of cereals. This is because rust spores travel freely, so disease that is allowed to proliferate in one paddock or region rapidly infects the surrounding regions. This mobility is also evident on a national scale. It is also evident that Australasia is isolated from other cereal growing areas of the world with respect to global rust movement (Park, unpublished, 2007). These are strong arguments in favour of a national approach to rust management. The need for nationally coordinated development and deployment of rust resistant cultivars is analogous to vaccination in humans, all in or it does not work.

Secondly, the existing rust pathogens mutate and there is the danger that other virulent strains will enter Australia. Therefore there is a significant argument for the industry to act nationally.

Thirdly, without the ACRCP, breeding for rust resistance would have fallen on the shoulders of the individual state breeding programs. This would have been far less effective on a national basis and may have involved considerable duplication of effort. Each state breeding program would have given rust different priorities for rust resistance and focused breeding programs on their own environments each of which faced different level of threats regarding severity and frequency. There would most likely have been no national survey of distribution of strains or any national monitoring of virulence and mutations, and no national collection of rust isolates to allow breeding and the research that has led to identification of new resistance sources.

Fourthly, without national monitoring of pathogenicity, breeders would have to rely on natural inoculum and uncertain screening facilities. There would be limited knowledge of future threats of new pathogens and no accepted testing group to provide the genetic and disease response data used to develop recommended lists to grain producers. The knowledge base would decline, susceptible cultivars used more and the likelihood and frequency of crop losses would increase (Rainbow, 2007).

It is likely that the total costs of breeding for resistance would have been higher than with the current approach and the level of protection from breeding lower. The implication would be that more fungicides would have been used than today at a far higher cost than is currently incurred. Increased fungicide use carries an increased risk of development of fungicide resistance. It is also quite likely that the frequency of outbreaks of a new rust strain could have increased without the degree of protection that has been conveyed by the ACRCP. This would be so particularly as the overseasoning of rust inoculum would have increased due to susceptibility of self sown wheat.

In conclusion, some breeding of resistant cultivars would have occurred without the ACRCP but the degree of disease resistance produced would have been lower and total breeding costs higher than with the ACRCP. Yield losses would have been higher and more fungicides would have been used.

For the final ‘without APRPC’ situation it is estimated that only half of the protection now apparent from controls would have been transpired. But this protection would have been associated with additional costs to breeding programs and increased fungicide use in some situations where crops were high yielding.

Analysis restricted to wheat

As wheat is the dominant cereal grown in Australia the current analysis is restricted to wheat. The ensuing investment criteria are therefore considered to be an underestimate as the ACRCP also builds resistance for other cereals (e.g. stripe rust of barley, leaf rust of barley, crown rust and stem rust of oats).

Periods of Investment and Associated Benefits

Investment in the ACRCP, as with most breeding type activities, is a continuum. As a high proportion of the investment for ACRCP in any one year does not deliver benefits until some future years, it has been necessary to commence the investment period for the analysis earlier than five years ago. The period of investment start year is taken as the year ended June 1991 and the last year as ending June 2007. The challenge then is to define the benefits from 1991 onwards that have resulted, and will result, from this investment.

It is assumed that overall there is a 10 year average lag between investment by the ACRCP in any one year and the full benefits from that investment. This average estimate of lag is influenced by:

(a) a short period to full benefits (1-3 years) from the early warning from surveys, annual assessments of current cultivar rust responses and assessments of advanced breeding lines.
(b) a long period to full benefits (15 years) from identification of new sources of resistance through research and advanced molecular techniques.

(c) a medium period to full benefits (5-10 years) from backcrossing and screening early generation material for breeders, and the delivery of the associated resistant lines by breeders.

If benefits in any one year (past and future benefits) over the 17 years of investment under consideration are traced back to the years of investment that led to those benefits then, the influence pathway can be represented as in Table 12.

Table 12: Links Between Benefits
in any One Year and Attribution to Previous Investments

Year of Benefit (year ended 30 June)	% of benefits accruing in that year attributed to the investment period 1991 to 2007
1991	0
1992	10
1993	20
1994	30
1995	40
1996	50
1997	60
1998	70
1999	80
2000	90
2001	100
2002	100
2003	100
2004	100
2005	100
2006	100
2007	100
2008	100
2009	90
2010	80
2011	70
2012	60
2013	50
2014	40
2015	30
2016	20
2017	10
2018	0

Attribution of Benefits from Resistance Breeding to ACRCP

There are other activities that could have claim to part of the benefits from resistance breeding. The investment by extension agencies in giving advice regarding cultural practices and the use of fungicides has already been excluded in the estimate of the value of control attribution from resistance. Other attribution claims could include:

- the 14 cereal breeding programs across Australia and their incorporation of resistance into their breeding lines, mostly in conjunction with ACRCP; their combined expenditure on these activities is likely to be significantly less than the expenditure by ACRCP.
- original imported germplasm, although any adding value to such is part of ACRCP activities.
- the activities and outputs of others involved with the ACRCP.

A conservative estimate of 50% of the benefits from cereal rust resistance breeding in Australia has been attributed to ACRCP.

Benefits from Resistance Breeding

Table 13 integrates the assumptions used to produce the annual benefits that can be attributed to ACRCP for its investment over the period 1991 to 2007.

Table 13: Annual Estimated Benefits for Investment in ACRCP over the Period 1991-2007

Year ended June	Annual benefits produced from resistance (m $)	Percentage of benefits that can be attributed to investment in breeding in period 1991 to 2007 (c)	Percentage of resistance benefits that can be attributed to ACRCP (d)	Percentage of resistance benefits estimated that would have occurred in absence of GRDC investment in a national program (e)	Estimated Benefit from ACRCP that can be attributed to the Investment (f)
1991	289 (a)	0	50	50	0
1992	289	10	50	50	7.2
1993	289	20	50	50	14.4
1994	289	30	50	50	21.7
1995	289	40	50	50	28.9
1996	289	50	50	50	36.1
1997	289	60	50	50	43.4
1998	345 (b)	70	50	50	60.4
1999	345	80	50	50	69.0
2000	345	90	50	50	77.6
2001	345	100	50	50	86.2
2002	345	100	50	50	86.2

2003	345	100	50	50	86.2
2004	345	100	50	50	86.2
2005	345	100	50	50	86.2
2006	345	100	50	50	86.2
2007	345	100	50	50	86.2
2008	345	90	50	50	77.6
2009	345	80	50	50	69.0
2010	345	70	50	50	60.4
2011	345	60	50	50	51.8
2012	345	50	50	50	43.1
2013	345	40	50	50	34.5
2014	345	30	50	50	25.9
2015	345	20	50	50	17.2
2016	345	10	50	50	8.6
2017	345	0	50	50	0

Notes:
(a) Brennan and Murray (1989); 1988 $ terms.
(b) Brennan and Murray (1998); 1998 $ terms
(c) See Table 12
(d) See earlier comments under 'Attribution'
(e) See earlier comments under 'Counterfactual'
(f) Note years 1991 to 1998 in 1988 $ terms, and 1999 to 2017 in 1998 $ terms

Summary of Assumptions

A summary of the key assumptions made is shown in Table 14.

Table 14: Summary of Assumptions for Estimating Impact of ACRCP

Item	**Value**	**Source**
Investment		
Year of first investment in ACRCP	1991	Agtrans assumption as first year of GRDC investment
Year of last investment considered	2007	Agtrans assumption
Average period of influence from one year of investment in ACRCP	10 years	Agtrans assumption after discussions with ACRCP
Benefits		
Value of rust resistance in wheat from 1991 to 1997	$289 million per annum (1988 $ terms)	Brennan and Murray (1989)
Value of rust resistance in wheat from 1998 to 2017	$345 million per annum (1998 $ terms)	Brennan and Murray (1998)
Attribution		

Benefits delivered from rust resistance control in absence of ACRCP	50%	Agtrans assumption after discussions with ACRCP
Benefits attributed to ACRCP as a proportion of total benefits delivered by all rust resistance activities	50%	Agtrans assumption after discussions with ACRCP

Results

All past costs and benefits were expressed in 2006/07 dollar terms using the CPI. All benefits after 2006/07 were expressed in 2006/07 dollar terms. All costs and benefits were discounted to 2006/07 using a discount rate of 5%. The base analysis used the best estimates of each variable, notwithstanding a high level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 20 years from the last year of investment (2006/07 to the final year of benefits assumed (2026/27)).

Investment criteria were estimated for both total investment and for the GRDC investment alone. Each set of investment criteria were estimated for different periods of benefits. The investment criteria were all highly positive as reported in Tables 15 and 16.

Table 15: Investment Criteria for Total Investment
(discount rate 5%)

Criterion	0 years	5 years	10 years	15 years	20 years
Present value of benefits (m$)	1,723	2,065	2,144	2,144	2,144
Present value of costs (m$)	90	90	90	90	90
Net present value (m$)	1,633	1,974	2,054	2054	2054
Benefit cost ratio	19.2	23.0	23.8	23.8	23.8
Internal rate of return (%)	554	554	554	554	554

Table 16: Investment Criteria for GRDC Investment
(discount rate 5%)

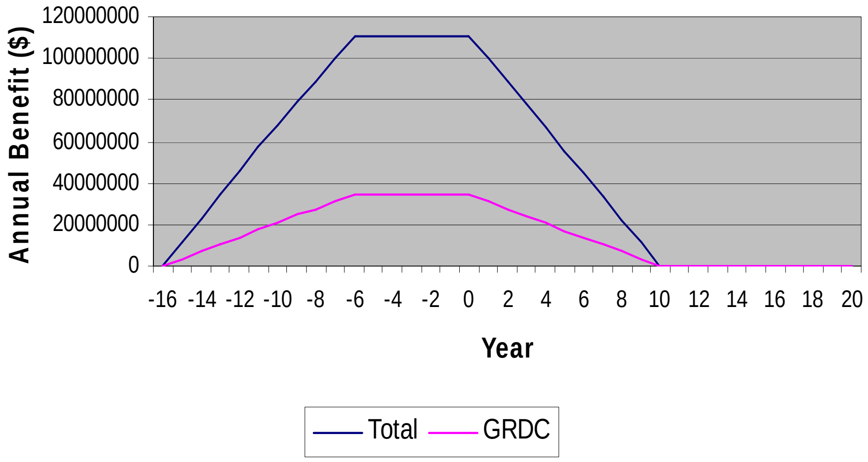
Criterion	0 years	5 years	10 years	15 years	20 years
Present value of benefits (m$)	531	636	660	660	660
Present value of costs (m$)	28	28	28	28	28
Net present value (m$)	503	608	632	632	632
Benefit cost ratio	18.8	22.5	23.4	23.4	23.4
Internal rate of return (%)	506	506	506	506	506

In terms of the quantified benefits, 100% could be attributed to the productivity and adding value component of the rural research priorities.

The cash flow of benefits is shown in Figure 1 for both the total investment and for the GRDC investment.

These high rates of return should not be unexpected since evaluations of ongoing wheat breeding efforts around the world continue to show significant benefits. For example the annual benefits associated with CIMMYT-derived germplasm have been estimated at 0.5 to US$ 1.5 billion (2002 dollar terms) for an annual investment of about US$10 million (Lantican et al, 2005).

Figure 1: Annual Benefit Cash Flow



Sensitivity Analyses

Sensitivity analyses were carried out on a range of variables and results are reported in Tables 17 to 19. All sensitivity analyses were performed using a 5% discount rate with benefits taken over the life of the investment plus 20 years from the year of last investment. All other parameters were held at their base values.

Table 17 shows results for the investment criteria when the proportion of control benefits that come from resistance for stem, stripe and leaf rust of 100%, 95% and 95% respectively are assumed to be 80% each or 50% each .

Table 17: Sensitivity to Assumption Regarding Proportion of Benefits from Control Derived from Resistance
(GRDC investment, 5% discount rate; 20 years)

Criterion	50% of control benefits come from resistance breeding	80% of benefits come from resistance breeding	Base
Present value of benefits (m$)	339	552	660
Present value of costs (m$)	28	28	28
Net present value (m$)	312	524	632
Benefit cost ratio	12.0	19.6	23.4
Internal rate of return (%)	250	404	506

Table 18: Sensitivity to Assumption of Percentage of Annual Benefits that Would Have Occurred without the ACRCP
(GRDC investment, 5% discount rate; 20 years)

	Percentage of Annual Benefits without ACRCP		
Criterion	75%	50% (Base)	25%
Present value of benefits (m$)	330	660	991
Present value of costs (m$)	28	28	28
Net present value (m$)	302	632	962
Benefit cost ratio	11.7	23.4	35.1
Internal rate of return (%)	251	506	761

Table 19: Sensitivity to Assumption of Attribution to ACRCP for Rust Resistance Benefits
(GRDC investment, 5% discount rate; 20 years)

	Level of Attribution to ACRCP		
Criterion	20%	50% (Base)	80%
Present value of benefits (m$)	264	660	1057
Present value of costs (m$)	28	28	28
Net present value (m$)	236	632	1028
Benefit cost ratio	9.4	23.4	37.4
Internal rate of return (%)	200	506	812

No sensitivity to adoption (high, medium, low) has been presented as data on adoption levels was not available from the survey of cereal pathologists.

Conclusions

Cost-benefit analysis undertaken in this report indicates that funds invested in building rust resistance in cereals has generated and will generate in future a substantial return. The seventeen year investment by GRDC is estimated to have provided a net present value of $632 million in 2006/07 dollar terms and a benefit cost ratio of nearly 23 to 1. The high returns identified by this analysis are in accord with a GRDC view that this is one of the more important investments made by the industry.

The investment criteria reported are probably underestimates as:

- the analysis has assumed conservative assumptions regarding attribution of rust resistance to the ACRCP,
- no environmental benefits have been included,
- benefits to cereals other than wheat have not been included,
- benefits from improved preparedness for new pathogens to Australia have not been accounted for, and
- no allowance has been made for the value of postgraduate teaching activities undertaken by ACRCP staff; this training has contributed significantly to Australian and global skill-base in rust resistance breeding.

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References

Anon (2007) “Rust Germplasm Screening and Enhancement: Cost Recovery Concept Paper”, ACRCP.

Australian Academy of Technological Sciences and Engineering (2002) “Pesticide Use in Australia”, Parkville, Melbourne.

Brennan J and Murray G (1988) “Australian Wheat Diseases: Assessing their Economic Importance”, Agricultural Science, (New Series), Vol 1, pp26-35

Brennan J and Murray G (1998) “Economic Importance of Wheat Diseases in Australia, NSW Agriculture”, NSW Agriculture, Wagga Wagga.

Hills A, Dickie R and Loughman R (1999) “Wheat Rust Management Begins Now”, Australian Grain, Vol 9, pp3-5.

Lantican M, Dubin H, and Morris M (2005) “Impact of International Wheat Breeding Research in the Developing World , 1988-2002”, CIMMYT, Mexico.

McIntosh R (2007) “From Farrer to the Australian Cereal Rust Control Program”, Australian Journal of Agricultural Research, Vol 58, pp 550-557.

Park R (2007) “Stem Rust of Wheat in Australia”, Australian Journal of Agricultural Research, Vol 58, pp 558-566.

Rainbow R (2007) “GRDC Cereal Rust Management Implementation Plan”, Confidential report, GRDC, Canberra.

Wellings C, Bariana H, and Park R (2004) “Cereal Rust Report Season 2004: Wheat Variety Response to Stripe Rust”, Vol 2, Issue 4, December 2004.