Grains Research & Development Corporation

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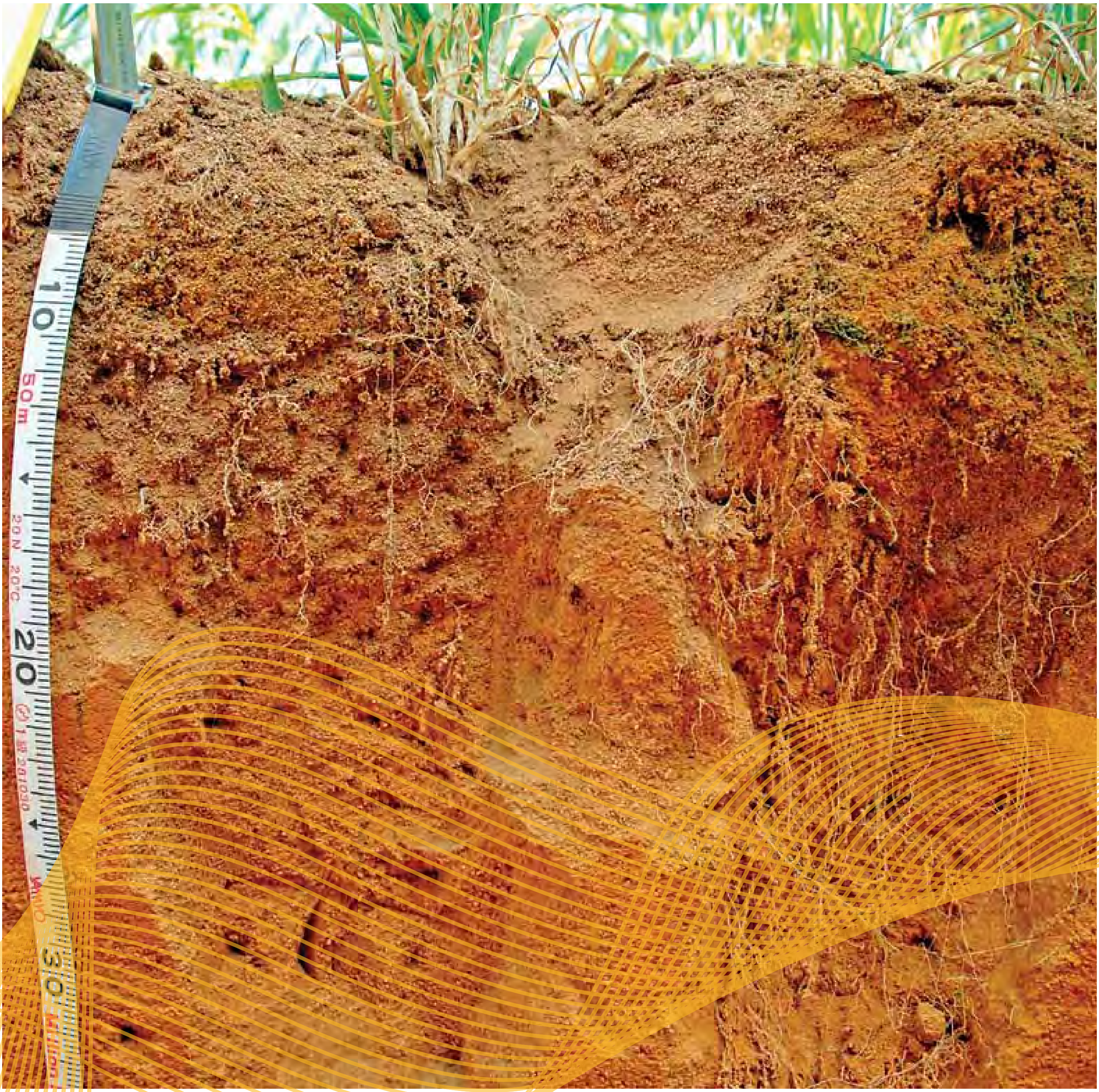
An Economic Analysis of GRDC Investment in the Soil Biology Program



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Title: **An Economic Analysis of Investment in the GRDC Soil Biology Program (Themes 1-3)**

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Impact Assessment:
An Economic Analysis of Investment in the GRDC Soil Biology Program (Themes 1-3)

Executive Summary

The Soil Biology Program was developed by the GRDC Board in 2002 as a new initiative. The goals set by the Board included overcoming biological constraints and managing soil biology as an integral part of sustainable farming systems. These were to be achieved by practical methods and products to improve profit margins.

The cluster of projects evaluated included the parts of the Soil Biology Program on inoculants, root diseases, and organic matter and nutrition. The projects contributed to the Board's goals by developing products and practices expected to contribute to more profitable and sustainable crop production. Most of the economic benefits evaluated were those anticipated from increased yields following the application of microbial inoculants. The benefit/cost ratio based on the best available estimates was 4 to1. The GRDC investment in the cluster to be evaluated totalled $8.1 million generating a net present value of benefits of $32 million. Partner organisations, which were mostly from a centre of concentration in soil biology research in Adelaide, contributed $8.5 million. The evaluation allowed for an estimated $9 million of post-project costs for further research and development of the outputs of the cluster.

The economic evaluation showed that the majority of the benefits are expected to be from increased profits from two phosphate-solubilising inoculants including a dual-purpose product that also includes *rhizobia* for nitrogen fixation. The phosphate-solubilising inoculant *Penicillium bilaii* (marketed as JumpStart) is a naturally occurring fungus. Applied as a seed dressing, the fungus grows along plant roots producing acids that release less available forms of Phosphorous. The availability of phosphates is a major constraint to agricultural production across much of southern Australia. Further profits are likely from an inoculant to reduce the impacts of root diseases and from research that will help to better define seasonal fertiliser requirements based on the capacity to simulate nutrient cycles for Nitrogen and Phosphorus.

Additional environmental benefits are expected from reductions in fertiliser and fungicide use. However the phosphate solubilising inoculant will only be a partial substitute for phosphate fertiliser. Overall this will result in small improvements in water quality from reduced off-farm export of nutrients. In terms of the environment life cycle on farm, there will be small positive contributions to more sustainable development from reduced inputs of fertilisers and fungicides. The carbon contribution is also likely to be minor and related to some organic matter increase associated with increased yields.

The major social benefit is likely to arise from the improved research capacity in soil biology. The GRDC investment was a catalyst leading to the development of a more coherent national effort. Soil biology was a relatively neglected field compared to the traditional focus on soil chemical and physical research.

The economic benefits were determined by the increased profits from the use of inoculants and better defined fertiliser requirements. As only one product from the program was being marketed by 2009, there was considerable uncertainty in relation to the likely yield increases and rates of adoption. The inoculants are being commercialised by a GRDC joint venture (Novozymes Biologicals Australia). Much of

the potential market intelligence information was necessarily confidential. Estimates for this evaluation were based on judgements on what published information was available together with experience from similar campaigns in Canada.

The evaluation took into account likely post-project costs for development, attribution of benefits, and the probability of success where appropriate. The uncertainty in benefit estimation was taken into account in a sensitivity analysis. The indicated range for the benefit cost ratio was from about break even for more conservative estimates to 12 to1 if a more optimistic view was taken of the possible benefits.

The major lessons learnt relevant to the evaluation related to opportunities to speed up the commercialisation process, for example by parallel development of commercial structures during the research phase and by avoiding delays in field trials caused by the major droughts during the last decade.

The following table provides a summary using the triple bottom line benefit framework to describe economic, environmental and social benefits.

Levy Paying Industry	Spillovers		
	Other Industries	Public	Foreign
Economic Benefits			
1. Increased profits from higher yields resulting from more efficient use of fertilisers, reduced disease, and reduced disease control costs	5. Benefits resulting from the pioneering leadership role GRDC had in expanding soil biology research across RDCs	7. Potential benefits from the research capacity developed in soil microbiology	11. Potential export markets for inoculants
Environmental Benefits			
2. More sustainable agriculture from reduced reliance on manufactured and mined fertilisers 3. Reduced fungicide use in farm environment	6. Potential use of natural inoculants to reduce reliance on manufactured fertilisers	8. Reduced off-farm export of nutrients 9. Reduced off-farm export of fungicides	12. More sustainable agriculture
Social Benefits			
4. Increased industry research capacity resulting from the pioneering leadership role GRDC had in expanding soil biology research		10. Potential spin-off benefits from the research capacity developed in soil microbiology	13 International scientific collaboration and capacity building

1 Introduction

Soil Biology was developed by the GRDC Board in 2002 as a new initiative within the then Sustainable Farming Systems Program. The GRDC investment in the cluster to be evaluated totalled $8.1 million. Partner organisations, which were mostly from a centre of concentration in soil biology research in Adelaide, contributed $8.5 million.

Soil biology was seen as a relatively neglected focus for research compared with the traditional emphasis on managing soil chemical and physical properties. There was little understanding of the roles of soil biology and that was compounded by the inherent complexity and lack of research tools. Research in soil biology could cover the extraordinary diversity of organisms present in soil. The range of organisms based on a size criteria extends from bacteria and fungi through to earthworms. But the focus in the Soil Biology Program is on the interventions through either new products such as inoculants or changed management practices. Benefits could include improved crop nutrition or reduced occurrence of soil-borne disease. The traditional and widespread example of the highly cost-effective inoculation of legumes with N-fixing symbiotic rhizobia has challenged researchers to find equivalent inoculants for phosphorus.

Mele (2009) has reviewed Australian research in soil biology and shown that the GRDC Soil Biology Program was a major catalyst in developing a new focus for a research effort which had previously been relatively minor compared to the traditional soil research issues.

There were four key trends emerging during the 1990s that gave soil biology research a high and more urgent profile and were drivers of the GRDC investment:

- In North America in particular, there had been an expansion in the market for natural inoculants with various claims, for example to enhance nitrogen (N) and phosphorus (P) nutrition.
- The widespread and relatively rapid adoption of no-till was based on farmer recognition of the many benefits, and to some extent despite recognition of the role traditional tillage practices had in controlling some fungal root diseases,
- Improved DNA tests to identify various soil organisms, particularly disease levels, and develop more confident control strategies, and
- Imperatives relating to sustainability and managing greenhouse gas emissions also saw greater recognition of the central role that soil biology had in Carbon (C) and nutrient cycling.

The trends gave rise to the 14 projects evaluated in this cluster and to the Soil Biology themes as listed in Table 1. The Program as illustrated particularly in Themes 4-6 was also a response to increasing farmer interest in broader soil issues that often come under the banner of soil health, and a response to opportunities to explore more environmentally acceptable alternatives to pesticides and fertilisers. The split of the Program for evaluation was done to create two less diverse groups. The Themes 4-6 are expected to be evaluated at a later date.

Table 1: Themes of the Soil Biology Program included in the GRDC Investment Cluster

Themes included in Investment Cluster	**Themes not included**
1: Microbial inoculants	4: Rhizosphere
2: Root diseases	5: Management and agronomy
3: Organic matter and nutrition	6:GRDC collaboration with other organisations

In 2006 in conjunction with Philom Bios Inc, GRDC began a joint venture to develop soil inoculants including commercialising the more promising opportunities developed by the Soil Biology Program. Philom Bios Inc. has a 25-year history of developing and marketing soil inoculants for legumes, cereals and canola in western Canada. The joint venture now operates as Novozymes Biologicals Australia.

The report identifies the project outputs, which lead to specific outcomes. Most projects in this cluster were either discovery projects generating new knowledge or projects, which required further investment to develop and market new products.

Much of the information on potential markets is subject to confidentiality requirements. The analysis has been based on the limited amount of publicly available information including experience with similar products in the Canadian market. A number of assumptions were therefore required to estimate potential outcomes via the alternative pathways to adoption. The outcomes are forecast to then estimate impacts from economic, social and environmental perspectives. A cost benefit framework is utilised and supported where possible with non-financial information on impacts. A sensitivity analysis of the baseline assumptions is undertaken and the conclusions and lessons learnt are then discussed in the final section of the report.

2 Project Investment

The goals for the Soil Biology Program approved by the GRDC Board in February 2001 were:

- Identify and overcome biological constraints to crop performance;
- Learn how to manage soil biology as an integral part of sustainable farming systems;
- Develop a suite of practical methods and cost-effective products for growers, and
- Help improve profit margins in grain cropping areas (Bender 2008).

As listed in Table 2, fourteen projects have been funded by GRDC in this investment cluster. Thirteen projects are from Themes 1-3 in the Soil Biology Program, now part of the Output Group 2, the Practices Line of Business. The Objective of Output Group 2 is: *"Better practices developed and adopted faster".*

Most of the projects began in 2002 as part of the newly created Soil Biology Program. One existing project (CSP245) that had commenced earlier was brought in to the Soil Biology Program because it had synergies with other projects in Theme 3. The CSO 00044 project (listed under Other in Table 2) was included in this cluster because it had a similar commercialisation pathway to other projects in the cluster and it built on early research in the cluster. CSO00044 is part of the GRDC New Products Line of Business.

Table 2 Projects in the Soil Biology Cluster

Project Number	**Title**	**Duration**	**Supervisor/ Organisation**
Theme 1: Microbial inoculants			
UF00002	Application of actinomycete endophytes for improved grain yields	7/1/2002-30/6/2003	Chris Franco Flinders University
DAS00036	Tri-inoculation for enhanced wheat growth under disease limiting conditions	1/7/2003-30/6/2006	Kathy Ophel-Keller SARDI
CSP00050	Quantifying the effect of hydrogen gas on soil biota and crop performance	1/7/2003-30/6/2007	Mark Peoples CSIRO
CSO223	Inoculants for growth promotion of cereals	01/09/2000-31/8/2003	Maarten Ryder CSIRO
GBE00003	Field evaluation of inoculant products	1/3/2002-1/3/2004	Greg Bender GRDC Coordinator
RJH00001	Field evaluation of inoculant products	1/4/2003-30/3/2007	Bob Hannam, Consultant
Theme 2: Root diseases			
DAS00027	Understanding suppressive soils	15/7/2002-15/7/2006	Kathy Ophel-Keller SARDI
CSO00016	Managing pythium to improve yield	1/7/2002-30/6/2006	Paul Harvey CSIRO
CSO00032	Management of irrigated maize residues for disease control	30/6/2004-1/1/2007	Paul Harvey CSIRO
Theme 3: Organic matter and nutrition			
CSO00029	Management of organic matter fractions for productivity	1/7/2003-30/6/2006	Jan Skjemstad CSIRO
CSO00030	A new approach to defining nitrogen availability to crops	1/7/2003-30/6/2006	Jeff Baldock CSIRO
UA00062	Biological cycling of phosphorus in farming systems	1/7/2003-30/6/2007	Ann McNeill University of Adelaide
CSP245	Influence of tillage practice on biological activity and organic matter	1/7/1997-30/6/2005	Margaret Roper CSIRO
Other			
CSO00044	Identifying phosphate solubilisation and plant-growth promotion by *Penicillium*-based rhizosphere inoculants.	1/09/2006 1/09/2008	Paul Harvey CSIRO

Source Project Reports

Table 3 lists the objective for each project.

Table 3: Objectives of the Projects in the Soil Biology Cluster

Project	Objective
Theme 1: Microbial inoculants	
UF00002	Proof of Concept that actinomycete endophytes are effective in broadacre cropping will lead to new biological agents for farmers
DAS00036	Proof of concept that TRINOC™ can provide an economic benefit to wheat crops when yield is limited by soilborne disease complexes
CSP00050	Demonstrate crop benefits from soil exposure to hydrogen gas and understand processes involved to develop applications
CSO223	Define effective use of *Penicillium radicum* or similar isolates to improve phosphorus nutrition of wheat
GBE00003	Develop new products and practices based on validation of outputs from the soil biology projects
RJH00001	Further develop new products and practices based on validation of outputs from the soil biology projects
Theme 2: Root diseases	
DAS00027	Research management practices that can be integrated with current farming systems to reduce the impact of wheat diseases and favour beneficial organisms
CSO00016	Quantify effects of Pythium and take-all disease complexes and develop practices to limit root disease in rotations
CSO00032	Identify causes of root rot of irrigated maize and develop more efficient disease control strategies
Theme 3: Organic matter and nutrition	
CSO00029	Develop a predictive tool for the impact of residue management on soil Organic Carbon levels and on key soil physical, biological and chemical functions
CSO00030	Research better matching of the supply of N from fertiliser, soil organic matter and the residues of crops and pastures with crop N demand
UA00062	Identify management practices on-farm that maximise biological cycling of P
CSP245	Show the impacts of tillage practices on soil microbial processes, organic matter and crop yield
Other	
CSO00044	Support the development & release of new plant growth-promoting (PGP) Penicillium inoculants for the Australian grains industry

Source: Project Reports

Investment Inputs

Estimates of the funding by GRDC and others by project by year for the fourteen projects are provided in Tables 4 and 5. GRDC contributed slightly over half the total funding.

Table 4: Investment by GRDC and Partner Organisations in the Projects in the Soil Biology Cluster (nominal $)

Project	Partner Organisations	GRDC	Total
Theme 1: Microbial Inoculants			
UF00002	1,544,700	1,345,538	2,890,238
DAS00036	660,143	365,588	1,025,731
CSP00050	1,011,008	915,038	1,926,046
CSO223	411,557	371,721	783,278
GBE00003	0	170,000	170,000
RJH00001	0	381,840	381,840
Total Theme 1	3,627,408	3,549,725	7,177,133
Theme 2: Root Diseases			
DAS00027	695,623	446,176	1,141,799
CSO00016	508,867	686,168	1,195,035
CSO00032	264,469	250,515	514,984
Total Theme 2	1,468,959	1,382,859	2,851,818
Theme 3: Organic matter and nutrition			
CSO00029	581,191	599,217	1,180,408
CSO00030	1,403,016	1,290,093	2,693,109
UA00062	629,182	599,959	1,229,141
CSP245	195,344	589,803	785,147
Total Theme 3	2,808,733	3,079,072	5,887,805
Other			
CSO00044	220,000	489,394	709,394
Total	8,125,100	8,501,050	16,626,150

Source: Project Reports

Table 5: Total Investment by GRDC and Partner Organisations for Years Ending June 1998 to June 2009 (nominal $)

Year (ending June)	Partner Organisations	GRDC	Total
1998	17,255	86,274	103,529
1999	17,978	86,274	104,252
2000	17,255	86,273	103,528
2001	151,245	212,189	363,434
2002	156,629	300,100	456,729
2003	984,795	1,283,396	2,268,191
2004	2,184,441	1,921,081	4,105,522
2005	2,187,508	2,104,903	4,292,411
2006	1,495,094	1,496,144	2,991,238
2007	548,900	395,098	943,998
2008	341,000	475,931	816,931
2009	23,000	53,387	76,387
Total	8,125,100	8,501,050	16,626,150

Source: Project Reports

3. Activities and Outputs

As shown in Table 6, the projects carried out a range of laboratory and field experiments to develop and test new knowledge, and contribute to product development. Apart from one project in Western Australia, the projects were located in the GRDC Southern Region. The concentration in the Southern Region of projects in the three themes reflected the greater incidence of root diseases, the generally low phosphate status, and also the research capacity in the Southern Region on microbial inoculants. Previous research and Canadian experience had shown the potential of inoculants particularly for solubilising phosphates.

Table 6: Summary of the Activities and Outputs for each Project

Project	Activities and Outputs
Theme 1 Microbial Inoculants	
UF00002	Identified in field trials in South Australia endophytes that are effective in increasing grain yield by disease suppression and/or plant growth promotion, developed protocols for large scale culture, and procedures for commercialisation. Outputs were: Delivered an effective endophytic actinomycete strain for commercial development as an inoculant for broadacre cereal cropping systems

DAS00036	Screened selected bacteria and fungi for superior biocontrol strains and assessed them in the field. Outputs were: Developed a system to mass screen for effective microbial strains in disease reduction. Proof of concept that TRINOC™ can provide an economic benefit to wheat crops when yield is limited by soilborne disease complexes and is suitable for commercial production as an inoculant.
CSP00050	Completed a range of experiments to demonstrate and understand how hydrogen can benefit crops. Outputs were: Delivery of report presenting data collected from Australian field trials on effects of hydrogen gas to GRDC. Delivery of recommendations to GRDC on how growers might use the technology arising from the hydrogen-based research.
CSO223	Completed a range of laboratory experiments on the major physical, chemical and biological factors controlling plant growth promotion by *Penicillium radicum*, and characterised further useful strains of plant growth-promoting *Penicillium* species. Outputs were: Information to enable farmers to more effectively use *P. radicum* (use on neutral to acidic soils with low disease backgrounds). Newly discovered *Penicillium* isolates with potential as plant growth promotants.
GBE00003	Field and laboratory trials to test liquid and granular formulations for inoculants and develop protocols for further field trials. Outputs were: Assessment of legume nodulation, nitrogen fixation and grain yield in response to inoculants. Shelf life, contamination, and other quality indicators for different storage temperatures. Feedback on ease of application and usefulness.
RJH00001	Completed over 50 field trials evaluating inoculants from GRDC soil biology projects. Outputs were: Report to GRDC with procedures for further testing and steps to commercialisation of outputs from other projects.
Theme 2 Root Diseases	
DAS00027	Used bio-assay and field studies to understand ecology of beneficial and deleterious organisms on r*hizoctonia* in SE Australia. Outputs were: Knowledge of temporal and spatial distribution of beneficial organisms. Regional distribution of beneficial organisms and management impacts defined.
CSO00016	Integrated fungicide, rotation & bio-control trials at 66 sites in Southern Australia to define incidence and impact of Pythium and a framework for prediction and management. Outputs included: Definition of the adverse effects of Pythium root rots Definition of the potential for integrated fungicide applications & crop rotation strategies to effectively control Pythium,

CSO00032	Field and glasshouse trials to find causes and control strategies for root rot in irrigated maize in SE Australia. Outputs were: Identification/isolation of causal agent(s) of maize root rot & lodging. Definition of the potential for integrated fungicide applications and crop rotation strategies to control maize root diseases.
Theme 3 Organic Matter and Nutrition	
CSO00029	Separated organic matter fractions for 10 soils to develop a model showing individual soil organic carbon (OC) fractions are better related to soil chemical, physical and biological properties than total soil OC. Outputs were: Quantification of the impact of residue management on soil OC fractions in cereal growing soils. Quantification of the impact of residue management on soil physical properties and OC as a source of energy for microbiological processes of soil OC fractions in cereal growing soils. A simple calculator to predict how residue management impacts on OC levels.
CSO00030	Defined for 9 locations in SE Australia the roles of different types of organic matter in soil N cycling to develop an improved capacity to predict N supply to grain crops. Outputs were: Identification and quantification of chemical, physical and biological factors that 1) define the potential mineralisability of soil and plant residue N and 2) account for losses of plant-available N. Quantification of the influence of soil type and agronomic practices on the chemistry and distribution of N in different pools of soil organic matter and plant residues and resultant rates of N mineralisation. Delivery of an improved capacity to predict N supply to grain crops that integrates the knowledge gained in outputs 1 and 2 with approaches used in existing N calculators.
UA00062	Undertook field and laboratory studies in Southern Australia to construct a simple model of P cycling that could be used to modify existing decision tools for P fertiliser management. Outputs were: Chemical composition of organic P identified and the mineralisation potential quantified for key defined fractions of soil organic matter in a number of soil types and for a range of management histories Influence of soil type, management and climate (rainfall distribution) on organic P, cycling processes and crop uptake measured and related to P mineralisation rate, enzyme activities & microbial biomass P. Delivery of an improved capacity to predict P supply from soil organic matter to crops in relation to management and a preliminary assessment of the impact on current decision support tools for P fertiliser.
CSP245	Conducted a trial at two contrasting sites in WA to compare impacts of different tillage, stubble and rotation regimes on crop yields and microbial processes. Outputs were: Measurement of the impact of no-tillage on microbial processes that cycle nutrients in the soil and impact on crop production Information for farmers to facilitate informed decisions about tillage practices.

Other	
CSO00044	Accurately identified the strains of *Penicillium*, defined where they perform consistently, and how they work. Outputs were: Consolidated intellectual property status for new *Penicillium* strains & developed the scientific tools & knowledge needed to support inoculant registration, commercial development & release. Characterised & quantified the rhizosphere competence of elite *Penicillium* strains & the plant-growth promotion (PGP) benefits resulting from inoculation. Completed preparations for inoculant field trials in potential markets

Source: Project Reports

4 Outcomes

A summary of the potential outcomes from each of the thirteen projects is reported in Table 7. Note that many of the projects were discovery or proof of concept projects. Therefore the potential outcomes listed are often based on small-scale field trials or laboratory results and will only be broadly indicative of the potential for commercial development.

Table 7: Summary of Potential Outcomes by Project

Project Number	**Potential Outcomes and Benefits**
Theme 1 Microbial Inoculants	
UF00002	Improved grain yields in the presence of Take-all, r*hizoctonia* and Crown rot diseases from inoculant application. Increased proportion of higher value crops as a consequence of reduced reliance on rotations to control diseases. Cost savings and environmental benefits from reduced use of chemicals to control diseases.
DAS00036	Subject to further field testing, increased control of *rhizoctonia* by an inoculant applied as a seed dressing. Increased research capacity from development of an assay to mass screen for more effective inoculants for r*hizoctonia* control.
CSP00050	Proof of concept that a 10-15% yield benefit is possible if the responsible micro-organisms could be developed as an inoculant.
CSO223	Increased yield from more effective targeting of situations where the *Penicillium radicum* inoculant was likely to be more effective. Potential for yield increases from new strains of *Penicillium* with plant growth promotant properties.
GBE00003	Increased yields from inoculants with more effective formulations tested over a wide range of environments.
RJH00001	Increased yields from inoculants (phosphate-solubilising and *rhizobia*) with more effective formulations tested over a wide range of environments and based on more effective trial protocols and product formulations.

Theme 2 Root Diseases	
DAS00027	Potential to reduce yield losses from disease, provided the finding in controlled environment studies that different cereal cultivars can affect root microflora and help suppress disease, can be demonstrated in the field.
CSO00016	Reduced yield losses from Pythium over extensive areas of the GRDC Southern Region from disease management strategies integrating fungicides and bio-control strains during highly susceptible rotation phases.
CSO00032	Reduced yield losses from new management strategies to control disease in irrigated maize crops in the Southern Region.
Theme 3 Organic Matter and Nutrition	
CSO00029	Improved capacity in southern Australia to manage soil organic carbon for more sustainable grain production
CSO00030	Improved capacity in southern Australia to manage the N supply to grain crops as a basis for development of improved decision support systems for more efficient use of N. Reduced environmental impacts from more effective use of N.
UA00062	Improved capacity in southern Australia to manage the P supply to grain crops as a basis for development of improved decision support systems for more efficient use of P. More sustainable grain production from improved management of soil phosphate use.
CSP245	Increased confidence in use of no-till in Western Australia from better understanding of impacts of tillage..
Other	
CSO00044	Increased yields from the use of inoculants to promote plant growth and reduce dependence on P fertiliser.

Overview of Outcomes

In summary, the major potential outcomes from the GRDC investment are likely to be:

- the increasing application of P solubilising and *rhizobia* inoculants to cereal and legume crops, particularly in southern Australia leading to higher yields and reduced fertiliser costs;
- changed disease control strategies including use of microbial inoculants leading to reduced yield losses from *rhizoctonia* and Pythium in southern Australia; and
- improved decision support systems for determining N and P applications more in line with crop requirements as determined by the season and nutrient availability.

As detailed in Section 7, each outcome requires further investment if it is to be achieved.

5 Benefits

This section considers the various categories of benefits and how benefits align with research priorities.

Economic Benefits
Most of the projects can be categorised as discovery projects with limited outcomes expected on-farm within the life of the project. Some projects were simply designed to establish proof-of-concept to inform decisions on further investment. The cluster included projects that established potential yield increases in laboratory or field trials but which required further development post-project to establish delivery methods and commercial potential.

In order to determine benefits for the cluster, the projects have been re-allocated into three sub-groups based on their economic benefits and pathways to adoption. The three groups are:

- Inoculants (yield increasing)
- Disease Control (including by inoculants), and
- Nutrient Balance

The main differences between the three groups are in the investments required, the probability of success, degree of attribution, and the time lag before outcomes occur in the form of increased yields. The information for each group together with assumptions on the timing and costs are developed in the Section 7 on the Measurement of Benefits.

A summary of the principal economic benefits from the groups in the Cluster is reported in Table 8.

Table 8: Summary of Principal Economic Benefits by Project Group

Project Group	Summary of Economic Benefits
Inoculants (nutrient increasing)	Increased profits from higher yields and reduced N and P fertiliser costs from the application of P solubilising microbial inoculants to cereal crops in southern Australia, including in combination with *rhizobia* inoculants for N fixation in association with grain and pasture legumes.
Disease Control (including by inoculants)	Increased profits following reduced yield losses from *rhizoctonia* and pythium in southern Australia as a result of changed disease control strategies including use of microbial inoculants
Nutrient Balance	Increased profits in southern Australia from N and P applications more in line with crop requirements as determined by the season and nutrient availability.

Environmental Benefits
In addition to the industry economic benefits listed in Table 8 for the three categories of benefits, the investment will also generate some environmental benefits.

The main environmental benefits anticipated are from the reduced applications of phosphate fertilisers when P-solubulising inoculants are used. The manufacturer recommendation is to use the lower rate recommended when a soil test has been done (Velthuis 2008). An example showed that adopting the lower rate would halve the rate that needed to be applied if an inoculant was used. Overall there is likely to be some small reduction in export of phosphates to waterways and leaching to groundwater when inoculants are applied to some farms within catchments. Blumenthal et al (2008) showed a whole-of-catchment approach was desirable to assess nutrient losses and that losses of phosphates from grain farms were likely to be one of the contributors to nutrient enrichment in waterways in some catchments.

In Canada an environmental Life Cycle Assessment (LCA) is being undertaken on the use of the inoculant JumpStart to document the positive environmental impacts. (Personal communication, Sanford Gleddie, 2009). The LCA is a comprehensive framework to assess for a product life-cycle, the inputs, outputs, and their impacts. Sustainability can be assessed by impacts in terms of resource depletion, and energy and carbon emissions.

Although no quantitative data is available, JumpStart will contribute to more sustainable grain production by reduced fertiliser inputs. Key impacts will be reduced energy inputs from savings in manufacture and transport, and the increased life of phosphate reserves.

Social Benefits
The major social benefit is likely to arise from the improved research capacity in soil biology generally and from opening up a new research field to expand the use of naturally occurring microbial inoculants. The GRDC investment was a catalyst leading to the development of a more coherent national effort in soil biology. The traditional focus for soil research had been on soil chemical and physical aspects.

Overview of Economic, Environmental and Social Benefits
The three categories of benefits will generate spillovers to other industries, and there will be public and foreign spillovers. An overview of benefits in a triple bottom line categorisation is shown in Table 9.

Table 9: Categories of Benefits from the Soil Biology Cluster Investment

Levy Paying Industry	Spillovers		
	Other Industries	**Public**	**Foreign**
Economic Benefits			
1. Increased profits from higher yields resulting from more efficient use of fertilisers, reduced disease, and reduced disease control costs.	5. Benefits resulting from the pioneering leadership role GRDC had in expanding soil biology research across RDCs	7. Potential benefits from the research capacity developed in soil microbiology.	11. Potential export markets for inoculants
Environmental Benefits			
2. More sustainable agriculture from reduced reliance on manufactured and mined fertilisers. 3. Reduced fungicide use in farm environment	6. Potential use of natural inoculants to reduce reliance on manufactured fertilisers	8. Reduced off-farm export of nutrients, 9. Reduced off-farm export of fungicides	12. More sustainable agriculture
Social Benefits			
4. Increased industry research capacity resulting from the pioneering leadership role GRDC had in expanding soil biology research		10. Potential spin-off benefits from the research capacity developed in soil microbiology	13. International scientific collaboration and capacity building

Public versus Private Benefits
The benefits identified from the investment are predominantly private benefits, namely benefits to grain producers predominantly in southern Australia. There also will be some public benefits produced, mainly environmental in nature.

Benefits to other Primary Industries
The GRDC investment in the soil biology projects has been a catalyst for investments by other R&D Corporations including those in broader soil health programs. The Soil Biology Cluster includes three of the six themes in the GRDC Soil Biology Program. The sixth theme was "GRDC Collaboration with other organisations" which included collaborative programs with LWA and MLA.

Distribution of Benefits Along the Grains Supply Chain

Some of the potential benefits from higher average yields will be passed along the supply chain to grain processors, and other users of grain including intensive animal producers and ultimately consumers. However, as grain is predominantly exported, benefits will be captured in the main by grain producers.

Benefits Overseas

There is potential for exports of Australian inoculants and technology for use in agriculture globally. For the benefits to be achieved, superiority of Australian inoculant strains would need to be demonstrated. Part of the benefit would be captured by Australian holders of the intellectual property.

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 investment in the Soil Biology Cluster of projects was predominantly focused on National Research Priority 1 and to a lesser extent on Priority 3. The investment was focussed on Rural Research Priorities 1 and 3. A summary of the priorities addressed is provided in Table 11.

Table 11: Categorisation of Benefits by Priorities

Benefit	**National Research Priority Addressed**	**Rural Research Priorities Addressed**
Productivity gains through yield increases		Priority 1 ***
Reduced off-farm export of nutrients and of fungicides	Priority 1 *	Priority 3 *
Increased industry research capacity	Priority 3*	

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

Additionality and Marginality
It is likely that a much lower form of support for soil biology research would have eventuated if GRDC had not supported the program over this period. Hence it was likely that if the government contribution to GRDC was absent, there probably would have been a lower level of support, with a lowered investment by GRDC and hence with less progress having been made. The focus of any investment would have been on the less risky and more applied projects rather than the strategic and discovery projects that accounted for most of the program. Additional information is provided in Table 12.

Table 12: Potential Response to Reduced Public Funding

1. What priority were the projects in this cluster when funded?	Medium priority as this was a new initiative competing with traditional research fields.
2. Would industry have funded this cluster if less funds were available?	Yes, but at a much reduced level.
3. Would industry have funded this cluster if only industry funds were available and no public funds?	Yes, 25% of that actually funded
4. If the answer to Q3 is no or reduced, why?	Perceived as a new research focus seen as higher risk reflecting the pioneering nature of the research and of the commercialisation process.
5. If the answer to Q3 is no or reduced, would it have been funded in another form by industry or by GRDC?	Only with a lag as community awareness of emerging issues such as climate change and impacts of energy costs on fertiliser prices increased priority.

6 Pathway to Adoption

A commercialisation process was necessary for some of the outputs of the research following completion of the research projects. The products developed by the projects included inoculants and improved knowledge of crop fertiliser requirements. It is envisaged the latter would be incorporated in existing decision support tools using existing pathways to adoption. For the inoculants, GRDC recognised by 2003 that a commercial partner would be required to develop commercial formulations to apply inoculants and to develop new markets. At that time the main market potential was thought to be inoculants for wheat and barley production (Thorne 2003). The only Australian expertise was in *rhizobia* inoculants applied as a slurry to seed for pulse crops. A granular formulation would be necessary for larger scale wheat and barley applications. There were Australian companies marketing inoculants, but their expertise was based on well-established products in existing markets. The search for an innovative commercial partner was extended to include opportunities internationally.

As detailed in the Annual Report (GRDC 2005), attributes considered in the expression of interest process and choice of a commercial structure included:
- ownership and management of intellectual property,
- focused corporate governance, and
- ease of interactions with the commercial sector.

Capabilities sought included:
• capacity to undertake the commercialisation, including the development of commercial formulations, of new soil inoculant products,
• expertise in, and capacity to undertake manufacturing,
• inoculant on-farm delivery technology, and
• expertise in the development of new inoculant markets.

Following the launch of the joint venture with the Canadian company Philom Bios in 2006, it was anticipated that the earliest of the new inoculants would be ready for commercial release in 2006–07 (GRDC 2005). The joint venture also marketed rhizobia inoculants. However the first commercial release involving outputs from the cluster being evaluated did not take place until 2009. In retrospect, there may have been opportunities to shorten the time to market and these will be further considered in the final section on lessons learned.

For most projects, there will be a substantial lag before adoption attributable to the projects' outputs begins. The pathways to adoption for practices and products that are at a commercial stage will in general be the standard in the grains industry. There is already a high degree of awareness of the research undertaken by the Soil Biology Program through media generated by GRDC, for example articles in GroundCover and presentations at Crop Updates. The Soil Biology Program overall has had a major extension arm through the LWA program on Healthy Soils (HSSF - Healthy Soils for Sustainable Farms). Over 17,000 farmers, advisors, extension and NRM staff were involved in at least one HSSF activity, such as education and training workshops, practical field demonstrations, soil assessment training, seminars and field days (LWA 2008).

Of the projects in the cluster, those relating to disease control by changing traditional practices and projects relating to nutrient balance build on existing farmer understanding and skills. The GRDC Farmer Survey (GRDC 2008) showed:
- About 60 percent of farmers surveyed used nutrient budgeting, and
- About 80 percent of farmers had improved confidence in managing crop diseases.

In comparison, there are aspects of the inoculant projects that are novel, particularly for farmers who have not routinely used *rhizobia* inoculants for legume crops and pastures. Lack of familiarity could constrain adoption at least initially. However, the recent sharp increase in fertiliser prices is creating a demand for new approaches. Recent survey results confirmed that about one-third of broadacre farmers had adopted an innovative change in fertiliser practice (ABARE 2009). The following table lists some key criteria relevant to adoption decisions generally and interprets how they would apply to inoculants.

Table 13: Characteristics of Novel Inoculants influencing Farmer Adoption

Adoption Criteria	**General Farmer Perspective on Adopting Novel Inoculants**	**Key Aspects for Inoculants from Soil Biology Cluster**
Return	How profitable compared with alternative investments?	Products have been extensively trialed to determine average response.
Risk	The likelihood of achieving profitability and is it knowable?	Farmers will need to test applicability in their situation and determine consistency of benefit.
Researchability	How easy is it for the farmer to test the approach?	Trials can be easily undertaken on a small scale provided seeding equipment is easily modified.
Compatibility	How does the approach fit with the current farm set-up and the farmer's social context?	Although *rhizobia* inoculants have a well-established role, the new inoculants have not been widely used in Australia.
Complexity	How easy to use, or to get new skills?	Easy to use and builds on *rhizobia* experience.
Communication	How easy is it to see the benefits and understand the approach?	The products will gain credibility from the commercial involvement by GRDC .

7 Measurement of Benefits

There is a high degree of uncertainty on the benefits likely to be realised from the investment in the cluster. The major factor is that the products are to some extent novel and some are only now reaching a commercial stage. In addition, although information on likely benefits from the field trials has been conducted on a range of crops and soil types, the information is mostly confidential apart from some published summary articles. There are also other potential products that will not have any market impact without further investment. These additional development costs are estimated so that net benefits can be evaluated. The probability of success in taking the outputs of the research from their current stage through to a commercial stage also needs to be estimated. The post-project costs are taken into account before deducting benefits adjusted by the probability of success.

The benefits as defined simply by the target area, increased farmer profitability and the adoption profile need to be estimated for each of the three groups of projects. The cost benefit analysis will estimate benefits including an allowance for the probability of success where appropriate, less approximate estimates of the post-project development costs incurred or likely to be incurred by various agencies including GRDC, CSIRO and Novozymes Biologicals Australia. The proportion of the benefits that can be attributed to the investment in the projects in the Cluster also has to be estimated for each group.

The benefits from the investment in the Cluster are those additional to the benefits that would have occurred if GRDC had not invested. The counterfactual scenario (the benefits if GRDC had not invested) are detailed in Section 7.5. The major assumption in defining the counterfactual is that the research effort in soil biology would have been reduced substantially.

7.1 Inoculants (nutrient increasing)

Benefits from use of inoculants

The first of the naturally occurring inoculants subject to testing by the Soil Biology cluster was *Penicillium radicum*, first developed in Australia during the 1990s prior to any involvement from the Soil Biology Program. Seed inoculation with *P. radicum* (now known as Pr70RELEASE™ marketed by Becker Underwood) was initially promoted to some extent as the Australian equivalent of the successful Canadian inoculant *P. bilaii.* Phosphate-solubilising activity was seen as the key property. However the CSO223 project demonstrated that *P. radicum* was more likely a growth stimulant that produced varied even unpredictable results, but best when used on acidic soils with low fertility and low root disease problems (Wakelin and Ryder 2004). It could be argued that there were benefits from adoption avoided. Better information would result in farmers avoiding wasting further funds and yield losses where a response was unlikely. But although several years have passed since the clarification emerged, *P.radicum* does not appear to have been repositioned, and has not achieved a significant market presence. The benefit estimation will therefore concentrate on products where there has been a significant contribution from the Soil Biology Program and which are part of the GRDC joint venture with Novozymes Biologicals Australia. However the estimates will need to recognise that new competitive products may emerge as farmers increasingly seek innovative approaches to crop nutrition.

Two inoculants, JumpStart and TagTeam are in the process of being launched by Novozymes Biologicals Australia. JumpStart is a formulation based on *P. bilaii* which is applied as a seed dressing. As the brochure (Novozymes Biologicals Australia 2009) states: "*P.bilaii* is a naturally occurring soil fungus discovered by Agriculture and Agri-Food Canada. It colonises (grows along) plant roots, releasing organic acids that release the "bound" mineral forms of less available soil and fertiliser phosphate, making it immediately available for the crop to use".

TagTeam, available in 2009 has a dual mode of action as it includes *P. bilaii* and *rhizobia* for their traditional role in N fixation in association with legume crops and pastures. JumpStart is awaiting regulatory approval for a possible launch in 2010. Two projects in Theme 1 were the vehicle for early field evaluation of inoculant products. In addition the project CSO00044 (classified as Other) has tested *penicillium* inoculants in Australia and Northern America to develop a better understanding of their rhizosphere ecology, genetic stability and the mechanisms associated with enhancing P-availability in soils and plant-growth-promotion. This will provide a better understanding of which inoculants to use under particular agro-ecological conditions for increased efficacy and consistent performance (Harvey et al 2009). Soil acidity is one of the key factors influencing phosphate availability. Farmers will see soil acidity as important in determining the likely response to inoculants on the range of acidic and alkaline soils in southern Australia. The Novozymes Biologicals Australia brochure states that phosphate is most available on soils of pH 6.5 to 7 (slightly acid to neutral).

There have been exceptional increases in fertiliser prices in recent years driven by oil prices and increased demand for crops for bio-fuel production. Survey results showed that broadacre farms increased fertiliser expenditure by one half in 2007-08, much less than could be expected by the almost doubling of the fertiliser price index (ABARE 2009). Clearly farmers were making major adjustments to the price rises that could not be accounted for by changes in areas planted.

The adjustment decision for phosphate application is simplified by the generally large reserves that have been built up by a long history of previous applications. Soils across southern Australia are particularly deficient in P. Efficiency of P-based fertiliser is low because most is rapidly immobilised at a time of high demand, and then only partly released to subsequent crops. Whether P reserves are sufficient to achieve a target yield will often require a soil test. The recommendation on where to use the product for maximum benefits states: "For soils low to medium in available phosphate use JumpStart with the lower recommended P fertiliser rate from soil test results. If you do not soil test, use with your normal P fertiliser rate." (Novozymes Biologicals Australia 2009).

From label information (Novozymes Biologicals Australia, 2009) JumpStart is marketed as suitable for use mainly on wheat, barley, canola and sorghum. TagTeam formulations are for the legumes, particularly field pea, lentil, faba bean, vetch, chickpea and lupin. There is scope for more frequent inoculation of legume crops. *Rhizobia* are under-utilised because there is a widespread belief that inoculants only need to be used on legume crops every few years. In recent years there have been granular formulations developed as alternatives to traditional slurries and with potential advantages for example for dry sowing. Yield benefits of $50/ha have been reported for *rhizobia* inoculants in situations where there had been recent legume crops (Meibusch, 2008). The *rhizobia* market is competitive so a dual benefit product such as TagTeam could expand the market and expand market share. But as JumpStart is targeted at cereals, it has a much larger potential market. Apart from trials on TagTeam, the research on *rhizobia* was not part of the Soil Biology cluster so that will need to be taken into account in the attribution of benefits.

The *rhizobia* market in particular is likely to expand as new dual action products are developed (Pulse Australia 2009). The first of a new generation of inoculants to be released by Becker Underwood in Australia contain *rhizobia* and a patented *Bacillus subtilis* strain (MBI600) with a role as a recognised plant growth promotant.

The target area and rate of adoption

A target area broadly defined as concentrated in the GRDC Southern Region is the likely location, at least initially of adoption resulting from the project. Areas of sorghum in the GRDC Northern Region are also likely. Most of the research and the trials on these naturally occurring fungal inoculants has been or is currently being undertaken in the Southern Region. The specific paddocks and areas adopting will vary from year to year, for example depending on nutrient status as determined by the season or the crop rotation being followed.

Canadian experience provides the only analogy as a basis for speculation on what might be achievable in southern Australia in terms of target area and rate of adoption. Several factors as discussed generally in Table 13, and particularly the likely profitability as discussed in the next section, will determine the rate of adoption. After about a decade there was 1.86m ha of cropping land treated with

Philom Bios inoculants such as JumpStart (Cross 1999). Canadian grain production is about 50 percent greater than the Australian total and includes a larger component of legume crops. The Philom Bios product TagTeam combines an inoculant for *rhizobia* with a phosphate solubiliser.

Farmers will want to know, or be able to easily establish for their situation, the likely response and the risks involved. Extensive trials can provide approximate answers to broad questions on average responses across sites and seasons, and taking into account soil, plant and management variables. Consistency and level of performance at paddock level can then be readily determined by farmer trials. In Canada as reported by Gleddie (2003) 400 controlled farmer-applied split-field trials showed that inoculation with a phosphate solubiliser increased average grain yields by 7.6 percent (95% confidence limit 1.2%). The trials demonstrate a broad degree of consistency in average response across sites and seasons, but, not unexpectedly, high variability for individual trials. Farmers would generally accept that split level trials cannot be expected to give a good indication of what is likely at farm or paddock scale and small scale testing is appropriate.

Given the limited information available on areas likely to be suitable for application of the JumpStart and TagTeam inoculants, a conservative estimate is made of a target area of one million ha. The Canadian rate of adoption data suggest that an area of one m ha could be achieved in a decade, as yield responses appear similar in Australia. The area proposed for Australia is only of the order of 5 percent of the area of crops on which responses appear possible. Clearly the target area is not a constraint. The rate of adoption as defined by experience with the products is likely to be the most critical factor initially. Views on the prospects for the rate of adoption have been sought from those listed in the Acknowledgments Section. More experience will need to accumulate before more confident assumptions can be made.

Farmer surveys (GRDC 2008) demonstrate that about 60 percent of farmers undertake nutrient budgeting and are therefore likely to investigate new approaches, such as new inoculants, to managing nutrients. However adoption is likely to proceed slowly until farmers see more examples of economic responses and an acceptable degree of consistency. Farmers and advisers can be expected to be conservative initially. They could be expected to prefer to trial new products on a small scale, or simply to wait until reliability is demonstrated (Wilhelm 2009). Adoption is assumed to begin in 2010-2011. The involvement of GRDC in the joint venture will also be a factor. GRDC has the capacity through a wide range of communication avenues to deliver targeted and credible information on where inoculants are likely to be of most value.

Increased yields and benefits/ha

As in Canada, there have been extensive trials in recent years across major Australian grain regions to better understand responses to the inoculants and to enable farmers to adopt the use of inoculants with confidence. A six percent yield increase for peas and five percent for wheat were two Australian results reported from 69 recent split-plot and replicated trials (Velthuis 2009).

Six split-paddock wheat trials using farmer equipment indicated an increased profit (excluding cost of the inoculant) of more than $40/ha with about equal contributions from increased yield and from reduced P fertiliser. A more conservative assumption is justified in extrapolating to make a benefit assumption that will apply generally and over a longer period. Allowing for the cost of the inoculant (probably of the order of $5-10/ha) and some increase in soil tests at a similar cost to the inoculant, an increased average farmer profit of $15/ha will be assumed.

Probability of Success
Given the inoculants are either being or about to be, marketed, the current investments in product development can be assumed to be successful.

Attribution and Post-project Investment
Given that the specific products and the likely market shares attributable to *rhizobia* products are yet to be finalised, it is assumed that 50 percent of the total benefits can be attributed to the Soil Biology Cluster. The attribution factor also takes into account other funds such as the grant of $897,700 from the Commercial Ready Program (Innovation Australia 2008). These funds, estimated at $400,000 pa from 2006/07 to 2013/14 are included in the post-project investment in the Summary Table (Table 12).

7.2 Disease Control (including by inoculants),

The group of projects includes three from Theme 2 on root diseases and one project from Theme 1, which is developing an inoculant for disease control. Further details of potential benefits follows.

The suppressive soils project (DAS00027) has provided the platform for further research on r*hizoctonia* as well as potential bio-control agents. The project also demonstrated that it may be possible to use crop and cultivar selection to suppress disease.

The maize disease project (CSO00032) has identified microbial strains with bio-control efficiency and potential for root disease management strategies based on integrating more effective fungicide applications and strategic crop rotations. However maize production has been severely curtailed by reduced water allocations in the traditional irrigated maize areas in southern Australia. The reduced area of crop has also reduced disease pressure because the crop is now much less likely to be grown on the same land as a previous maize crop (personal communication Kieran O'Keefe, 2009)

The Pythium project (CSO00016) has made major contributions to a new understanding of how widespread Pythium is and to its incidence. The project has advanced potential management strategies to achieve a degree of control. A range of further research and development activities are needed to more effectively integrate fungicides, bio-control strains and diversified rotations (Harvey and Lawrence 2008).

The project UFO0002 (in Theme 1) on actinomycete endophytes has undertaken extensive research on an inoculant to control r*hizoctonia* and other diseases. The potential target area is extensive. Indicated crops include wheat and barley in the Southern and Western Regions that are subject to r*hizoctonia*, Take all, Crown rot and Pythium disease and in Northern Region crops subject to Crown rot. The project included a wide range of field trials which provided an initial basis for estimating potential benefits.

The three disease control projects above were much broader and exploratory in their focus, and not as advanced in terms of trials to demonstrate potential benefits as was UFO0002. Their benefits are more speculative than those possible from the

UFO0002 project targeting r*hizoctonia*. However even for that project, there are a number of risk factors to be overcome before a product can be delivered to a commercial market with confidence. In Canada there was a lag of the order of a decade between isolation of the active ingredient and the launch of the first commercial phosphate inoculant. Manufacture of the inoculant needed to be scaled up together with development of shelf-stable formulations, packaging and market research. The inoculant because of its disease control properties will need to proceed through a product registration process against comprehensive criteria that include safety to users, other people and the environment, residues in food, trade impacts, effectiveness and safety to treated plants.

Losses from *rhizoctonia* include typical losses of 5 to 15 percent but with some much higher (Sandow, 2007). Incidence is often sporadic, and higher in lower rainfall areas across southern Australia and Western Australia. Cultivation was a traditional control measure so the incidence of no-till has been a factor increasing the incidence of *rhizoctonia*. However there is evidence of *rhizoctonia* suppression after several years of intensive conservation cropping. Over the three years to 2007, 14 percent of soil samples submitted to Bayer CropScience for a PreDicta B™ test had a high risk of *rhizoctonia* (McKay 2007). The Syngenta product Dividend is currently used for *rhizoctonia* control and for other purposes. It is understood to be used over one to two million hectares.

The target area and rate of adoption
The overall estimates of benefits for the disease group of projects will give greatest weight to the *rhizoctonia* benefit given the data is less speculative than for the other three projects. The target area assumed, based on the limited information available is for an area of a half million ha. A period of a decade is assumed for the target area to be reached from when adoption begins in 2014/15.

Yield Increase and Benefits/ha
The inoculant being developed for r*hizoctonia* has achieved yield increases of the order of 10 percent in extensive trials across southern Australia. In addition there have been plant growth promotion benefits resulting in the potential for a yield increase in situations where the disease does not eventuate. A 10 percent yield increase is equivalent to increased gross income of the order of $40/ha (2 t/ha at $200/t). A more conservative net benefit estimate of $10/ha will be assumed discounting trial results for more extensive application and allowing for the cost of the inoculant and some soil testing.

The inoculant is a seed dressing so an inexpensive soil test now often used routinely pre-sowing would often be necessary to determine if the disease is present. The disease is not apparent in the crop until a few weeks after crop emergence. The target area is likely to be much smaller than the total cropped area because of the nature of incidence of the disease, and because it is likely that a bio-control inoculant for *rhizoctonia* would be used in an integrated control program incorporating a wide range of agronomic methods.

Probability of Success
Given the likely time and route to market for the inoculant in particular, a probability of success of 50 percent is assumed for the Disease Control Group.

Attribution and Post-project Investment
Further trials and development costs are being incurred to develop products and practices. These are estimated to be $500,000 pa from 2007/08 to 2012/13. Given that the additional investments required to take the products and practices to market have been costed, attribution is 100 percent.

7.3 Nutrient Balance

The projects in Theme 3 (Organic Matter and Nutrition) were essentially discovery projects exploring the potential to better manage C, N and P cycles and budgets by improved understanding of the various storage fractions and processes involved. The projects apart from CSP245 were in the GRDC Southern Region.

CSP245 was an existing project brought in to the Soil Biology Program to better define whether tillage could still be used occasionally in an essentially no-till system. The research would have given farmers confidence that a cultivation for example for weed or disease control was not deleterious. The project showed that after seven seasons of cropping there were no significant differences between microbial functions and grain yield between conventionally cultivated (1 pass) and no-tillage treatments. The Project Proposal in 1997 included an ex ante Benefit/Cost Analysis that was based on the value of additional information in refining N decisions. The extra value of $1/ha/pa was assumed to apply to the estimate of 40 percent of the cropped area under no-till in 2002. The project was extended to 2005 by which time the area under no-till had almost reached 90 percent (Llewellyn et al 2008). Some part of the benefits in the long term from adoption of no-till could be attributed to CSP245 but this has not been attempted.

The Nitrogen project CSO00030 has already given rise to further investments including by GRDC to develop improved approaches to defining N requirements. YieldProphet is the likely vehicle. Based on the CSIRO simulation model, APSIM, it was developed by the Birchip Cropping Group in collaboration with CSIRO. Its role was initially as a risk management tool for dryland farming systems in the Victorian Wimmera and Mallee, with an emphasis on decision support for nitrogen fertiliser inputs. Current subscriber numbers are of the order of 400 including 50 consultants (Hochman, personal communication, 2009). The area directly influenced is likely to be at least of the order of 500,000 ha. As noted by Thomas (2009) experience has been that decision support tools have not achieved high rates of adoption. But YieldProphet exemplifies the potential for influence by other more diffuse measures, for example from the number of consultants involved and from the way in which models consolidate understanding. The analysis by Hochman et al (in press) of the performance of YieldProphet subscribers in southern Australia will provide a more effective knowledge base for the large number of research initiatives aimed at improving water use efficiency.

The target area, rate of adoption and benefit/ha
Given that the area being managed by subscribers to YieldProphet continues to expand, the CSO00030 project can add value particularly across southern Australia. Adoption of the added value could be assumed to begin by 2014/15 and reach 500,000 ha by 2025. An evaluation by Agtrans et al (2007) based benefits for the current YieldProphet on an estimate of $10/ha. Hochman et al (in press) have shown their remains scope to improve YieldProphet and for farmers to improve profitability. Simulations maintaining N at non-limiting levels increased yields by 10

percent, or of the order of $40-50/ha. For this evaluation based on the scope available, it will be assumed that improved N information can increase profit by a further $10/ha.

Probability of Success
Given that the further investments required have begun the probability is set at 100 percent.

Attribution and Post-project Investment
Estimates of the additional investments required to develop enhancements to YieldProphet are estimated at $400,000 pa from 2007/08 to 2013/14. Taking into account that although the investment to enhance YieldProphet has been costed, delivery will be through YieldProphet, attribution is assumed to be 50 percent.

7.4 Other Assumptions

Benefits not Valued
The principal benefits identified but not valued in the analysis include environmental and capacity building benefits.

The counterfactual or the "Without GRDC investment" scenario
The benefits being evaluated are those resulting from the GRDC investment in the Soil Biology Program measured against a base line of what the benefits would have been if GRDC had not invested. The Program was a new initiative in 2002 of the GRDC Board and was the catalyst for expanded research by several Rural R&D Corporations and for the collaborative "Healthy Soils for Sustainable Farms" involving several Rural R&D Corporations. In addition the Program was followed by the formation in 2006 of the GRDC joint venture to commercialise inoculants from the Program. It is unlikely that the joint venture, now Novozymes Biologicals Australia would have eventuated without a substantial research program to build on. The two examples indicate that there would only have been, at least initially, minor activity in soil biology without the program.

There were two related issues that would have promoted the level of activity in soil biology developed more momentum during the last five years. The issues were:
- the eventual and wider recognition that climate change was beginning to have increasing impacts globally, and
- increased energy costs leading to exceptional increases in fertiliser prices.

Expanded research on soil biology was then seen as having a crucial role in developing more sustainable farming systems. However priorities would most likely have shifted to increased understanding of Soil Organic Matter and carbon cycling.

In summary taking into account, the above factors, the benefits for the "Without GRDC investment" are assumed to contribute one third the value of benefits with the GRDC investment and lagged by five years.

7.5 Summary of Assumptions

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

Table 14: Summary of Assumptions

Variable	Assumptions (financial years)	Source*
Benefits from Soil Biology Cluster –		
Inoculants – Maximum adoption in target areas	1 m ha	See text –in southern Australia and some in the GRDC Northern Region.
Benefit/ha	$15	Conservative estimate based on over $40/ha for 6 wheat trials (Velthuis 2009).
Probability of Success Attribution proportion	• 1.0 • 50%	• Based on high proportion of research completed. • 50% attributed to research outside the Soil Biology Cluster
Adoption profile	10% increase from 2011 up to maximum	See text – a typical rate also based on Canadian experience with JumpStart and TagTeam.
Post-project investment	$0.4m pa from 2007 to 2014	Includes allowance for extensive field trials, and grants for example $897,700 from Innovation Australia (2008).
Diseases – Maximum adoption in target areas	0.5 m ha	Conservative estimate weighted to area of r*hizoctonia*
Benefit/ha	$10	Conservative estimate based on 10% yield increase in extensive trials.
Probability of Success Attribution proportion	• 0.5 • 100 %	• Based on risk in the development to be done, including product registration, • Most R&D has been costed.
Adoption profile	10% increase from 2015 up to maximum	A typical rate for similar products and practices.
Post-project investment	$0.5m pa from 2008 to 2013	Includes allowance to achieve product registration and further field trials for Pythium and maize strategies.
Nutrition – Maximum adoption in target areas	0.5 m ha	Based on experience with YieldProphet in southern Australia .
Benefit/ha	$10	Based on potential (Hochman et al ,in press)
Probability of Success Attribution proportion	• 1.0 • 50 %	• Based on proportion of research completed • Product delivery is dependent on investment outside Soil Biology Cluster.
Adoption profile	10% increase from 2015 up to maximum	Based on experience with YieldProphet.
Post-project investment	$0.4m pa from 2008 to 2014	Includes a current project plus further development.
Scenario Without GRDC investment		
Benefits	One third of total benefits with the investment	Recognises that the Soil Biology Program was a major catalyst.
Adoption profile	Benefits lagged by 5 years	The research effort would have been delayed and fragmented.

* Assumptions are by the author unless stated

7.6 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 a high level of uncertainty for some estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2008/09) to the final year of benefits assumed (2038/39). The costs are those for the projects in the Soil Biology Cluster. (The post-project costs totalling $9 million have been subtracted from benefits.)

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 positive (or other) as reported in Tables15 and 16.

Table 15: Investment Criteria for Total Investment and Total Benefits for Each Benefit Period -(discount rate 5%)

Criterion	**Period of Benefit (in Years from Last Investment in 2008/09)**					
	0	**5**	**10**	**20**	**25**	**30**
Present value of benefits (m$)	-2.07	-1.39	16.82	59.27	72.87	83.52
Present value of costs (m$)	20.62	20.62	20.62	20.62	20.62	20.62
Net present value (m$)	-22.69	-22.01	-3.80	38.65	52.25	62.90
Benefit cost ratio	-0.10	-0.07	0.82	2.87	3.53	4.05
Internal rate of return (%)	nc	nc	3.5	11.4	12.1	12.4

nc not calculable

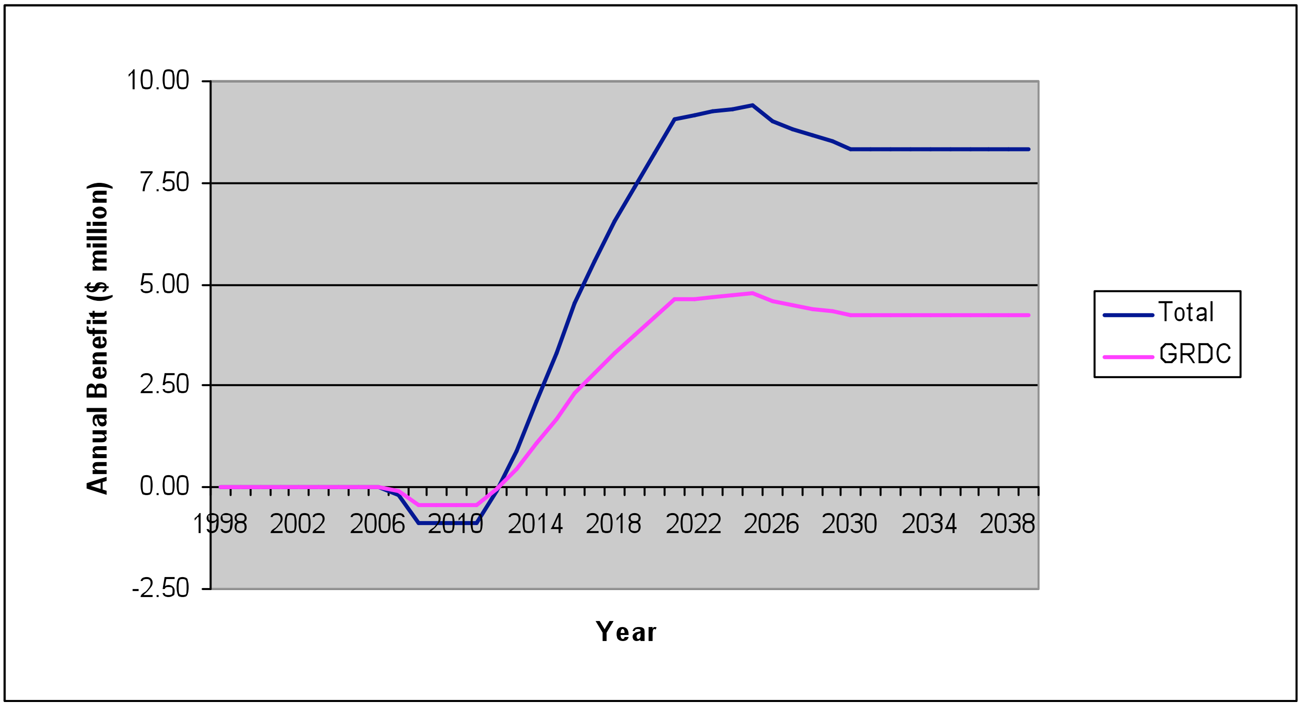
Table 16: Investment Criteria for GRDC Investment and Benefits to GRDC for Each Benefit Period - (discount rate 5%)

Criterion	**Period of Benefit (in Years from Last Investment in 2008/09)**					
	0	**5**	**10**	**20**	**25**	**30**
Present value of benefits (m$)	-1.05	-0.70	8.55	30.12	37.03	42.44
Present value of costs (m$)	10.48	10.48	10.48	10.48	10.48	10.48
Net present value (m$)	-11.53	-11.18	-1.93	19.64	26.55	31.96
Benefit cost ratio	-0.10	-0.07	0.82	2.87	3.53	4.05
Internal rate of return (%)	nc	nc	3.5	11.4	12.1	12.4

nc not calculable

The cash flow of benefits is shown in Figure 1 for both the total investment and for the GRDC investment in the cluster. The peak in the cash flow reflects the assumptions relating to the benefits assumed for the "Without GRDC investment" scenario rather than any decline assumed for the benefits with the project. The short period of negative benefits occurs as a result of the post-project investment and the lag from the end of the projects until benefits begin.

Figure 1: Annual Benefit Cash Flow



The contributions from the three sources of benefit as determined by the project groupings are presented in Table 17.

Table 17: Contribution of Source of Benefits to Present Value of Benefits

Project Group	% Contribution to Present Value of Benefits
Inoculants (nutrient increasing)	69
Disease Control (including by inoculants)	15
Nutrient Balance	16
Total	100

The quantified benefits are allocated to the Rural Research Priorities as expressed in Table 18.

Table 18: Allocation of Quantified Benefits to Rural Research Priorities

Rural Research Priority	Allocation (%)
1. Productivity and Adding Value	95
3. Natural Resource Management	5
Total	100

7.7 Sensitivity Analyses

Sensitivity analyses were carried out to show the importance of assumptions about which there is the most uncertainty. Results are reported in Tables 17. All sensitivity analyses were performed using a 5% discount rate with benefits taken over the life of the investment plus 30 years from the year of last investment. All other parameters were held at their base values.

The target area for the yield increasing inoculants in particular was the most speculative assumption. The target area assumed of one million ha is only of the order of five percent of the Australian area of crops. Experience might show that a much larger area was suitable. A larger target area would also be associated with a larger benefit/ha and a more rapid rate of adoption. Therefore the HIGH benefit scenario assumed a trebling of the benefits assumed for the BASE case. The assumption of trebling benefits is equivalent to a doubling of the area and an increase in benefits/ha of 50 percent. For the LOW case, benefits were assumed to be halved and lagged five years from the BASE case level. Lower benefits/ha would result in slower adoption.

Table 19 shows the investment criteria when the assumption regarding the levels and timing of benefits are varied.

Table19: Sensitivity to Changes in Levels of Benefits
(GRDC investment, 5% discount rate, 30 years)

Criterion	Level of Benefits		
	LOW	BASE	HIGH
Present value of benefits (m$)	13.69	42.44	131.51
Present value of costs (m$)	10.48	10.48	10.48
Net present value (m$)	3.21	31.96	121.03
Benefit cost ratio	1.31	4.05	12.55
Internal Rate of Return (%)	6.1	12.4	20.3

These sensitivity results show for plausible assumptions of benefits that because there is a considerable degree of uncertainty about some of the key assumptions, a wide range of rates of return are possible. If the benefits are trebled then the benefit cost ratio would be of the order of 12.5 to 1. On the other hand if the benefits are reduced and adoption is slower, the project does little better than break even.

8 Confidence Rating

As shown in the previous section, the results produced are highly dependent on the assumptions made, many of which are uncertain. There are two factors that warrant specific 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 assumptions of Table 14 which determine the results of the investment analysis (Table 15 and 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; and
- Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 20: Confidence in the Analysis of the Investment in the Soil Biology Cluster

Coverage of Benefits	**Confidence in Assumptions**
Medium	Medium

9 Conclusions and Lessons Learned

When GRDC took the initiative to fund the first major national program in soil biology in 2002, soil biology was seen as a relatively neglected focus for research. The risks associated with investing in a new research area were undoubtedly compounded by vesting the program with a strategic focus. The GRDC Soil Biology Program was a catalyst for other Rural R&D Corporations to invest in soil biology and generate a more coherent national approach.

The results of this evaluation of the likely impacts typifies the high risk/ high return nature of much strategic research. The GRDC investment in the cluster to be evaluated totalled $8.1 million. Partner organisations, which were mostly from a centre of concentration in soil biology research in Adelaide, contributed $8.5 million. Given the strategic nature of the research, an allowance of a further $9 million was made for further research and development after the projects were completed.

The economic benefits quantified were from estimates of increased profits mainly from increased yields. Most of the benefits were attributed to the two inoculants TagTeam and JumpStart being marketed in 2009 and 2010 respectively. Some environmental benefits are likely from reduced use of fertilisers and fungicides. As a consequence, there will be reduced export of fertilisers and fungicides to groundwater and to waterways. Because inoculants would only be applied to a small proportion of land in a catchment, the impact at catchment level would be minor. In terms of environmental life cycle analysis, the use of inoculants will make small contributions to more sustainable grain production through for example savings in fertiliser manufacture and transport and through extending the life of phosphate reserves. The major social benefit identified was the catalyst role the Soil Biology program had in encouraging a more concerted national effort and building capacity in what had been a relatively neglected field.

The economic evaluation based on judgements of the possible levels of adoption and benefits indicated a net present value of $32 million and a benefit/cost ratio of the order of 4. The time lag from the start of the Soil Biology Program to the break-even point is of the order of 20 years. Sensitivity analyses aiming to capture the possible range of adoption and benefits indicated a range from break-even to a net present value of $120 million.

The majority of the benefits quantified were from inoculants being developed by the GRDC joint venture which now operates as Novozymes Biologicals Australia. The first products from the joint venture are now being marketed following extensive trials to determine their adaptation. The products are being launched in competitive commercial markets so much of the potential market intelligence information is therefore confidential. Estimates for this evaluation were based on judgements on what published information was available together with experience from similar campaigns in Canada.

The joint venture to develop and market inoculants was in many respects a new commercial approach by GRDC so there is an opportunity to consider what lessons can be learned. When the program was launched in 2002, there was early recognition of the need for testing new approaches such as granular formulations for delivering inoculants. Many field trials were done to determine which crops and soil types were likely to show yield responses. One of the problems with the early trials was the concern that lack of a robust and proven formulation to carry the inoculants might have mitigated against yield responses. Greater priority to researching the delivery of inoculants may have sped up the process. There was also scope much earlier in the program to undertake parallel investigation of possible commercial structures to minimise delays in products reaching the market (Personal communication, John Thorne, 2009).

Other learnings from the program related to delays in testing and developing inoculants (Personal communication, Sanford Gleddie, 2009). There were substantial delays resulting from changes in biosecurity processes, but to some extent they were not foreseeable or avoidable. In addition and in comparison with Canada, the extent of testing required to develop confident recommendations covering the diversity of crops, soil types and seasons was underestimated. Inherent variability of the response and the severity of major droughts during the last decade were factors.

A simple sensitivity analysis will suffice to show how important time to market is in evaluation. As shown in Section 6, it is likely that the time to market was of the order of two years longer than forecast. If the evaluation assumed all benefits were brought forward two years, net benefits in present value terms would have increased by $6 million, or about one-sixth. Clearly any small investments such as ensuring trial sites had some irrigation capacity would have been profitable.

The strategic and risky nature of the projects in the cluster does increase the uncertainty involved in an economic evaluation. Assessments of the likely economic returns from strategic programs would clearly need to take that into account. A traditional approach to risk is diversification. The potential contribution of a new research focus could be demonstrated with less uncertainty if it included a greater mix of projects. The cluster of projects that was the subject of this evaluation were less diverse than the overall Soil Biology Program which included more applied projects and a highly successful collaboration through the "Healthy Soils for Sustainable Farms" collaboration.

Constraints on the availability of data on efficacy of the inoculants have contributed to the degree of uncertainty on the potential applicability of the inoculants being developed. Adoption of the inoculants by farmers will also be constrained until experience accumulates on the situations where inoculants can be used with confidence to generate a consistent economic response. However the potential is there for the phosphate-solubilising inoculants in particular to contribute to a more profitable and sustainable agriculture.

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Project Leaders and Researchers of the 14 Projects in the Soil Biology Cluster

(As listed in Table 2).

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