



An Economic Analysis of GRDC Investment in Summer Coarse Grains-Breeding in the Northern Region



GRDC Impact Assessment Report Series:

Title: An Economic Analysis of GRDC Investment in Summer Coarse Grains-Breeding in the Northern Region

July 2009

GRDC Project Code: ATR00006

This report was commissioned and published by the GRDC. Enquiries should be addressed to:

Mr Vincent Fernandes
Corporate Strategy & Program Support
Grains Research and Development Corporation
PO Box 5367
KINGSTON ACT 2604
Phone: 02 6166 4500
Email: v.fernandes@grdc.com.au

Author:
Agtrans Research
PO Box 385
TOOWONG QLD 4066
Phone: 07 3870 4047
Email: info@agtrans.com.au

ISBN No. 978-1-875477-64-7

© 2009 Grains Research and Development Corporation.
All rights reserved.

Disclaimer

Any recommendations, suggestions or opinions contained in this publication do not necessarily represent the policy or views of the Grains Research and Development Corporation. No person should act on the basis of the contents of this publication without first obtaining specific, independent professional advice.

The Grains Research and Development Corporation will not be liable for any loss, damage, cost or expense incurred or arising by reason of any person using or relying on the information in this publication.

Impact Assessment: An Economic Analysis of the GRDC Investment in Summer Coarse Grains-Breeding in the Northern Region

Executive Summary	3
1. Introduction	5
2. Project Investment	6
3. Project Activities and Outputs.....	7
4. Outcomes.....	8
5. Benefits.....	9
6. Pathway to Adoption	13
7. Measuring Benefits	13
8. Confidence Rating.....	23
9. Conclusions and Lessons Learned	24
Acknowledgments	25
References	26

Executive Summary

The evaluation showed that under the best available assumptions the investments by GRDC in the cluster Summer Coarse Grains – Breeding are overall producing low but satisfactory returns.

There are two maize projects and one sorghum project in the cluster. The projects are in the GRDC Northern Region spanning the period from 2001/02 to 2007/08. Outputs up to mid-2008 are included in this evaluation. The GRDC investment in the projects totalled \$3.653 million in a total investment of \$9.254 million. Net Present Value of the overall investment is estimated at \$16 million with a benefit cost ratio of 2.28. Sorghum contributed 88 percent of the benefits and 75 percent of the costs. The GRDC partner in all three projects was the Queensland Department of Primary Industries and Fisheries, now Primary Industries and Fisheries (PI&F). The cluster was part of an on-going investment by GRDC in long-established breeding programs.

The sorghum breeding program has placed increased emphasis on breeding for yield increase whilst maintaining disease and drought resistance. A large number of improved lines are licensed to seed companies to produce hybrid seed. Virtually all Australian sorghum genetic material incorporates some contribution from the PI&F/GRDC partnership.

Sorghum is the major summer crop in the GRDC portfolio and is an important contributor to the expanding market for feed grain. Yields have maintained an upward trend of 1.75 percent per annum over recent decades despite increased drought frequency in Queensland particularly. Although the majority of the yield increase should be attributed to improvements in farming systems, there is evidence of the yield trend attributed to varietal improvement increasing from the historic rate of about 0.5 percent to 0.75 percent annually. The evaluation assumed an increased trend of 0.2 percent per annum attributable to the investment with the balance attributed to the breeding input by the seed hybrid companies. There is a high degree of uncertainty about the extent of the attribution because objective data is not available.

The only maize benefits included were for the small and isolated industry of about 5,000 ha located on the Atherton Tableland. The local dairy industry is the main market for the maize produced. Some outputs were produced for other locations in the form of improved germplasm but possible benefits were seen as too speculative to include. Although the breeding program has contributed to a rate of yield increase of 2 percent on the Tablelands, benefits are only of the same order as costs. A key factor in the evaluation was to what extent seed companies would maintain the rate of increase if PI&F/GRDC did not invest. The market is small and varieties can rapidly lose rust resistance in the high rainfall tropical environment. Seed companies do produce hybrid varieties that are widely used in larger markets in other maize-producing regions.

Over the last decade the sorghum and maize programs have been evolving to a more clearly defined public sector role concentrating more on a pre-breeding role and longer term strategic research. In addition the maize program has a broader geographic focus and is now based at Hermitage near Warwick where the sorghum program is based. The benefits for each program could be expected to increasingly reflect the increased pre-breeding role. As a consequence this evaluation will not be

a reliable guide to likely benefits from future investments. Sorghum in particular will continue to have a key role as a summer crop in sustainable rotations, as a feed grain and as a crop with potential to be well adapted to climate change. An overview of identified benefits in a triple bottom line categorisation is shown in the following table. Of the identified benefits, the economic benefits are the only category which can be valued with an acceptable degree of reliability.

Categories of Benefits from the Investment

Levy Paying Industry	Spillovers		
	Other Industries	Public	Foreign
<u>Economic Benefits</u>			
<p>Yield increases and reduced yield variability for sorghum growers generally and to Atherton Tableland maize growers.</p> <p>Maintaining disease resistance in sorghum reduces insecticide usage.</p> <p>Maintaining sorghum as a viable crop increases profitability of sustainable crop rotations.</p>	<p>Reduced costs and more stable supplies for livestock industries using sorghum as a feed grain.</p> <p>A maize crop is valuable in disease control in the peanut industry.</p>	<p>Increased resilience of rural communities from more drought tolerant varieties better adapted to climate change.</p>	<p>Marginal contribution to foreign consumers of livestock products based on sorghum.</p>
<u>Environmental Benefits</u>			
<p>Reduced impacts from insecticides from reduced spraying from maintaining more resistant varieties.</p>	<p>Reduced spraying costs for other crops including cotton by reduced spray impacts on beneficial insects.</p>	<p>Reduced off-farm export of insecticides from reduced spraying needed for more resistant varieties.</p>	<p>Nil</p>
<u>Social Benefits</u>			
<p>Improved farmer well being through avoidance of chemical use by farmers.</p> <p>Increased industry research capacity through coordination of a national sorghum research program.</p>	<p>Avoiding rural adjustment problems on the Atherton Tableland by underpinning dependent communities.</p>	<p>Increased resilience of communities from more drought tolerant varieties better adapted to climate change.</p>	<p>Nil</p>

1. Introduction

This report evaluates the impacts of investments by GRDC in the cluster Summer Coarse Grains – Breeding. There are two maize projects and one sorghum project in the cluster. The projects are in the GRDC Northern Region spanning the period from 2001/02 to 2007/8. Outputs up to mid-2008 are included in this evaluation. The GRDC investment (nominal \$) in the projects totalled \$3.653 million in a total investment of \$9.254 million.

Sorghum is the largest summer crop in the GRDC portfolio, and third to wheat and barley as a feedgrain. The major enduse for both sorghum and maize is as a feedgrain for the domestic market. For sorghum, export markets usually underpin domestic prices other than in years of widespread droughts when exports are negligible. Although maize is grown in diverse and more favoured environments in eastern Australia for grain and for silage, the total grain production is relatively minor and most seed is from private sector breeding programs. The GRDC research focus for maize has broadened in recent years from the small industry on the Atherton Tableland to include more drought resistant hybrids for Central Queensland and higher yielding irrigation hybrids. The production from the Tablelands accounts for less than ten percent of the national total.

The distinguishing feature of the sorghum and maize industries is that they are both based on hybrid seed such that new seed is purchased for each crop planted. Queensland PI&F (Primary Industries and Fisheries, previously QDPI) has had a long standing role in the breeding of maize for the Atherton Tablelands. Similarly with sorghum, although the emphasis has changed to pre-breeding with a more strategic role supporting private sector breeding. Sorghum is a crop of tropical and sub-tropical origin grown throughout the GRDC Northern Region from northern NSW to Queensland. Queensland produces about two thirds of the sorghum crop on average. Main production areas are Central Queensland and eastern and western Darling Downs. The sorghum industry is based on hybrid seed production from breeding programs run by PI&F providing germplasm to commercial plant breeders. For several decades, the focus of the program had been to resolve constraints for example by breeding for increased midge resistance (MR), drought tolerance using stay-green (SG) germplasm, and resistance to the sorghum ergot disease first observed in 1996. Diversification of germplasm sources to achieve increased yield accounted for 55 percent of the breeding effort in recent years.

Following the introduction of research levies in the early 1990s and industry concerns on the low level of yield increases, the GRDC involvement in sorghum breeding has increased to the current levels. Changes include a greater focus on yield increase particularly from a strengthened strategic component, and on developing skills. There is a substantial GRDC investment in strategic pre-breeding research in several projects not included in this cluster. Commercial arrangements have also been developed since 1989 through an upfront licensing process for parent lines or germplasm used by commercial seed companies.

2. Project Investment

The three projects that have been conducting Summer Coarse Grains - Breeding are listed in Table 1. In terms of the GRDC Performance Framework (GRDC 2008) projects in "Summer Coarse Grains – Breeding" are part of Output Group 1 – Varieties. The Objective for that Output Group is "*Growers have access to superior varieties that enable them to effectively compete in global grain markets.*" There is also a GRDC performance indicator (GRDC 2008) to achieve a rate of gain from improved sorghum varieties of 1.5 percent annually

Table 1: Projects in – "Summer Coarse Grains – Breeding"

Code Duration	Title	Project Leader and Organisation
DAQ00015 7/2002-6/2007	Crop Improvement of Grain Sorghum in Australia - Core Breeding	D. Jordan and R. Henzell, PI&F
DAQ00092 7/2005-8/2008	Maize germplasm enhancement and productivity improvement for tropical Australia	I. Martin, PI&F
DAQ532 10/2001-6/2005	Maize germplasm enhancement for eastern Australia	I. Martin, PI&F

Source: Project Proposals

Table 2: GRDC and Partner Contributions to the Projects (nominal dollars)

Code	GRDC	Partner	Total
DAQ00015	2,723,278	4,084,917	6,808,195
DAQ00092	427,210	761,790	1,189,000
DAQ532	502,825	754,238	1,257,063
Total	3,653,313	5,600,945	9,254,258

Source: Project Proposals and estimates of Partner Contributions.

For the four projects funded over the period since 2001 GRDC has invested \$3.653 million or 39.5 percent of the total resources in nominal terms. The partner organisation, PI&F, contributed the remainder through its ongoing conduct of the core breeding programs for sorghum and maize.

Annual Expenditure for the Projects is shown in Table 4. Note that the smaller maize program started a year before the sorghum project.

Table 3: Annual Expenditure for the Projects (nominal Dollars)

Year (to 30 June)	GRDC	Partner	Total
2002	121,071	181,607	302,678
2003	644,141	966,212	1,610,353
2004	644,532	966,798	1,611,330
2005	685,461	1,028,192	1,713,653
2006	701,816	1,087,087	1,788,903
2007	709,510	1,107,074	1,816,584
2008	146,782	263,977	410,759
Total	3,653,313	5,600,945	9,254,258

Source: GRDC Project Proposals and estimates of Partner Contributions

3. Project Activities and Outputs

The three projects are continuing phases of long-established breeding programs run by the Queensland PI&F.

DAQ00015 – the major activity of the program is germplasm enhancement of lines that are further developed by commercial breeders. The project includes some technology development, providing support to strategic projects, and coordination of sorghum R&D generally. Each year the program makes new crosses, which are then evaluated in preliminary yield tests and advanced tests at more sites. Due to the long lead times in the breeding processes, the 374 lines that were licensed during DAQ00015 were initiated prior to the project starting in 2002. The lags involved in the breeding process will be taken into account in the following sections.

DAQ00092 and DAQ532- the main outputs in both projects were varieties with improved rust resistance for the Atherton Tableland maize industry in the tropics. The project also develops and tests lines for other environments in the tropics and sub-tropics including some for irrigation. In the sub-tropics the industry is based on seed developed by commercial seed companies. Lines from the projects are contributed to the seed companies for further development and testing in the sub-tropics. These included five lines with good drought tolerance for Central Queensland.

The principal outputs from the investments are listed in Table 4.

Table 4: Outputs Achieved by the Project Investments

DAQ00015	<ul style="list-style-type: none"> • Improved sorghum germplasm delivered via commercial breeding companies • Germplasm and support provided to other projects in the Australian Sorghum Research Program • Appropriately coordinated and directed Australian Sorghum Research
DAQ00092	<ul style="list-style-type: none"> • Maize varieties with improved rust resistance to Polysora, in particular for the Atherton Tablelands • Improved maize germplasm for two other districts in North Queensland • Release of improved drought-tolerant maize genetic material for Central Queensland and for irrigation
DAQ532	<ul style="list-style-type: none"> • Release to private breeding organisations of subtropical maize inbreds with specific traits that can be used directly as parents of commercial hybrids • Release of completed maize hybrids and parental inbreds adapted to wet and dry tropics • Maize germplasm accessed from international breeding organisations

Source Final Reports

4. Outcomes

The major outcomes are the increased yields achieved by higher yielding varieties. The sorghum project has a significant component of capacity building and research coordination, which would contribute to industry development in the longer term. The new varieties incorporate improved or maintained resistance to disease so that some of the outcome is in maintaining production. It has been suggested that for crops generally new varieties are resistant to pests and diseases for an average of 5 years. But it can take 8 to 11 years to breed new varieties (USDA, 1990).

For sorghum, the additional yield is across the Australian crop as virtually all hybrids include some component of germplasm from the breeding program.

For maize the major outcomes that can be readily evaluated are for the small industry on the Atherton Tableland. The environment is tropical and high rainfall with many plant disease problems including those from tropical rust epidemics. The breeding of resistant varieties has made a major contribution to stabilising the local industry. The last decade has been particularly challenging following the instabilities of the previous decade and the demise of the Atherton Tableland Maize Marketing Board. Some factors in the last decade were the extreme rust years from above average rainfall, the decline of the dairy industry (a major market for Atherton Tablelands maize) following dairy industry deregulation, and the loss of a local market following the shut down of a feed lot. The feedlot had increased demand for an early spring crop grown under irrigation. But that allowed build-up of rust to epidemic proportions for the following summer crop of maize because the spring

varieties (temperate zone varieties from the USA) were not resistant. In addition the maize industry faced competition from the sugar industry established on the Tablelands during the 1990s.

The maize program did produce outputs in the form of lines with potential in other tropical and subtropical environments and for irrigation. Some trials were disrupted by Cyclone Larry. Lines with improved drought resistance have been released to private seed companies. Outcomes from these releases have not been estimated in this evaluation because the possible benefits are from either small markets or are speculative at this stage.

As with breeding projects generally there will be a substantial lag before outcomes result from the improved varieties and from the germplasm produced during the projects. The lags will be estimated in Section 7. The anticipated outcomes from the projects are summarised in Table 5.

Table 5: Major Outcomes Anticipated from the Sorghum and Maize Projects

Project and grain	Outcomes
Sorghum - DAQ00015	Commercial hybrids with improved yields are expected to be increasingly adopted. As virtually all commercial hybrids include some background from the lines produced by the project, benefits will arise from the total Australian crop.
Maize - DAQ00092 and DAQ532	On the Atherton Tablelands, new hybrids with rust resistance have been rapidly adopted and have contributed to increased yields. Seed companies are testing lines adapted to other environments.

Source Final Reports

5. Benefits

An overview of benefits in a triple bottom line categorisation is shown in Table 6.

Table 6: Categories of Benefits from the Investment

Levy Paying Industry	Spillovers		
	Other Industries	Public	Foreign
<u>Economic Benefits</u>			
Yield increases and reduced yield variability for sorghum growers generally and to Atherton Tableland maize growers. Maintaining disease resistance in sorghum reduces insecticide usage.	Reduced costs and more stable supplies for livestock industries using sorghum as a feed grain. A maize crop is valuable in	Increased resilience of rural communities from more drought tolerant varieties better adapted to climate change.	Marginal contribution to foreign consumers of livestock products based on sorghum.

Maintaining sorghum as a viable crop increases profitability of sustainable crop rotations.	disease control in the peanut industry.		
<u>Environmental Benefits</u>			
Reduced impacts from insecticides from reduced spraying from maintaining more resistant varieties.	Reduced spraying costs for other crops including cotton by reduced spray impacts on beneficial insects.	Reduced off-farm export of insecticides from reduced spraying needed for more resistant varieties.	Nil
<u>Social Benefits</u>			
Improved farmer well being through avoidance of chemical use by farmers. Increased industry research capacity through coordination of a national sorghum research program.	Avoiding rural adjustment problems on the Atherton Tableland by underpinning dependent communities.	Increased resilience of communities from more drought tolerant varieties better adapted to climate change.	Nil

Public versus Private Benefits

The benefits identified from the investment are predominantly private benefits, namely benefits to grain farmers in the GRDC Northern Region. Seed companies make additional profit if there are increased seed sales and they contribute through licence fees to the PI&F/GRDC breeding program. These transactions are transfer payments and are therefore not accounted for in this economic evaluation. The benefits to grain farmers arise through a form of public-private partnership between the PI&F/GRDC breeding program and the private sector seed companies. The partnership builds on the promotion by the public sector of a longer term strategic perspective, one that is accountable to grain farmers and the public for environment and social dimensions. The strategic perspective includes maintaining a high level of midge resistance, increasing drought tolerance and increasing genetic diversity. These are areas seen as long-term and high risk by the private sector. In addition sorghum is a major contributor to rural economies through much of the GRDC Northern Region. Improved drought and disease resistance will contribute to the support of local economies leading to more resilient communities.

Distribution of Benefits along the Grains Supply Chain

Some of the potential benefits from higher average yields will be passed along the supply chain in the form of lower costs to users of grain including intensive animal producers and ultimately consumers of animal products. However in other than drought years a proportion of grain is exported, so that benefits will be captured in the main by grain producers. Expansion of sorghum production will reduce the need for imports of feed grains and reduce supply chain risk for users of livestock feed.

Benefits to Other Primary Industries

Maize and sorghum are key feedgrains underpinning intensive livestock production in the Northern Region. A major end use for Atherton Tableland maize is in the local dairy industry, which is relatively isolated from alternative sources of feed grains. Sorghum is the predominant feed grain produced in the Northern Region. Beef cattle feed lots are the major market. Their continuing expansion depends on a viable grain sorghum industry. The breeding program includes development of waxy sorghum to increase digestibility for more efficient livestock feeding.

Benefits Overseas

There is a small export market of sorghum seed, which could be expected to continue to expand as yields and disease resistance are improved. Benefits are captured through licence fees. The Australian breeding efforts for sorghum and maize benefit from international exchanges of germplasm. In the longer term benefits to Australia from strategic research for sorghum are likely to increase because of the decline in public spending on strategic research particularly in the USA (GRDC Final Report DAQ00015). The situation for maize is likely to be different because there are major international programs on breeding more drought tolerant maize, for example for increased food security in sub-Saharan Africa.

Match with National Priorities

The Australian Government's national and Rural R&D priorities are reproduced in Table 7.

Table 7: National and Rural R&D Research Priorities 2007-08

Australian Government Priorities	
National Research	Rural Research
<ol style="list-style-type: none"> 1. An environmentally sustainable Australia 2. Promoting and maintaining good health 3. Frontier technologies for building and transforming Australian industries 4. Safeguarding Australia 	<ol style="list-style-type: none"> 1. Productivity and adding value 2. Supply chain and markets 3. Natural resource management 4. Climate variability and climate change 5. Biosecurity

The investment in the projects was predominantly focused on National Research Priority 1. The investment was focussed on Rural Research Priorities 1 and to a lesser extent on 3 and 4. The benefits as categorised by priorities are presented in Table 8.

Table 8: Categorisation of Benefits by Priorities

Benefit	National Research Priority Addressed	Rural Research Priorities Addressed
Productivity gains through yield increases and more sustainable rotations	Priority 1 ***	Priority 1 *** Priority 2 * Priority 3 *

Less chemical usage on-farm from disease resistant varieties	Priority 2 *	Priority 3 *
Maintaining a cropping option able to adapt to climate change		Priority 4 **

*** Strong contribution **Some contribution * Marginal contribution

Additionality and Marginality

As shown in Table 9, if the PI&F/GRDC partnership in the cluster had not supported this program, it is highly unlikely that the private sector would have increased their investment in sorghum or maize breeding and maintained the same rate of progress in yields. For sorghum, there are two major seed companies and two smaller companies breeding hybrid seed. Their input is likely to be of the same order as the investment in the cluster being evaluated (David Jordan, pers. comm.). On a global scale, the Australian market for sorghum and maize seed is small and risky. Several multi-national seed companies have withdrawn from the sorghum seed market in recent decades. Demand for seed is highly variable from year to year so that large inventories need to be maintained. The role for joint public sector and industry investment is clear. Although there have been major economic and environmental benefits from improved midge resistance from earlier phases of the sorghum program there is still a need for strategic research to maintain resistance and to increase diversity lost as a consequence of breeding for midge resistance. In addition there are new diseases such as ergot. The research by the cluster also has a strong focus on strategic research to increase drought tolerance. Overall without the PI&F/GRDC partnership the rate of progress would have been reduced and the industry would have been more vulnerable.

Table 9: Potential Response to Reduced Public Funding

1. What priority were the projects in this cluster when funded?	High
2. Would industry have funded this cluster if less funds were available?	No
3. Would industry have funded this cluster if only industry funds were available and no public funds?	No
4. If the answer to Q3 is no or reduced, why?	As in the USA, the private sector sees strategic investment in sorghum pre-breeding as risky. For sorghum and maize, the Australian markets would be considered too small.
5. If the answer to Q3 is no or reduced, would it have been funded in another form by industry or by GRDC?	Total effort would have been substantially reduced

6. Pathway to Adoption

Graingrowers have access to a wide range of information on hybrid varieties marketed by seed companies. For sorghum there are currently four seed companies producing hybrid seed adapted to the wide range of sorghum environments and planting times. Seed companies also conduct extensive regional testing and demonstration sites that are well publicised. The Queensland and NSW Departments of Primary Industries also produce consolidated agronomic information on the varieties but not including yield comparisons. The seed companies give high priority to defensive traits such as midge resistance and stay green for drought tolerance in their breeding programs. The industry has adopted a uniform rating scale for midge resistance so that varieties of different companies can be readily compared.

Consideration was given to the inclusion of sorghum in the National Variety Trials to provide information on varietal performance. The Review (Juttner 2009) concluded that in comparison with winter crops "... sorghum and maize have a wide planting window and decisions on planting time depend on stored soil water. Variability in soil types (i.e. water holding capacity), planting time and varietal maturity would require a large number of trials to evaluate performance. Sorghum varieties are widely tested by breeding companies and there has been little demand for additional or independent testing". Another important difference compared with winter crops is that seed needs to be purchased for every planting so that it is relatively easy to buy small amounts of a new variety for on-farm testing.

The adoption time for new varieties is relatively short and, as there is rapid turnover of new varieties, variety life cycles are short.

For maize, adoption is also rapid. On the Atherton Tablelands, new varieties have been released on average every two years to keep pace with the more rapid evolution of diseases in the tropical environment. The Tablelands maize industry is compact and there are only a small number of growers. They purchase seed annually through a local company that markets seed from the PI&F/GRDC program.

7. Measuring Benefits

The areas impacted by the sorghum and maize breeding programs included in this cluster differ substantially in scale. More emphasis will be placed on assessing sorghum benefits, as it is a much larger industry than the maize industry on the Atherton Tableland. The sorghum breeding program provides germplasm for varieties that underpin the Australian sorghum production averaging \$300 million in recent years. In contrast, although the total value of Australian maize production is of the order of \$70 million, this evaluation is limited to the part of the industry on the Atherton Tableland with production of less than \$10 million.

For sorghum and maize, the benefits to be estimated over the next 30 years are the increased yields resulting from the investment by the QPI&F/GRDC partnership. The increase is in comparison with a scenario based on the yields that would have eventuated without the QPI&F/GRDC partnership investment. Both breeding programs were long-established so the analysis needs to take into account the contributions from previous investments that result from the long lead times inherent in crop breeding programs.

The outputs from the sorghum core breeding program are germplasm licensed to seed companies to produce new varieties of hybrid seed. Trends in yields achieved by graingrowers of the new improved varieties will embody the yield benefits from the QPI&F/GRDC partnership along with other influences. In summary these include four main components:

- Longer term contributions from a strategic research component using novel technologies to enhance the core breeding program,
- Breeding of superior lines of germplasm by QPI&F/GRDC in the core breeding program,
- Improved hybrids from further crosses by seed company of the QPI&F/GRDC lines with other lines, and
- An improved farming system from changes in the operating environment, for example from changed input costs, reduced tillage, increased fertiliser or from improved rotations.

National yield trends will incorporate a range of other factors, for example from the changes in location and in seasonal patterns, and changes in relative profitability compared with alternative land uses. The following sections will estimate the change in yield trends for maize and sorghum taking some account of the above factors. A comparative check on the estimates can be provided by an outside view briefly considering contributions to the components of yield trends determined for other crops and regions.

In a study of crop yields in the USA, Fuglie et al (1996) showed. "The average annual growth in U.S. crop yields during 1975–92 was 1.33 percent for corn, 1.54 percent for sorghum, 1.13 percent for wheat, 1.23 percent for soybeans, and 2.23 percent for cotton". More recently Duvick et al (2004) showed that USA corn yields had been advancing at 2.5 percent annually.

The earlier USA study showed that the half of the yield growth not attributed to improved seed varieties came from other inputs and management factors. Australian experience suggests a rate generally closer to one third for varietal improvement (Reading 2008). For wheat yields in South Australia, Black et al (2008) showed annual trends from improved varieties of 0.5 percent, compared with 1.2 percent attributed to farming systems improvements and an interaction of farming systems with improved varieties.

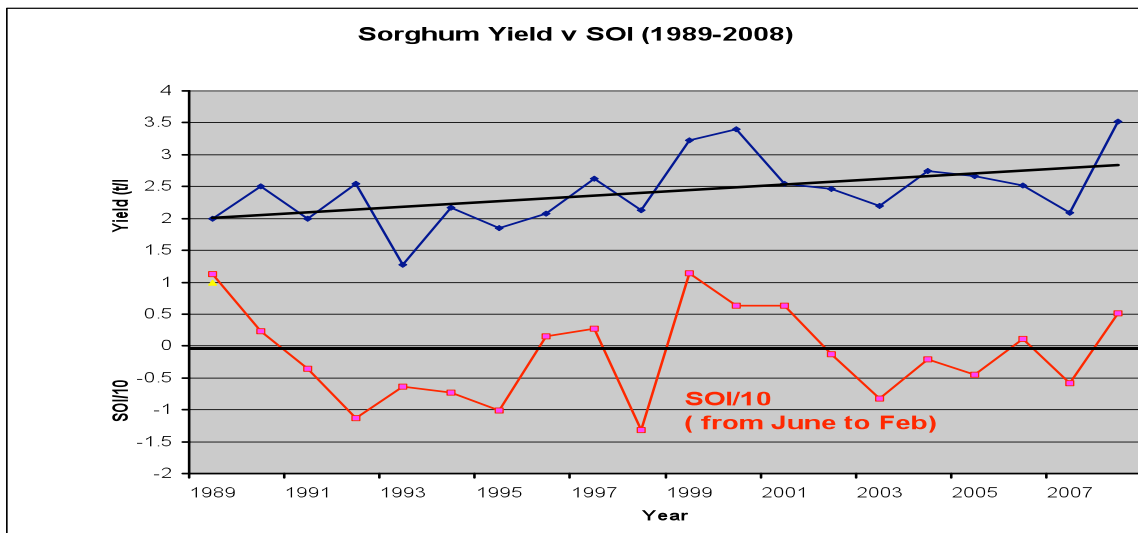
Sorghum benefits

The breeding program for sorghum has had success over several decades through gradually increasing yields and more particularly from the early 1980s with the release of the first Australian bred lines with midge resistance (MR). In the late 1990's the total value of MR was estimated at about \$30 million per year (QPI&F 2009a) resulting from direct savings in chemical control, and benefits in integrated pest management from reduced impacts of spraying on beneficial insects.

Public–private sector partnerships have developed since 1989 through a licensing process for QPI&F parent lines for germplasm used by commercial seed companies to produce hybrid seed for domestic and to a small extent export markets. Following the introduction of research levies in the early 1990s and industry concerns on vulnerability to drought and the level of yield increases, the GRDC involvement in sorghum breeding has increased to the current levels.

Changes include a greater focus on a pre-breeding approach, yield increase particularly from a strengthened strategic component involving CSIRO and University of Queensland, and developing skills to introduce novel technologies. These included evaluating molecular markers, increasing genetic diversity, and understanding GxE (genotype x environment) interactions. The degree of past selection, for example for midge resistance had been a factor in reducing genetic diversity. The GxE approach was seen to be particularly valuable in understanding such a variable production environment. The large GxE interactions reduce heritability and the likely success of an emphasis on yield increases.

Figure 1: Australian Sorghum Yields and the SOI, 1989-2008



Source: Yield data - (ABARE 2008), SOI (<http://www.longpaddock.qld.gov.au/>) for the period from June to February when the impact on rainfall, fallow moisture and yields is likely to be greatest.

As shown in Figure 1 the national average sorghum yield has been highly variable. Droughts associated with major El Niño events as indicated by the Southern Oscillation Index have been one factor (Nicholls 1986). There is also a clear upward trend in yields despite a downward trend in the SOI for much of the period. The current yield trend which includes a varietal improvement component and an improved farming systems component is 1.75 percent. The trend in northern NSW was much higher at about 3 percent (estimated from NSW DPI 2009) reflecting partly the reduced drought impact particularly during the 1990s, and partly the increased adoption of improvements in farming systems. Potgeiter et al (2005) have used the correlation between SOI and future rainfall to forecast sorghum yields. Their model showed that seven of ten local authority areas in the GRDC Northern Region with significant upward trends in yield were in Northern NSW. The current national trend of 1.75 percent is likely to have been reduced by the greater than expected frequency of drought over the last two decades. However any adjustment would have little impact on assessment of the difference in trend due to the sorghum breeding project from 2002/03 to 2006/07.

One factor that may have actually decreased yields is the trend for more opportunity cropping. Increased profitability from sorghum cropping has increased opportunities to develop more sustainable cropping systems and to control weeds and diseases in wheat-fallow systems. Opportunities include additional crops in part because of

improved soil moisture storage with reduced tillage. Berndt and White (1976) first showed the benefits from opportunity cropping in a simulation study using a simple crop water balance model. Growing a summer or winter crop when there was adequate soil moisture stored was shown to be superior to fixed winter or summer cropping on the Eastern Darling Downs. The superiority was reduced for a soil with higher water storage at Dalby. At Roma lower average rainfall was such that there was little advantage from opportunity cropping. However yields will often be lower with opportunity cropping but profitability will be increased over all years by greater cropping intensity.

The adoption of no-till over the last two decades has been demonstrated by Llewellyn et al (2008). The benefits over a rotation are substantial. Holland and Felton (1989) showed that no-till increased sorghum yields by 0.5 tonnes or more in northern NSW. Similarly Wylie (2008) quotes a southern Queensland example of an increase of 23 percent averaged over eight years to 1995. In Central Queensland, Shepherd and Routley (2008) have shown that adoption of a wide range of practices with the potential to increase yields is increasing. Increased adoption of improved farming practices could clearly be contributing at least a one percent annual increase in sorghum yields nationally.

The productivity of the sorghum industry is closely tied to beef industry profitability through competition for input resources and because beef feedlots are a major market for sorghum. For the decade up to 2006 the cattle/grain price ratio doubled (based on ABARE 2008 prices for cattle and grain), a trend that would have probably have had some negative impact on sorghum productivity. Over the last few decades in common with many crops sorghum prices have trended downwards.

The actual yield trend to date of 1.75 percent per annum is the starting point for determining how much of the trend is due to the QPI&F/GRDC investment in the breeding program. The actual trend to 1999 in the trend in varietal improvement was considered to be approximately 0.5 percent over the previous 30 years (DAQ Project Proposal 1999). At that time there had been GRDC investment and a greater emphasis on breeding for yield gain for only a few years so any benefit from that investment would not be apparent because of the lags involved. During the project DAQ00015 that extended from 2002/03 to 2006/07, 374 unique inbred lines were licensed to Australian breeding programs. All lines were based on crosses made before 2002. Thus any yield increase recorded would need to be attributed to investments made some years before.

Jordan et al (2006) reported a more detailed analysis of yields for 35 trials from 1996 to 2005 in comparison with three old hybrids. The analysis indicated an increased trend from the 0.5 percent reported in 1999 up to about 0.75 percent. The increase would have been gradual and over a period of more than a decade. The trend would not yet have shown up in the national trend in a statistical sense because yield variability is the dominant feature over short periods. Since 1996 there was increased emphasis on breeding for yield gain and increased investment by GRDC in sorghum research including a much strengthened strategic component which is well integrated with the core breeding program. The benefits from strategic research could be expected to be much longer term than those for a breeding program. The breeding program being evaluated does have a key role in coordinating sorghum research including the strategic projects.

An increased trend of 0.75 percent in varietal improvement is consistent with the general pattern for similar crops of about one third to one half of yield increases being attributable to improved varieties and the balance to improved farming systems. Of course there could be exceptions to what is simply an average across a range of crops. Exceptions would usually have plausible explanations in terms of known factors contributing to major shifts in yields.

From the above summary of the range of relevant information, an estimate can be made of the increased yield trend resulting from the investment in the sorghum project. Of the assumed increase of 0.25 (from an annual rate of 0.5 percent increasing to 0.75 percent), 0.2 is estimated to be attributed to the project. Some of the trend increase of 0.25 percent would need to be attributed to the breeders of hybrid seed, and some would be an outcome of prior research projects particularly those strategic research projects where benefits were more immediate. Because of these factors, there is a high degree of uncertainty about the increased sorghum yield that can be attributed to the project. Therefore the assumption of a 0.2 percent increase will be the focus of a sensitivity analysis in the final project evaluation.

For the sorghum project starting in 2002/03 there was some material under development from the previous project that would have been available for release in 2003. The lag from then until a new hybrid is marketed can vary from as short as two years to more than a decade depending on the process used. The time to market if an inbred from the breeding project is crossed by a seed company inbred is of the order of five to seven years. Once marketed, sorghum hybrids are typically adopted rapidly and have a life of the order of five years although there are exceptions.

Taking account of the range of possible times to market, an average period of six years approximates the lag from the start of a project until outcomes begin to occur in the form of increased yields. Similarly following the end in 2007 of the sorghum project in the cluster (DAQ00015), outcomes are assumed to taper off over a six year period.

Maize benefits

As discussed previously the major benefits from the breeding program are from the increased yields for the small industry on the Atherton Tableland. The environment is tropical and high rainfall with many plant disease problems including tropical rust epidemics. Over the last two decades an annual yield increase of the order of 2 percent (QDPI 2008) has been reported based on farmer sources. Current yields are of the order of 8 tonnes per ha. Over the six year period of the projects in this evaluation, an increase of the order of one tonne per hectare could therefore have been expected. However, an estimate of the benefits needs to take into account that some of the trend would have resulted from improved agronomic measures, and also that the benefits are compared to yields that would have eventuated in the absence of the research.

Varietal trials support a yield increase assumption of about 10 percent or 0.8 tonnes comparing the current widely grown variety AT8 with the previous standard QX8. (Martin 2005). The breeding cycle used is relatively short compared with sorghum so benefits are assumed to have begun from 2005/06, or four years after the start of the project. The pattern of benefits will be different to that used for sorghum to take account of yield declines from the rapid loss of resistance to rust.

As discussed in the following, there are further assumptions to be made to fully define the benefits from the investment.

The Counterfactual

The above discussion has concentrated on the yield trends being achieved. But as has been pointed out, the benefits are determined by the difference between the yield trends and the trends that would have resulted in the absence of the PI&F/GRDC investment - the "without" scenario. In the absence of the PI&F/GRDC investment, it is assumed for sorghum that some of the increase in varietal improvement would continue through continuing breeding efforts by seed companies. For maize, the yield advantage of 0.8 tonne/ha of the current varieties over an older variety is taken as a measure of the difference due to the cluster investment. There are lags as discussed previously from the start and end of the projects and these are summarised in Table 10.

Attribution

The increased yield trends as a result of the investment in the cluster have been estimated after taking into account attributions that needed to be made. For example for sorghum the increase in the trend of 0.2 percent was estimated by allowing for other contributors to the assumed total increase due to improved varieties of 0.25 percent.

Annual Benefit/ha and area benefiting

Over the last few decades in common with many crops sorghum and maize prices have trended downwards. Productivity gains including a contribution from increased yields from improved varieties have been offsetting factors in maintaining profitability. As shown in Table 10, the analysis assumes constant future prices. For sorghum, the area benefiting uses the Barrett (2009) outlook from ABARE, which is available to 2014, and then uses a conservative constant value. For maize, the benefits are confined to the current scale of the industry on the Atherton Tableland.

Decline in benefits/ha

The key issue is whether the knowledge or products developed are subject to deterioration so that they do not provide a base for further research to build on. For example if a variety resulting from an investment is subsequently displaced by a higher yielding variety from a future investment, then the benefit from the first investment is maintained. The benefit from the future investment is the gain over the variety displaced.

For sorghum, the yield increase above the "without" scenario that is achieved by the investment in the cluster is assumed to be maintained. The "without" scenario assumes that other investments in breeding by seed companies are maintained throughout the analysis. The "with" scenario also assumes that seed company investments are maintained. Therefore a constant yield increase would be maintained. Note the analysis only needs to make an assumption on the difference in yield between the "with" and "without" scenarios, not on the trends for each scenario.

Table 10 summarises the major assumptions.

Table 10: Summary of Major Assumptions

Description	Value	Source (by the author unless stated)
SORGHUM		
<u>With GRDC investment</u>		
Area benefiting <ul style="list-style-type: none"> to 2009 2010 – 2020 after 2020 	<ul style="list-style-type: none"> 750,000 ha 1% pa No increase 	<ul style="list-style-type: none"> ABARE Barrett et al (2009) for 2010 to 2014
Lag from change in investment (2003-2007) to change in yield	6 years	Based on Jordan (2008)
<u>% yield increase</u> <ul style="list-style-type: none"> to 2009 by 2013 	<ul style="list-style-type: none"> 1.75 pa 2.0 pa 	Historic trend (Fig 1) Varietal increase from 0.5 to 0.75 based on Jordan et al (2006)
<u>Without GRDC investment</u>		
% yield increase <ul style="list-style-type: none"> to 2009 by 2013 	<ul style="list-style-type: none"> 1.75 pa 1.8 pa 	<ul style="list-style-type: none"> Historic trend (Fig 1) 2% in "With GRDC" scenario less 0.2 % attributed to PI&F/GRDC investment.
Benefit from yield increase	\$150/tonne	Based on Barrett et al (2009), NSW DPI (2009) and WEA (2007).
<u>Increased yield (With – Without)</u> <ul style="list-style-type: none"> 2009-2013 % difference in yield/ha by 2013 from 2013 	<ul style="list-style-type: none"> From trends 0.5% Constant 	Note: The per annum yield trend advantage increases gradually from zero in 2009 to 0.2 or 0.5% extra t/ha by 2013 and then remains constant.
MAIZE (Atherton Tableland)		
Area benefiting	5,000 ha	Current estimate of expected average based on seed sales of PI&F varieties (Ian Martin, pers. comm.)
Benefit/tonne	\$200	Estimated from QPI&F (2009) and Barrett et al (2009)
Lag from change in investment (2002-2008) to change in yield	4 years	Estimate based on shorter breeding cycle for maize (Ian Martin, pers. comm.)
<u>Increased yield (With – Without)</u> <ul style="list-style-type: none"> At 2006 By 2012 By 2018 	<ul style="list-style-type: none"> 0.0 0.8 tonne 0.0 	Martin (2005)

Climate change is another factor that has been considered in determining the assumptions in Table 10. Potential national impacts on agriculture have been estimated, for example by Gunasekera et al (2007). However sorghum is regarded as a highly adaptable crop. Likely impacts in the GRDC Northern Region are not currently considered to be as large as in other regions (Howden et al 2008).

For maize the situation is different and complex because other investment in breeding is minimal and very rapid breakdown of rust resistance is highly likely. There are however resistant varieties likely to be released in two to three years.

They promise large increases in yields. But climate change also needs to be considered. The Atherton Tableland has experienced above average rainfall over the last decade in common with much of northern Australia. If that were to persist, rust could be a bigger problem. Overall the yield increase achieved by the project is assumed to decline to zero by 2018 as detailed in Table 10.

Cost Benefit Results

All past costs and benefits were expressed in 2008/09 dollar terms using the CPI. All benefits after 2008/09 were expressed in 2008/09 dollar terms. All costs and benefits were discounted to 2008/09 using a discount rate of 5%. The base run used the best estimates of each variable, notwithstanding uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2007/08) to the final year of benefits assumed (2037/38).

The present value (PV) of benefits from each source of benefits (sorghum and maize) was estimated separately and then summed to provide an estimate of the total value of benefits.

Investment criteria were estimated for both total investment and for the GRDC investment alone. Each set of investment criteria was estimated for different periods of benefits. The investment criteria were all positive as reported in Tables 11 and 12.

The net present values of the total investment and the GRDC investment are shown in Tables 11 and 12 respectively. This is considered to be the benefit accruing to Australia. The majority of the benefit accrues to grain growers as the majority of grain is exported at export prices or sold into a domestic feedgrain market dominated by feed wheat in most years. Therefore increased production is unlikely to have a major impact on prices. In terms of the Rural Research Priorities the major contribution is to the Productivity and Added Value priority. As shown in Section 4 there were some other contributions to the other priorities, but these benefits have not been quantified.

The analysis demonstrates that under the assumptions made the investment is likely to continue to achieve positive returns. However as is usual for plant breeding projects where there are long lags involved, the investment does not break even for about a decade.

Table 11: Investment Criteria for Total Investment and Total Benefits for Each Benefit Period (discount rate 5%)

Criteria	Years from last Investment					
	0	5	10	20	25	30
Cumulative PV of Benefits	0.43	6.12	13.58	22.96	26.20	28.73
Cumulative PV of Costs	12.62	12.62	12.62	12.62	12.62	12.62
Cumulative NPV	-12.20	-6.50	0.95	10.34	13.58	16.11
Benefit Cost Ratio (BCR)	0.03	0.48	1.08	1.82	2.08	2.28
Internal Rate of Return (%)	neg	neg	5.9	10.3	10.9	11.2

Table 12: Investment Criteria for GRDC Investment and Benefits to GRDC for Each Benefit Period (discount rate 5%)

Criteria	Years from last Investment					
	0	5	10	20	25	30
Cumulative PV of Benefits	0.17	2.42	5.36	9.07	10.35	11.35
Cumulative PV of Costs	4.99	4.99	4.99	4.99	4.99	4.99
Cumulative NPV	-4.82	-2.57	0.38	4.09	5.36	6.37
Benefit Cost Ratio (BCR)	0	0	1.08	1.82	2.08	2.28
Internal Rate of Return (%)	neg	neg	5.9	10.3	10.9	11.2

The two sources of benefits included in the evaluation are increased maize yields and increased sorghum yields. As expected from the respective size of the industries and the pattern of the yield increases, the majority of the benefits are from the sorghum projects. Table 13 shows the relative contributions.

Table 13: Contribution of Source of Benefits to Present Value of Benefits

Source	% Total Present Value of Benefits
Sorghum – yield increase	88
Maize – yield increase	12
Total	100

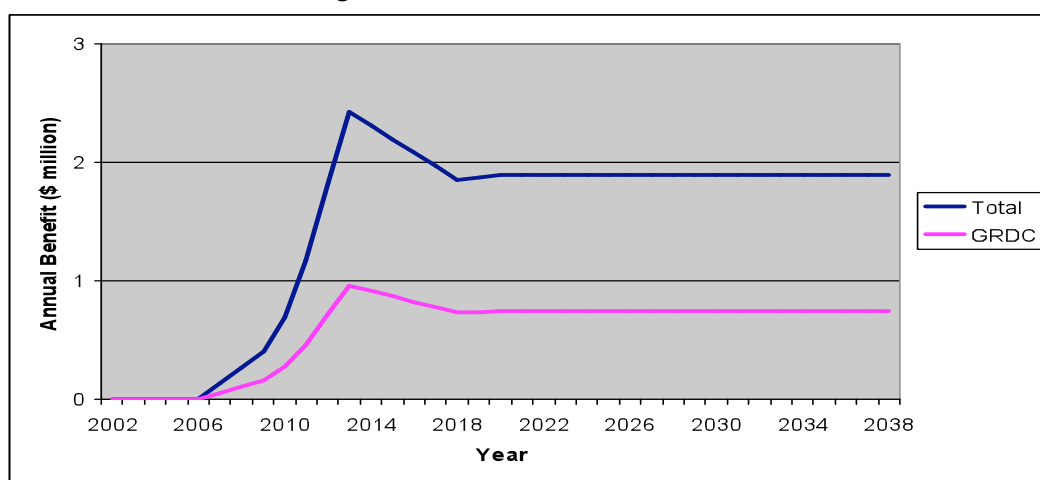
The quantified benefits are allocated to the Rural Research Priorities as expressed in Table 14.

Table 14: Allocation of Quantified Benefits to Rural Research Priorities

Rural Research Priority	Allocation
1. Productivity and adding value	100%

The annual net benefit cash flows for both the total investment and GRDC investment for the 30 year period from the year of first investment are shown in Figure 2.

Figure 2: Annual Benefit Cash Flow



The peak in benefits results from the maize benefits beginning before the sorghum benefits. The maize project started a year earlier and the more rapid breeding cycle account for the peak. The maize benefits decline rapidly to zero whereas sorghum benefits are assumed constant once they reach their maximum value in 2020.

Sensitivity Analysis

Given that sorghum accounts for 88 percent of the benefits, the sensitivity analysis can be restricted to the assumptions determining the sorghum benefits. The benefits arise from the yield difference. Two key assumptions are the timing and magnitude of the difference between the yields assumed to result from the PI&F/GRDC investment in sorghum from 2002/03 to 2006/07 and those assumed for the “without scenario”. In the latter case the only investment would have been from the

continuing programs of the seed companies. The base case assumed a difference of 0.2 percent in the rate of yield increase would apply with a lag to reflect the time to market and the adoption cycle. There is much more uncertainty about the yield difference than the lag so the sensitivity analysis will be confined to low and high values of the yield difference.

Table 15: Sensitivity of Investment Criteria to the Assumed Difference in the Rate of Increase in Sorghum Yield over the Period 2009 to 2013
(GRDC investment, 5% discount rate, 30 years)

Criteria	Low Rate 0.1% p.a.	Base Case 0.2% p.a.	High Rate 0.3% p.a.
Cumulative PV of Benefits	6.95	11.35	17.53
Cumulative PV of Costs	4.99	4.99	4.99
Cumulative NPV	1.96	6.37	12.54
Benefit Cost Ratio (BCR)	1.39	2.28	3.52
Internal Rate of Return (%)	7.5	11.2	14.7

The historic yield trend to date has been 1.75 percent. The difference is between the 2 percent yield increase assumed to be reached by 2013 as a result of varietal improvement and the lower rate achieved in the "Without scenario". Thus the "High" rate of 0.3 percent assumes that in the "Without scenario" yields would have declined below the historic rate of 1.75 percent. The implication is that private seed companies would not have been able to maintain the historic rate of gain.

For the "Low" rate, a smaller attribution is implied to the PI&F/GRDC investment compared with the contribution from the seed companies. The sensitivity analysis does span a wide range of possible outcomes and does therefore show some confidence that the investment provides a positive return but it is not likely to be a high return.

8. Confidence Rating

The results produced are highly dependent on the assumptions made, many of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 16). The rating categories used are High, Medium and Low, where:

- High:denotes a good coverage of benefits or reasonable confidence in the assumptions made
- Medium:denotes only a reasonable coverage of benefits or some significant uncertainties in assumptions made

- Low:denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 16: Confidence in the Analysis of the Investment in Summer Coarse Grains –Breeding

Coverage of Benefits	Confidence in Assumptions
High	Medium

9. Conclusions and Lessons Learned

The projects in the cluster Summer Coarse Grains – Breeding have produced outputs that have contributed to improved yields of maize and sorghum. The maize improvements are primarily of benefit to the small industry on the Atherton Tablelands. Regular releases of new varieties have resulted in continuing increases in yield and have provided increased resistance to rust.

The sorghum projects have produced a large number of improved lines that are licensed to seed companies to develop improved hybrids. The emphasis is on yield increase together with resistance to disease and drought.

The evaluation showed that under the best available assumptions the investments by GRDC in the cluster Summer Coarse Grains – Breeding are producing positive returns. Outputs up to mid-2008 are included in this evaluation. The GRDC investment in the projects totalled \$3.653 million in a total investment of \$9.254 million.

The Net Present Value of the overall investment over 30 years is estimated at \$16 million with a benefit cost ratio of 2.28. The projects began in 2001/02 and it is estimated that break even on the investment will not be achieved until about 2020. The pattern and level of benefits are typical of many on-going breeding programs.

The sorghum project accounted for 74 percent of the total investment and 88 percent of the benefits. The benefit cost ratio for sorghum is thus higher at 2.64 than the ratio for maize of 1.26. There is clearly a much higher research intensity for maize than sorghum when compared to the size of the target industry. For this cluster, the sorghum investment is about three times the maize investment. However, the sorghum gross value of production is over 40 times that of the maize industry on the Atherton Tablelands.

The relative returns being achieved for sorghum and maize need to be interpreted in a wider context. For maize the history of development on the Atherton Tableland is one of responses to government regulation and deregulation and the impacts on isolated communities (Gilmore 2005). The history of Queensland Government support for maize breeding since 1920 cannot be separated from Queensland Government support for the now defunct Atherton Tableland Maize Marketing Board (1923-1994). Current production levels are only half of those achieved in the early days of the Board.

Any conclusions on the likely future returns from investment in sorghum and maize breeding will need to take into account the limitations and uncertainties of this analysis. Foremost is the attribution of a yield gain to varietal improvement against other possible sources. The rate of yield increase for sorghum appears to be stable over the last few decades. However, extreme droughts particularly in Queensland in the last two decades may have suppressed the rate of yield increase. In addition there are legitimate competing claims to attribute increases to improved farming practices rather than varietal gain. Adding to that attribution and for sorghum particularly, the analysis was not able to objectively partition a likely gain from varietal improvement between the PI&F/GRDC investment and that from seed companies. Next in importance after attribution of varietal gain was the likely increase in the value of the capital stock of germplasm over the period of the analysis. The greater emphasis over the last decade on strategic research for sorghum is likely to result in more rapid gains in future.

The change in emphasis in the maize program to broaden the research focus to include other regions has been underway for some years but will now have gathered momentum that should feature in future evaluations. The headquarters for maize breeding has shifted to Southern Queensland.

Two lessons stand out from this evaluation. The lessons are important because they provide objective feedback to researchers and to industry on the scope and value of the current research effort. First is the difficulty in obtaining objective information on which to attribute benefits, particularly in relation to what might be achieved by the private sector focus alone and how the broader longer-term public sector focus can add to that. Research programs that attempt to show the gains they are achieving compared to those that could have been achieved without the investment in the program will be better placed to show their value. The second relates to the difficulties inherent in comparing ex ante evaluations with those that are partly ex post as this evaluation is. An ex ante evaluation of future investments in maize or sorghum breeding would need to recognise the limitations in this evaluation. The major one is the uncertainty involved in estimating the yield trends based on historic data and on assumptions on how the private sector breeders might respond if there was no GRDC investment. In addition, trends from future investments are likely to be increasingly determined by the increased focus on strategic research in recent years and by increasing impacts from climate change.

Acknowledgments

Grains Research and Development Corporation, Canberra
Vince Fernandes, Business Analyst

Sorghum and Maize Breeding Organisations

David Jordan, PI & F, Hermitage
Solomon Fekybelu, PI & F, Hermitage
Robert Henzell, PI & F, Warwick.
Robert Martin, PI & F, Kairi
Rodney Coe, HSR Group
Ivan Calvert, Pioneer Hi-Bred Australia, Toowoomba
Neil Muller, Pacific Seeds, Toowoomba.

References

- ABARE (2008). "Australian Commodity Statistics 2008", Canberra.
- Barrett, D., Bragatheswaran, G., Lawrance, L. and To, H. (2009) "Outlook for wheat, coarse grains and oilseeds to 2013-14". Australian Commodities, vol 16 no 1.
- Berndt, R.D. and White, B.J. (1976) "A simulation-based evaluation of three cropping systems on cracking-clay soils in a summer rainfall environment". Agricultural Meteorology 16:211-229.
- Black, I, Dyson, C., Hayman, P. and Alexander, B. (2008). "The determinants of South Australian wheat yield increases". Global Issues Paddock Action. Proceedings of the 14th Australian Agronomy Conference. Adelaide.
- Duvick, D. N., J. S. C. Smith, and M. Cooper, 2004: "Longterm selection in a commercial hybrid maize breeding program". In: J. Janick (ed.) Plant Breed. Rev., 24, 109–151. John Wiley & Sons, Engelwood Cliffs, NJ, USA
- Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee (1996). "Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions", AER-735, U.S. Department of Agriculture, Economic Research Service.
- GRDC (2008). GRDC Annual Report 2007-08. GRDC, Canberra
- Juttner, J. (2009). "Outcomes From The Formal Review Of The GRDC National Variety Trial Program". (Juan Juttner, GRDC), Canberra
- Gilmore, M. (2005). "Kill, Cure or Strangle - The history of government intervention in three key agricultural industries on the Atherton Tablelands, 1895-2005". Ph D thesis, James Cook University of North Queensland, Townsville.
- Gunasekera, D., Yeon Kim, Tulloh. C., Ford, M. (2007) "Climate Change -Impacts On Australian Agriculture" Australian Commodities Vol. 14 No. 4.
- Holland, J and Felton, W. (1989). "Effect of tillage practice on grain sorghum production in northern New South Wales." Australian Journal of Experimental Agriculture 29(6) 843 - 848
- Howden, S.M., Gifford, R.G. and Meinke, H. (2008). "Grains". In An overview of climate change adaptation in Australian primary industries – impacts, options and priorities, Edited by C.J. Stokes & S.M. Howden CSIRO. p44-70, Report prepared for the National Climate Change Research Strategy for Primary Industries.
- Jordan, D. (2008). Report to GRDC on the Commercialisation of Sorghum Germplasm Owned Jointly With DPI&F, Period 1/6/2008 to 30/6/2008 QDPI, Brisbane.
- Jordan, D., Hammer, G L and Henzell, R. G. (2006). "Breeding for yield in the DPI&F breeding program". In: A.K. Borrell and D.R. Jordan, 5th Australian Sorghum Conference. 5th Australian Sorghum Conference, Gold Coast, (1-8). 30 January - 2 February 2006.

Llewellyn R, D'Emden F and Gobbett, D (2008) "Adoption of No-till and Conservation Farming Practices in Australian Grain Growing Regions: Current Status and Trends", Preliminary Draft Report for SA No-till Farmers Association and CAANZ, CSIRO

NSW DPI (2009). "Grain Sorghum". Farm Enterprise Budget Series - North East NSW.

Nicholls, N., 1986. "Use of the Southern Oscillation to predict Australian sorghum yield". *Agric. Forest Met.*, 38, 9-15

Potgeiter, A, Hammer, G., Doherty, A., and de Voil, P., (2005). "A simple regional-scale model for forecasting sorghum yield across North-Eastern Australia". *Agricultural and Forest Meteorology* 132: 143-153.

Reading P (2008) "Positioning the Australian Grain Industry for Growth – Innovation", Australian Grains Industry Conference, July.

Shepherd, A. and Routley, R. (2008) " Participatory RD&E leads to the adoption of improved farming practices in central Queensland". in *Global Issues, Paddock Action. Proceedings of the 14th ASA Conference, Adelaide, South Australia*

Martin, I (2005). "Matching corn varieties to situations". Research Update for Growers - Northern Region - March 2005 . GRDC Canberra.

QDPI (2008). "Zea". Vol 3, No 1. Maize Newsletter (ed. I Martin), Queensland Department of Primary Industries and Fisheries, Brisbane.

QPI&F (2009a). "Sorghum Breeding".
<http://www2.dpi.qld.gov.au/cropresearch/15350.html>

QPI&F (2009b). "Maize Production in Queensland".
http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/26_3491_ENA_HTML.htm

U.S.A Department of Agriculture (1990). "New Germplasm Helps Assure Food for the Future," USDA News Feature, News Division, Office of Public Affairs, Dec. 6.

WEA (2007). "Least Cost Supply Chain". Fact Sheet, Wheat Export Authority, Canberra.

Wylie, P. (2008). "High Profit Farming in Northern Australia ". GRDC Canberra.