

An Impact Assessment of CRDC Nutrition Investments 2008-2016

**Final Report to Cotton Research and
Development Corporation**

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Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACRI	Australian Cotton Research Institute
AVG	Aminoethoxyvinylglycine
BCR	Benefit-cost ratio
C	Carbon
CO ₂	Carbon dioxide
CBA	Cost-benefit analysis/analyses
CH ₄	Methane
CRC	Cooperative research centre
CRDC	Cotton Research and Development Corporation
CRRDC	Council of Rural Research and Development Corporations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GHG	Greenhouse gas/es
GRDC	Grains Research and Development Corporation
ha	Hectare
IPL	Incitec Pivot Ltd
IRR	Internal rate of return
K	Potassium
Kg	Kilogram
MIRR	Modified internal rate of return
MVCGA	Macintyre Valley Cotton Growers' Association
N	Nitrogen
N ₂ O	Nitrous oxide
NPV	Net present value
NUE	Nitrogen use efficiency
P	Phosphorus
PVB	Present value of benefits
PVC	Present value of costs
R&D	Research and development
RD&E	Research, development and extension
RDC	Research and Development Corporation ¹
S	Sulphur
WUE	Water use efficiency

¹ Note that this report uses the term RDC to include not only the six Research and Development Corporations but also the nine rural industry owned companies that receive matching dollar support from the Commonwealth Government.

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Executive Summary

The Report

This report presents the results of an impact assessment of a cluster of nine nutrition research projects funded by the CRDC over the years 2008-2016. In addition to CRDC funding (a combination of statutory levies paid by industry participants and matching Commonwealth funding), other resources were provided by research organisation contributions.

Methods

The nine individual projects were first analysed qualitatively within a logical framework that considered project rationale, objectives, activities/outputs, outcomes, and impacts. Several of the impacts were then valued. Benefits were calculated for a range of time frames up to 30 years from the year of last investment. Past and future cash flows in 2015/16 \$ terms were discounted to the year 2015/16 using a discount rate of 5% to estimate investment criteria.

Impacts

Most of the impacts identified were economic in nature, however some social and environmental impacts also were identified. Some of the cluster impacts were valued; the decision not to value certain impacts was due either to a high degree of uncertainty surrounding potential impacts, a shortage of necessary data, or the likely low relative significance of the benefit compared to those that were valued. It is expected the Australian cotton growing industry will be the primary beneficiary of the investment however significant benefits to the domestic grains industry were also identified.

Investment Criteria

Total funding from all sources for all nine projects totalled \$11.32 million (present value terms). The benefits from the impacts valued were estimated at \$61.15 million (present value terms). When total benefits were compared against total costs this produced a net present value of \$49.83 million, and a benefit-cost ratio of 5.4 to 1. This estimate is a lower-bound estimate for return on investment since not all projects in the cluster had benefits that were valued.

1. Introduction

Background to Impact Assessment

The primary purpose of impact assessments of CRDC investments is to assist with portfolio management and provide accountability to the CRDC Board, its levy paying industries and the Australian Government. The results of the impact assessments can also be used as inputs into the development and/or assessments of further research investments.

A further purpose of the CRDC impact assessments is to contribute to a process being undertaken for the Council of Rural Research & Development Corporations (CRRDC). This process aims to demonstrate the impacts and benefits that have emerged or are likely to emerge from the 15 Rural Research and Development Corporations (RDCs) including producer-owned companies. Valuation of these impacts, along with identification of investment expenditure, is required to demonstrate the RDCs' contribution to Australian rural industry as well as environmental and social impacts to Australia.

The Importance of Cotton Nutrition Research

Nutrition is a critical component for profitable agricultural production. Australian cotton producers are heavily reliant on fertiliser inputs to provide crop nutrition, and this typically represents a substantial proportion of overall input costs. Rates, timings, and application methods all need to be optimised, while plant and soil testing methods need to provide information capable of enabling adjustment of these variables under different circumstances. Ongoing nutrition research is required to capitalise on new technologies, adjust current practices to new cultivars and farming systems, and address long-standing knowledge gaps.

In addition to these economic aspects, crop nutrition also has environmental implications in areas including greenhouse gas emissions and water quality.

While the projects in this cluster focused on a wide range of issues, there were two issues of prominence that were addressed. The first was that of nitrogen use efficiency, as growers were applying increasing volumes of nitrogen (N) fertiliser, either due to decreasing NUE or as 'insurance' for achieving high yields. The second was that of ongoing depletion of soil reserves of key nutrients, particularly phosphorus (P) and potassium (K).

2. Methods

The evaluation approach follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including RDCs, Cooperative Research Centres (CRCs) and some Universities. The impact assessment uses Cost-Benefit Analysis (CBA). This entails both qualitative and quantitative approaches. The methods used are in accord with the evaluation guidelines of the Council of Rural Research & Development Corporations (CRRDC, 2014).

The Evaluation Approach

The evaluation approach was to identify and briefly describe objectives, outputs, outcomes, and impacts for each project investment. The individual project outcomes and impacts were then integrated and described at the cluster level. The principal economic, environmental and social impacts across all projects were then summarised in a triple bottom line table.

Some, but not all, of these impacts were then valued in monetary terms. Based on the extent of impact associated with each project in the above process, selected projects were chosen for valuation of their individual impact or their contribution to an aggregated impact. This resulted in valuation of benefits from a total of six projects from the population and these are deemed to represent the principal benefits derived from the investment in the cluster.

This allowed two key sets of aggregate investment criteria to be produced:

- The costs and benefits for the six projects were aggregated to form a set of investment criteria for this subset of projects. The results represent an upper limit for the Program's economic impact when the benefits are compared with only the costs of those six projects.
- The benefits for the six projects were aggregated and compared with the costs of the nine projects in the population, to provide a lower limit for the cluster's investment criteria.

3. Description of Projects

Table 1 provides a list of the project codes and titles of all nine projects defined in the population of the nutrition cluster.

Table 1: Projects Included in the Nutrition Cluster

Project ID	Project Name
CGA1405	Understanding Soils and Plant Nutrition for Cotton Growers
CRC139	Nutrient Redistribution Within Cotton Plants
CRC1115	Developing N-efficient Cotton Systems that Produce Low GHG Emissions and Promote Healthy Soil
CRC1117	Understanding Greenhouse Gas Emission from Broadacre Irrigated Cropping Systems
DAQ1001	Defining Critical Soil Nutrient Concentrations in Soil Supporting Irrigated Cotton and Grains in Northern NSW and Queensland
FTRG1601	Identifying Practical Solutions to Optimising Nitrogen Use Efficiency (NUE) and Water Use Efficiency (WUE) in Cotton Production
UNE1501	Phosphorus Availability in Raingrown Cotton
UQ1302	Developing Soil Testing and Fertiliser Response Guidelines to Manage P, K and S Fertility for Irrigated and Dryland Cotton Cropping Systems
US1301	The Physiology of Cotton Crop Nutrition, Shade and Waterlogging

A full description of each of the nine projects is presented in Table 2. The projects are summarised in a logical framework format (objectives, activities and outputs, outcomes and impacts).

Table 2: Project Descriptions

CGA1405: Understanding Soils and Plant Nutrition for Cotton Growers	
Project Details	Research Organisation: Macintyre Valley Cotton Growers' Association Period: November 2013 – June 2014 Principal Investigator: Nigel Corish
Rationale	<p>The Macintyre Valley Cotton Growers Association (MVCGA) had identified soil and crop nutrition as key areas for business improvement. Based on this observation, a focus group was established with the objective of increasing yields and increasing fertiliser use efficiencies among growers.</p> <p>In meetings with CRDC this focus group identified various issues surrounding crop nutrition. It had been observed that many growers were basing nutrient application decisions on the previous year's crop, rather than empirical soil test data. A number of gaps were identified in grower knowledge of fertiliser levels, types and application methods. Growers were heavily reliant on consultants to determine fertiliser usage rates.</p> <p>Grass-roots educational activities offered a cost-effective means of improving grower knowledge and addressing these issues. This project was therefore undertaken with the intent of providing education and training on nutrition management directly to MVCGA growers.</p>

Objective	1. To better educate MVCGA members about soil nutrition by providing nutrition training courses.
Activities & Outputs	<ul style="list-style-type: none"> • Agricultural consulting firm, the Back Paddock Company, was contracted to provide a training courses for members of the MVCGA. This consisted of one cotton nutrition workshop attended by 14 growers, and two workshops focussing specifically on nitrogen and attended by 30 growers. • Training covered the key factors influencing growth and production of high yielding cotton, namely soil, water and climate. There was a focus on the impact of soil properties and plant nutrition, and best practice principles to manage these factors for sustainable production. • Soil testing was another aspect covered, with growers learning to better interpret soil tests to identify available nutrients and associated fertiliser requirements. • The course highlighted the influence of local growing conditions, including day degree accumulation (cumulative temperature throughout the growing season), on fertiliser demand. It was explained that less fertiliser is required in seasons where cumulative day degrees are not high enough to achieve high yields. • Advice on nitrogen management was provided, covering four key aspects – rate, timing, placement, and type of fertiliser. • The course highlighted areas of concern around nitrogen loss including volatilisation, leaching and denitrification. The point was made that combined nitrogen losses could reach 40% if fertiliser was not applied correctly. • A nitrogen trial was conducted in collaboration between the Principal Investigator and the CRDC CottonInfo team. Results were presented at the end of season review and formed part of the CottonInfo nitrogen trial results for the 2014/15 season. • Response to the workshops was positive, with attendees commenting that workshops had changed their thinking regarding fertiliser decisions.
Outcomes	<ul style="list-style-type: none"> • Growers who attended the workshop will be better equipped to make fertiliser decisions, with less dependence upon external guidance. Areas of likely improvement included interpretation of soil tests, identification of critical nutrient levels, and calculation of optimal fertiliser application rates. • Growers are now better able to communicate with research and advisory personnel due to better knowledge of soil nutrition. • Attendees expressed their desire for more workshops and information on soil nutrition. • The MVCGA plans to continue to build on the training initiative instigated through this project. • The project may have implications for growers outside the Macintyre Valley through extension conducted by the CottonInfo team.
Impacts	<ul style="list-style-type: none"> • Potentially increased grower profits due to increased fertiliser use efficiency. • Reduced emissions of the greenhouse gas nitrous oxide (N₂O), due to decreased N fertiliser usage • Potential reduction in off-farm impacts from nutrient (particularly nitrogen) losses. • Increased industry knowledge and capacity for future change.

CRC139: Nutrient redistribution within cotton plants	
Project Details	Research Organisation: University of Sydney Period: October 2007 – March 2012 Principal Investigator: PhD Student: Meredith Errington, Supervisor: Lindsay Campbell
Rationale	Boll filling is a critical stage of cotton growth with significant implications for yield. During this time demand for nutrients is greatest and nutrients from vegetative

	<p>structures are mobilised and redistributed around the cotton. Should nutrients not be redistributed to the bolls in sufficient quantities, fibre yield and quality may be restricted.</p> <p>While substantial research has been carried out on soil nutrient uptake for cotton plants, there was comparatively little knowledge available on the partitioning of nutrients between vegetative and reproductive structures within the plant. Better understanding of the nutrient distribution process, particularly under stressed conditions, would provide valuable input to the ongoing development of cotton fertiliser programs.</p> <p>Traditional soil fertiliser applications typically cannot meet increased nutrient demand from rapidly developing bolls, an issue likely to become more pronounced as the industry increases adoption of high-yielding varieties.</p> <p>As a scholarship grant, this project was funded with the dual purposes of enhancing scientific understanding of cotton nutrient distribution, and supporting the PhD postgraduate study of the applicant.</p>
Objectives	<p>The project sought to test the following hypotheses:</p> <ol style="list-style-type: none"> 1. That effective translocation of nutrients (largely nitrogen, potassium, phosphorus and zinc) is essential for high cotton yields. 2. That nutrient uptake is not limited by root uptake but driven by fruit load and nutrient redistribution is driven by internal physiological mechanisms. 3. That supplemental nutrients applied at critical development stages by either soil or foliar fertilisation increases nutrient uptake and promotes higher yields. 4. That nutrient uptake and redistribution is more efficient in high fruit retention crops.
Activities & Outputs	<ul style="list-style-type: none"> • Glasshouse and field experimentation was conducted involving both conventional cultivars and high yielding Bollgard® cotton, grown under luxurious or stressed nutrient conditions. Focus was on the nutrients Nitrogen (N), Potassium (K), Phosphorus (P) and Zinc. • The redistribution of N, P and K from vegetative to reproductive tissues was examined and quantified at three levels: from a single leaf, from leaves in five node segments up the mainstem, and from pooled tissues of various ages from a whole plant. • A large variability in redistribution of N, P and K from vegetative to reproductive plant organs was observed, both at the level of the individual plant and across different experimental conditions. • The relationship between nutrient and water supply and nutrient redistribution was assessed in experiments providing different rates of fertiliser and irrigation. Water stress significantly reduced N, P and K distributions, while addition of P and K fertilisers decreased redistribution of those nutrients. • A positive correlation was observed between redistribution and the ratio of reproductive to vegetative tissue for N, however this was not the case for P or K. • Nutrient distribution was shown to be influenced by a wide range of agronomic, environmental and seasonal factors. • No correlation was observed between redistribution and boll size or yield. This lack of relationship was considered an indication that management, nutrient or water stresses may have more impact on redistribution than crop boll load. • Findings contradict the widely-held hypothesis that a high boll load or a large ratio of reproductive to vegetative structures places excessive demands on nutrient resources. The lack of relationship indicates that management stresses, nutrient supply to the roots, or excess water supply may have more impact on the redistribution process than the boll load of the crop.

	<ul style="list-style-type: none"> • Evidence assessed throughout the project suggested that N, P and K redistribution is not primarily a sink-driven process, i.e. is not driven primarily by boll demand. It was concluded that redistribution is a supplementary process for supplying developing bolls, secondary to root uptake. • A novel method for calculation of redistribution at a whole of plant scale was developed. • Findings were used to suggest a benchmark against which to class cotton crops as efficient or inefficient users of N and K in terms of redistributions. • The PhD student conducted the project successfully and completed the doctoral thesis. • A number of questions arising from the research were identified as opportunities for further research.
Outcomes	<ul style="list-style-type: none"> • Understanding of the causes, processes, and implications of nutrient redistribution in cotton crops has been advanced. • The data contribute to the understanding of how high-yielding cotton crops use N, P and K and how this understanding can be used to predict and explain the nutrient requirements of cotton plants. • Greater understanding of the physiological basis for variation in nutrient use-efficiency enables identification of why crops are sensitive to variations in nutrient supply under certain conditions, and contributes to understanding of how to increase nutrient use efficiency. • Further research is needed before a definitive set of conditions likely to promote root uptake and redistribution of N through the boll filling period can be identified. • If project findings could be used to enhance nutrient application timings, rates or methods then nutrient use efficiency could be increased. • The scholarship recipient is now employed by Monsanto Company in the Technology Development Team as a Cotton Agronomic and Trials specialist (Monsanto, 2016). • As of 2016 there has not been further research work in this area, primarily due to lack of available funding (Lindsay Campbell, pers. comm., 2016).
Impacts	<ul style="list-style-type: none"> • Increased scientific knowledge and industry research capacity. • Potential for increased grower profit in future due to manipulation of nutrient use-efficiency. • Increased nutrient use-efficiency may lead to decreased GHG emissions.

CRC1115: Developing N-efficient Cotton Systems that Produce Low GHG Emissions and Promote Healthy Soil	
Project Details	<p>Research Organisation: CSIRO</p> <p>Period: July 2010 – June 2013</p> <p>Principal Investigator: Ian Rochester</p>
Rationale	<p>Previous research undertaken within the long-term cropping systems experiment at the Australian Cotton Research Institute (ACRI) had provided preliminary insights into means of improving yields by raising soil health. Areas for improvement included increasing soil carbon levels, improving soil physical parameters and nutrient use-efficiencies, and enhancing biological processes within the soil profile. This work had also indicated the potential for innovative legume-based cropping systems to raise cotton yields and lower nitrogen (N) fertiliser requirements, while also reducing greenhouse gas (GHG) emissions.</p> <p>This project sought to explore some of these areas with a focus on improving soil health. Research was also planned to entail investigations of changes in soil organic</p>

	carbon levels, soil tilth, soil microbial biomass, crop nutrition and water use-efficiencies.
Objectives	<ol style="list-style-type: none"> 1. To develop management strategies to improve organic carbon (C) status of cotton soils. 2. To assess the impact of legume cropping systems on soil health. 3. To determine better strategies to improve crop nutrient use-efficiency. 4. To assess cropping system impact on soil health. 5. To improve precision of crop nutrition and soil fertility tools in Nutri LOGIC. 6. To link research to project CRC1117 on GHG emissions.
Activities & Outputs	<ul style="list-style-type: none"> • An ongoing ACRI cropping experiment was used to assess different options for management of stubble in cotton cropping systems. This involved observing changes in soil carbon levels, soil microbial biomass and water holding capacity. Findings were used to update results from the previous 15 years of experimentation. • Analyses revealed that incorporated stubble placement contributed to a substantially higher rate of C recovery than surface placement, while the type of stubble had no significant impact. • N fixation was found to be substantially higher with the use of vetch stubble over cotton stubble. • Legume crops were found to provide some organic N to later crops, as well as providing minor improvements in soil water holding capacity, encouragement of soil organic matter accumulation and facilitation of root exploration. • Soil health was shown to directly impact on crop production by providing a better environment for root exploration, nutrient uptake, and water storage and extraction. The incorporation of rotation crops was suggested as a more effective means of improving soil health than soil or crop management. • Experiments to assess changes in nutrient use efficiency were conducted by comparing current and redundant cotton cultivars. It was concluded that the use-efficiency of P and K increased with the release of improved cultivars while N and S efficiencies also tended to increase, albeit more slowly. • The data collected during the project were collated to more precisely indicate response to N fertiliser applications and indicate the quantities of N fertiliser required, after taking into account the rotation system, climate of the region, soil analysis value and the expected yield for the cotton crop, based on yields realised from previous crops in a specific field. • Information relating to soil fertility and cotton nutrition has been provided regularly to cotton growers and their consultants through phone conversations, field days, courses and industry publications. This project has assisted in two summer undergraduate projects (CSIRO-funded) and two post-graduate projects. • This project provided evidence to suggest that nutrient use efficiency may be a contributing factor to ongoing improvements in cotton yield.
Outcomes	<ul style="list-style-type: none"> • Data produced in this project was incorporated into a revision of the NutriLOGIC package released for the 2014/15 cotton seasons (Michael Bange, pers. comm., 2016). This enabled more precise estimates of N needed to optimise current production. • This project has demonstrated how cropping systems can use N fertiliser inputs more effectively. • By demonstrating the benefits of including legumes in rotation, reducing tillage operations and incorporating crop stubble, the likelihood of such practices being adopted has increased.
Impacts	<ul style="list-style-type: none"> • Potential increase in profits due to increased use of legumes in rotations, and improved management of fertiliser and stubble.

	<ul style="list-style-type: none"> • Potential reduction in GHG emissions due to improved understanding of crop stubble management. • Potential reduction in off-farm impacts from nutrient (particularly nitrogen) losses. • Increased industry and scientific capacity.
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CRC1117: Understanding greenhouse gas emission from broadacre irrigated cropping systems	
Project Details	<p>Research Organisation: CSIRO Period: July 2010 – June 2013 Principal Investigator: Ben Macdonald</p>
Rationale	<p>Emissions of greenhouse gases (GHGs), particularly CO₂, N₂O and CH₄ from agricultural production systems are a significant environmental concern. While emissions were being assessed in many dryland cropping systems, this was not occurring at a significant level in irrigated cotton systems. Some short-term research had been conducted; however, there was an absence of long-term measurements encompassing the complete rotation.</p> <p>Fertiliser use is a key factor influencing crop GHG emissions. Research indicated that the majority of Australian cotton crops were over-fertilised. While such a situation was potentially leading to high N₂O emissions, understanding of the causes and extent of the issue was limited.</p> <p>This project was therefore supported to further the understanding of GHG emissions from irrigated cotton crop production in order to assist in emission reduction. Work in this project was closely tied to CRC1115, which ran concurrently and had shared involvement from some project staff.</p>
Objectives	<ol style="list-style-type: none"> 1. To measure GHG emissions (N₂O, CH₄ and CO₂) in crops and fallows. 2. To improve knowledge of emissions from irrigated cropping systems. 3. To develop low emissions/carbon-neutral irrigated cropping systems.
Activities & Outputs	<ul style="list-style-type: none"> • GHG monitoring equipment was installed in an ongoing cropping system experiment established in 1994 at ACRI. This experiment contained a two- year irrigated cotton – faba bean – fallow rotation cycle. • The monitoring equipment enabled simultaneous measurement of CO₂, CH₄ and N₂O emissions. Environmental variables, including soil and air temperatures, soil water and nutrient levels were measured periodically to facilitate observation of their relationship with emissions. • Four N application rates were tested – 0, 120, 200 and 320 kg/ha. From these tests the following results were determined: <ul style="list-style-type: none"> ○ N₂O emissions were not significantly different for the first 3 rates; however, the 320 kg/ha rate caused emissions more than 8 times higher than for 200 kg/ha. The majority of N₂O emissions occurred during the cotton phase. ○ CO₂ emissions were less influenced by the application of N fertiliser. It was identified that the bulk of carbon dioxide losses occurred during the fallow period of the experimental rotation. This highlights a clear need to increase the amount of soil organic carbon in the soil to off-set the carbon losses. ○ There was no significant effect of N fertiliser on CH₄ emissions observed during any of the rotation phases. • It was suggested that N rates in excess of 180 kg/ha exceeded crop requirements in most scenarios, and the maximum N rate should not exceed 250 kg/ha if low emission cropping systems are to be developed. Where cotton is grown with optimum N application and stubble management, carbon production could be carbon positive.

	<ul style="list-style-type: none"> Extension activities were conducted including publishing of industry and journal articles, and conference presentations.
Outcomes	<ul style="list-style-type: none"> Findings add weight to the view that reducing N applications may lead to lower input costs to growers without yield reductions, as well as reduced GHG emissions. Scientific understanding of GHG emissions from irrigated cropping has been advanced. Work from this project was directly continued in CSIRO project CLW1401: <i>Monitoring greenhouse gas emissions from irrigated cropping systems</i>. This project seeks to improve on results from project CRC1117 and enable improved calculation of GHG emissions from cotton production (Ben Macdonald, pers. comm., 2016).
Impacts	<ul style="list-style-type: none"> Potential improvement in profits from reducing N fertiliser from inefficient levels. Potential reduction in GHG emissions due to reduced N fertiliser use and adoption of practices that raise soil organic C. Potential reduction in off-farm impacts from nutrient (particularly nitrogen) losses. Increased scientific capacity.

DAQ1001: Defining Critical Soil Nutrient Concentrations in Soil Supporting Irrigated Cotton and Grains in Northern NSW and Queensland	
Project Details	<p>Research Organisation: Queensland Department of Primary Industries & Fisheries</p> <p>Period: July 2009 – June 2012</p> <p>Principal Investigator: Mike Bell</p>
Rationale	<p>It was widely believed that crop nutrient budgets for cotton and grains were negative for most or all nutrients, with the balance being made up by background soil fertility reserves. In such a scenario stores of key nutrients such as phosphorus (P) and potassium (K) were being gradually depleted, with negative long-term implications on fertiliser costs and water use efficiency.</p> <p>Existing guidelines for crop P and K requirements were limited and optimised application strategies poorly developed. Soil testing strategies were confounded by slow release mineral reserves with uncertain availability. Long-term studies had clearly indicated that acid-extractable P pools were being accessed by plants, however the rate of release and ability of this release to meet crop demands were not clear. Existing soil tests for P (such as the widely-used Colwell P test) and K considered only the immediately plant-available nutrients, leaving background reserves unaccounted for. This was creating uncertainty about fertiliser requirements for maximising yields.</p> <p>Assessment of K had been advanced by the Tetraphenyl boron-K (TB-K) technique, however this method was overestimating plant-available K in some soils. Research was needed to determine if this could be overcome in order to provide a means of differentiating plant-available from unavailable K. If successful, this would need to be followed up by assessing the rates of release from these reserves in different soils.</p> <p>This project was conducted as a collaboration between CRDC and GRDC in order to further understanding of the dynamics of soil P and K reserves, and improve the ability of grain and cotton producers to account for their presence in nutrient management calculations.</p>
Objectives	<ol style="list-style-type: none"> To assess the size and availability of P and K reserves in the major grains/cotton growing soils of the northern region.

	<ol style="list-style-type: none"> 2. To develop diagnostic criteria that can be used to predict the need for P and K fertilisers and support effective fertiliser use efficiencies in the cotton and grains cropping systems. 3. To investigate the most effective P and K fertiliser application strategies (form, placement and timing) in soils with low background nutrient status, including the residual value of nutrients for subsequent crops. 4. To communicate these findings to the cotton and grains industries, agribusiness and the fertiliser industry by a combination of publications, updates, newsletters and field days/farm walks.
Activities & Outputs	<ul style="list-style-type: none"> • An extensive soil sampling and lab analysis campaign was conducted across QLD and northern NSW. This was conducted both within the project and by assisting sampling campaigns conducted by agricultural consultants, regional soil surveying teams and staff of other projects. • The soil sampling activities resulted in the development of a region-wide database covering most of the major cropping soils and districts in the northern grains region and containing subsoil analyses from over 800 locations. • Several trends emerged from the analyses: <ul style="list-style-type: none"> ○ There is a more consistent occurrence of slow release reserves of K than P, although there are regions where K reserves are minimal. ○ Occurrence of P reserves are patchy, variable and probably linked to geology and native vegetation. • Work with P indicated that: <ul style="list-style-type: none"> ○ Colwell P provides a good indication of easily available P that can be accessed by a current crop, while slow release P minerals tend to replenish these available stores between crops. ○ Different tests were suitable in different situations, with the TB-K potentially more suitable at detecting slowly soluble K reserves than the BSES-P test. ○ Both diagnostic methods of detecting slow release forms of P and K are suitable as occasional characteristic tests for soil status rather than annual monitoring tests for guiding fertiliser inputs in the short term. • The project established a field research program consisting of 10 carry-over sites from previous research and 16 newly established trials. These trials comprise cotton (both irrigated and dryland), sorghum, wheat, grain legumes and other grains. Sites investigated issues of subsoil nutrient replacement and occurrence of multiple limitations at a single site. • Relative soil P and K requirements were compared in the individual field sites, in a long-term K trial site and in glasshouse trials. • A soil sampling protocol was developed to characterise responsiveness to deep placed fertiliser in dryland systems. • Findings have enabled the development of broad guidelines for P and K fertilisation application strategies for grain crops with a greater focus on the use of subsoil banding as opposed to the use of shallow bands. However, the situation is less clear for cotton. • The project established a network of trial sites giving regional producers a focus for the fertility decline issues, and a way to have a look at potential fertiliser placement solutions. • Subsoil banding of P and K fertilisers was a new concept in marked contrast to the ideas of shallow bands (often in the seeding row) and minimal soil disturbance in direct drill systems. While the frequency of application, and fine tuning about rates and band spacings, still needed further work, the extent of potential yield gains was demonstrated (Mike Bell, pers. comm., 2016).

Outcomes	<ul style="list-style-type: none"> Improved understanding of regional distribution of P and K will enable better focus of research towards regions where continued negative nutrient budgets will have greatest impact on productivity. The soil testing protocols developed in this project are now widely adopted in the grains industry with assessment of P and K fertility in the 10-30cm layer a focus. Adoption in dryland cotton systems is growing but irrigated cotton producers have generally stayed with the existing soil sampling regime (Mike Bell, pers. comm., 2016). The northern grains region and commercial testing laboratories now routinely use the BSES-P tests as an indicator of slow release P reserves, in conjunction with the standard Colwell P and PBI diagnostics (Mike Bell, pers. comm., 2016). Further research is needed to gain better understanding of the interactions between the cotton root system and the uptake of soil P and K, as well as the most effective application strategies to enable crop recovery of applied fertilisers in both irrigated and dryland cotton production systems. Contributions to crop P and K uptake from soil layers below the depth of cultivation have yet to be determined. Research is ongoing in projects conducted by the GRDC More Profit from Crop Nutrition 2 initiative and CRDC. These projects are attempting to develop improved soil test-crop response relationships for P, K and S in the northern grains region. This additional work has also resulted in a growing frequency of grain growers testing or adopting deep banded applications, however there has not yet been significant change by irrigated cotton producers due to current lack of demonstrated productivity/profitability response. It has been shown that negative nutrient budgets over an extended period of time have eroded native fertility reserves to the extent that increased nutrient inputs will be required to maintain crop productivity and/or flexibility of land use. The network of sites was extended in subsequent GRDC and CRDC projects, with the grains projects resulting in a growing frequency of growers now either applying deep bands in test strips, or indeed incorporating deep placement within their fertiliser program. There has been little change by irrigated cotton producers, as there has yet been no productivity/profitability response demonstrated and no effective application strategy developed to ensure good fertiliser recovery (Mike Bell, pers. comm., 2016).
Impacts	<ul style="list-style-type: none"> Increased profits for grain producers and indirectly to dryland cotton producers, particularly in the long term, due to improved P and K fertiliser management strategies. Increased industry soil testing capacity for P and K.

FTRG1601: Identifying Practical Solutions to Optimising NUE and WUE in Cotton Production	
Project Details	<p>Research Organisation: NSW Department of Primary Industries</p> <p>Period: September 2015 to May 2016</p> <p>Principal Investigator: Jonathan Baird</p>
Rationale	<p>Nitrogen use efficiency (NUE) is determined by the proportion of applied nitrogen that is lost through denitrification, volatilisation, run-off/leaching processes or otherwise not utilised by the crop. In addition to economic concerns, denitrification can have harmful environmental impacts as the process leads to the release of the potent greenhouse gas nitrous oxide (N₂O).</p> <p>An additional issue facing the industry was the trend of rising fertiliser input costs and application rates. Further research was required to determine whether such inputs were in fact necessary to achieve high yields, or simply a compensation for poor NUE.</p>

	<p>There was therefore a need to investigate the factors influencing NUE and water use efficiency (WUE), and the interaction between the two efficiency measures. Previous CRDC project DAN1502 – <i>Optimising Water and Fertiliser Management in Cotton</i>, had investigated this area and suggested 250 kg/ha of N with a 70mm irrigation deficit as a baseline optimum combination for maximising profitability. Further research was required to validate these results and develop grower recommendations for best practice nitrogen and water management. A second project, CLW1401 – <i>Monitoring greenhouse gas emissions from irrigated cropping systems</i>, was already investigating the issue of denitrification and N₂O emissions and this provided an opportunity for collaboration.</p>
Objectives	<ol style="list-style-type: none"> 1. To investigate the impact of different irrigation techniques on nitrogen uptake and nitrogen use efficiency. 2. To communicate results/findings to industry. 3. To provide technical support to Dr Ben Macdonald in the extension of GHG research outcomes.
Activities & Outputs	<ul style="list-style-type: none"> • Two experiments were conducted to investigate the influence of irrigation management on N loss. • The first experiment investigated different irrigation techniques for mitigating N losses. These included irrigating down tractor wheel furrows adjacent to the fertilised furrow, irrigating down furrows where the fertiliser N was direct drilled, and irrigating with twice the volume of water. Of the three techniques trialled no significant difference in cotton yield was observed. • Results showed N losses as highest early in the season, highlighting the importance of managing the first irrigation event after N application. • The second experiment investigated impacts of varied irrigation (50 and 70mm deficit) and N rates (0, 150, 250 and 350 kg/ha) on N loss. Losses were measured by collecting run-off tail water. WUE and NUE were also calculated. • Under the conditions of this project's experimentation, the management strategy combining 250 kg/ha of N with a 70mm irrigation deficit produced the highest profit margin, confirming the results of previous project DAN1502. No significant yield gain was achieved from higher rates of N or irrigation above these levels. • Extension was conducted via an extension tour with 5 field days. These activities disseminated research findings and were attended by over 400 personnel.
Outcomes	<ul style="list-style-type: none"> • The findings of this project have added to the growing body of evidence that applying N in excess of 250 kg/ha is not economically justified in most instances. • Better understanding of crop WUE and NUE will allow growers to be more confident in their crop's ability to utilise applied nitrogen, lessening the practice of applying additional nitrogen.
Impacts	<ul style="list-style-type: none"> • Potential increased profitability due to increased N use efficiency and reduced N losses. • Potential reduction in off-farm impacts from nutrient (particularly nitrogen) losses. • Potentially decreased GHG emissions due to reduced N losses.

UNE1501: Phosphorus Availability in Raingrown Cotton	
Project Details	<p>Research Organisation: University of New England Period: June 2014 – February 2016 Principal Investigator: Brendan Griffiths</p>
Rationale	<p>Phosphorus dynamics in cotton production has been an area of longstanding uncertainty, particularly in dryland production. While it was known that crop</p>

	<p>responses to applied P varied substantially in different scenarios, the industry lacked means for predicting yield responses under such uncertainty. Several particular areas of interest included the influence of residual fertiliser P and mycorrhizal infection on yield, and the knowledge gap in relation to soil testing methods and correlation between test values and P occurrences in-plant.</p> <p>Incitec Pivot Ltd (IPL) had been conducting an ongoing long-term trial researching P and N factors in a rotation which included raingrown cotton as a summer rotation crop. This long-term trial provided an opportunity to address key knowledge shortages surrounding cotton P use. By understanding how and when cotton responds to P, industry could be better able to improve management of the nutrient.</p>
Objectives	<ol style="list-style-type: none"> 1. To investigate phosphorus uptake dynamics under a range of background soil Colwell P values – enriched through the continuous addition of P based fertiliser over time. 2. To investigate the effect of the addition of deep applied P fertiliser. 3. To investigate the impact of the dispersion of an enriched layer of P on plant P uptake. 4. To investigate the adequacy of plant P concentration (as leaf tissue testing) to reflect plant nutrient status. 5. To look at correlations between plant nutrient uptake and the soil test extraction methods of Colwell P and BSES P.
Activities & Outputs	<ul style="list-style-type: none"> • The experiment was initially planned to be conducted in northern NSW, however it was deemed necessary to relocate to another IPL site in QLD due to rainfall at the NSW site being insufficient to support raingrown cotton. • The experiment examined a combination of different fertiliser application rates as well as surface and deep banded applications. Little difference in crop P uptake was observed between the different application methods. • The relationship between plant tissue P concentration and lint yield was examined. This process enabled plant tissue P concentration critical values to be developed. • Testing was conducted on the level of soil nutrients and to quantify mycorrhizal colonisation. Plant structures of tissue, leaf and petiole were analysed along with lint yield and quality. • Tissue testing was shown to still provide a valid basis for assessing in-crop P status, however its reliability decreases after peak flowering. • It was indicated that the critical value for cotton for a likely response to soil P is likely to be much higher than the widely accepted 6 mg/kg using the Colwell method, and may in fact be closer to 25 mg/kg. • This experiment potentially provided a means for validation of soil test critical values investigating soil test extraction methods currently being employed (such as Colwell P & BSES P), as well as providing a basis for the validation of in crop-tissue testing as a method of ascertaining in crop nutrient status. • The project demonstrated a positive response to the application of P. This positive response is at odds with other contemporary research (Brendan Griffiths, pers. comm., 2016). It was not entirely clear what mechanism was responsible for this response however it was postulated that it may have been due to favourable early season growing conditions (including high rainfall) improving surface root activity, or that soil with high existing P reserves behaves differently than that with fertiliser P applied for that season. • Extension material was developed based on project findings. This material was delivered during information tours and field days, and has been incorporated into cotton production lecture material at the University of New England.
Outcomes	<ul style="list-style-type: none"> • Understanding of the mechanisms for observing and increasing cotton P uptake has been increased.

	<ul style="list-style-type: none"> • Better understanding of P application methods may enable more sustainable and efficient nutrient application.
Impacts	<ul style="list-style-type: none"> • Potentially increased profits due to improved management of P inputs in raingrown cotton. • Increased scientific and industry capacity regarding raingrown cotton production.

UQ1302: Developing Soil Testing and Fertiliser Response Guidelines to manage P, K and S Fertility for Irrigated and Dryland Cotton Cropping Systems

Project Details	<p>Research Organisation: University of Queensland Period: July 2012 – June 2015 Principal Investigator: Mike Bell</p>
Rationale	<p>Current cotton farming nutrient management is based primarily on the concept of cost-effective nutrient management, whereby fertiliser is applied to the point at which marginal yield increase equals the cost of purchasing and applying additional fertiliser. While such an approach is economically optimal in the short term, it can be less efficient in the longer term as declining nutrient reserves necessitate more frequent fertiliser applications. Unless farm managers consciously undertake either nutrient replacement or nutrient build-up approaches, soil fertility reserves of currently non-limiting nutrients will continue to decline until they, too, become limiting.</p> <p>While the most common limiting nutrient in the northern region is nitrogen (N), reserves of phosphorus (P), potassium (K) and sulphur (S) have also been declining to the point where application of these nutrients can result in significant yield increases.</p> <p>Reliable and practical testing procedures are essential if producers are to identify and adapt to issues of residual nutrient shortages. However, there are clear limitations in existing soil test diagnostics. These limitations include depth of sampling and soil test to be used, the critical soil value in different soil layers and the most appropriate application strategy for each nutrient in different soil types.</p> <p>There was a pressing need to develop improved soil and tissue testing guidelines to determine fertiliser needs and to develop application strategies that ensure efficient use of applied fertilisers. The development of new soil tests and sampling strategies for slowly soluble P and K reserves is quite advanced, although the program of field trials needed to confidently predict crop responsiveness was in its infancy. The existing commercial S soil test seems adequate but work on sampling strategies (particularly sampling depth) to predict S status and likely crop response had yet to commence.</p> <p>This project therefore sought to conduct field and glasshouse trials to address these testing limitations, and to then integrate findings with similar advances in N fertility management from other programs. This would ultimately enable the development of improved decision support tools to facilitate adoption of best practice nutrient management.</p>
Objectives	<ol style="list-style-type: none"> 1. To define critical soil test values (including appropriate soil sampling strategies and diagnostic methods) to indicate fertiliser P, K and S requirements for irrigated and dryland cotton cropping systems. 2. To develop a suite of guidelines for fertiliser application strategies (rates, banding v mixing and fertiliser forms) to optimise cotton productivity in irrigated and dryland systems.

	<ol style="list-style-type: none"> 3. To develop a framework to allow nutrient budgets to be developed for irrigated and dryland cotton and grains-cotton farming systems. This will integrate outcomes from projects focussed on P, K and S with those on N in both farming systems. 4. To lead a nationally coordinated extension and development program for crop nutrition and nutrient management issues.
Activities & Outputs	<ul style="list-style-type: none"> • A number of field experiments were established at dryland and irrigated cotton sites in QLD and NSW. • Experiments investigated the interaction between nutrient application rate and method, interactions between P and K where both were expected to be limiting, and the role of supplementary foliar applications. • Banded P and K applications, supplementary foliar P and K applications, and alteration of in-band constituents were all demonstrated to be ineffective methods for achieving maximum nutrient use efficiency in cotton. • A database of seed P and K concentrations was developed from the field trials conducted during the project, but due to the lack of yield responses observed it was impossible to use this data to identify critical nutrient concentrations. Results from this work indicated that the industry had potentially been over-applying P while current K removal rates were about right. • A long-term trial exploring the efficacy of organic amendments (manure & compost) was maintained near Cecil Plains, QLD with the effectiveness of annual applications of amendments on rainfed cotton and winter cereal production assessed. • A number of less intensive sites were also established to quantify the effectiveness of top dressing P and K in irrigated systems – a practice found to show visual responses in preceding wet seasons. • The nutrition module in myBMP was reviewed and updated with respect to project findings. The Nutripak guidelines were also reviewed. A focus was placed on the application strategies for P and K fertiliser, with emphasis placed on the importance of broadcast/incorporation of product, as opposed to banding. However, the extent of practice changes had to be moderated due to the lack of effective application strategies developed in the field program (Mike Bell, pers. comm., 2016). • The goal of defining critical soil test values for P, K and S requirements could not be achieved. This was due to inconsistent responses to applied fertiliser, likely due to inability to identify responsive sites and inability of the cotton crop to recover applied nutrient.
Outcomes	<ul style="list-style-type: none"> • The database of seed and lint P and K concentrations will be of use to guide nutrient budgeting practices; this may allow the industry to calculate removal rates based on a much wider range of soil types and regional production systems. • Updating extension vehicles such as myBMP will lead to greater knowledge and understanding by growers and consultants on the use, management and behaviour of key macronutrients in cotton soils. • It is expected this project will have only minimal impact in terms of practice changes, with the potential exception of a shift from banded to broadcast P and K fertiliser application methods. This result is due to none of the traditional application strategies demonstrating good crop recovery of applied nutrient; a number of the crops were found to still contain very low P concentrations in particular (Mike Bell, pers. comm., 2016). • The reasons for the poor recovery of applied fertiliser varied. In dryland cotton crops, the typical banding of fertilisers in otherwise direct drill systems was shown to be very ineffective at ensuring crop recovery of applied nutrients (although it is an effective strategy for the grain crops grown in rotation). In the

	<p>flood irrigated cotton crops, even broadcast and incorporated applications were utilised poorly, and the impact of flood irrigation on the functionality of roots in the beds/hill (where fertiliser is typically placed) became the focus of new research. Preliminary observations suggest that regular flood irrigation limits the root activity in the cotton beds/hills, and so limits recovery of (and response to) applied P and K fertiliser. If this is the case, the impact of irrigation method and frequency, crop rotations and soil ameliorants (to improve structure and reduce the period when soils are anaerobic during each irrigation event) on fertiliser recovery and growth response will be key components of a management response (Mike Bell, pers. comm., 2016).</p>
Impacts	<ul style="list-style-type: none"> • The lack of response to nutrients has led to further research currently underway on root growth and this may lead to a potential future increase in grower profits due to improved management and uptake of nutrients. • Increased industry soil testing capacity.

US1301: The Physiology of Cotton Crop Nutrition, Shade and Waterlogging	
Project Details	<p>Research Organisation: University of Sydney Period: March 2012 – March 2015 Principal Investigator: PhD student: Najeeb Ullah Project Supervisor: Daniel Tan</p>
Rationale	<p>Waterlogging can be a significant impediment to profitable cotton production. It can reduce cotton yield and quality while also increasing nitrogen losses, with the extent of these losses directly associated with the duration for which roots are in a waterlogged environment. Most Australian cotton is grown on clay soils with inherently low drainage and is therefore vulnerable to waterlogging. The problem is compounded by the occurrence of the cotton reproductive phase during the summer months, a time which typically sees the highest rainfalls.</p> <p>Despite these risks there is a shortage of solutions available for addressing the issue. Waterlogging tolerance is a difficult and complex trait to develop, and is unlikely to be adequate on its own. A need was identified for the development of effective cultural or chemical means of reducing the impacts of waterlogging. To achieve this, understanding of the impact of environmental factors and plant adaption needed to be advanced.</p> <p>Ethylene is a key plant hormone, with its increased presence linked to water stress and contribution to plant senescence and growth reductions. This project therefore sought to investigate the role of ethylene in waterlogged cotton so that procedures could be developed to reduce its impact.</p>
Objectives	<p>The broad objective of this project was to develop an understanding of the key physiological processes regulating yield losses in cotton under waterlogged environments. The specific objectives of project experiments were:</p> <ol style="list-style-type: none"> 1. To investigate the effect of overcast/low-light conditions on cotton growth and yield under waterlogged environments. 2. To understand the mechanisms of waterlogging damage in cotton by studying physiological responses of various layers of the plant canopy. 3. To optimise the application rate and time of an anti-ethylene agent, aminoethoxyvinylglycine (AVG) for waterlogged cotton. 4. To study the relationship between ethylene release and waterlogging sensitivity in cotton, using contrasting cultivars. 5. To identify key factors regulating fruit losses in waterlogged cotton using an ethylene-mutant.
Activities & Outputs	<ul style="list-style-type: none"> • Project activities were focused on a series of three glasshouse trials and five field trials conducted at ACRI.

	<ul style="list-style-type: none"> • The experiment compared crops waterlogged at an early stage, a late stage, and a non-waterlogged control. • Fruiting retention was measured one day before and after waterlogging, seven days after termination of waterlogging and at crop maturity. • Tests measured crop maturity, quality and yield throughout the experiment. • Experiments were conducted examining the role of ethylene in waterlogged cotton. • Testing was conducted on gas exchange and fluorescence, total soluble sugar, leaf nitrogen, and ethylene accumulation. • Effects of individual or combined waterlogging and shade stresses were studied on different phases of the cotton crop. It was found shade did not alleviate waterlogging yield losses in cotton. Reductions under combined waterlogging and shade stresses were greater than under individual stresses. • Study of physiological responses of various layers of the plant canopy confirmed that newly pollinated flowers are relatively more sensitive to waterlogging induced-abscission than the developed bolls, implying a potential role of ethylene. Based on these findings it was suggested that waterlogging remediation techniques should also focus on preventing the loss of early fruits (potentially through ethylene management) rather than only increasing nutrient supply. • Experiments were conducted aimed at optimising the application timing and rate of AVG for waterlogged cotton. • AVG was shown to improve cotton yield both under waterlogged and non-waterlogged conditions (average 13% and 9% improvements respectively). Project data suggested 125 [a.i.] ha⁻¹ of AVG applied 24 h prior to waterlogging as the optimum application rate for ameliorating yield losses in waterlogged cotton. Possible mechanisms of AVG-induced growth and yield promotion could be through increased nutrient uptake and fruit retention. This could potentially be achieved by growers with application of AVG in conjunction with a foliar fertiliser. • This study provided clear evidence that inhibited photosynthesis and elevated ethylene production are major reasons for yield reduction in waterlogged cotton. AVG effectively suppressed ethylene production and subsequent fruit abscission. However, it had a limited effect on photosynthesis and shoot growth of severely waterlogged cotton, indicating that blocking ethylene biosynthesis alone may not be adequate to mitigate waterlogging damage and an integrated approach of fertiliser and ethylene management should be adopted. • The project formed the basis of the PhD for the Principal Investigator. • Research findings were communicated through scientific journals, conferences, grower publications and research seminars. A summary of the study was presented at the World Cotton Research Conference in 2016 (Najeeb Ullah, pers. comm., 2016).
Outcomes	<ul style="list-style-type: none"> • Enhanced scientific understanding of waterlogging in cotton, particularly the role of ethylene, has been advanced. • While AVG treatments have shown potential for amelioration of waterlogging yield losses, further research is needed to determine its economic viability and there is currently no activity in this area (Najeeb Ullah, pers. comm., 2016). • If further investment was to occur then potential reduction in yield losses, nutrient losses and GHG emissions could result.
Impacts	<ul style="list-style-type: none"> • Increased industry research capacity and scientific knowledge.

4. Project Investment

The Investment

The following tables show the annual investment by project for both CRDC (Table 3) and for researchers and any other investors (Table 4). Table 5 provides the total investment by year from both sources.

Table 3: Investment by CRDC for Years Ending June 2008 to June 2016 (nominal \$)

Project ID	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
CGA1405	0	0	0	0	0	0	7,450	0	0	7,450
CRC139	38,000 ¹	38,000 ¹	38,000 ¹	38,000 ¹	38,000 ¹	0	0	0	0	190,000
CRC1115	0	0	0	279,060	290,006	0	0	0	0	569,066
CRC1117	0	0	0	116,873	136,320	142,136				395,329
DAQ1001	0	0	149,225	159,824	149,067					458,116
FTRG1601	0	0	0	0	0	0	0	0	60,706	60,706
UNE1501	0	0	0	0	0	0	0	61,966	0	61,966
UQ1302	0	0	0	0	0	447,672	455,647	463,888	0	1,367,207
US1301	0	0	0	0	0	15,272 ²	15,272 ²	15,272 ²	0	45,816
Totals	38,000	38,000	187,225	593,757	613,393	605,080	478,369	541,126	60,706	3,155,656

1: Based on CRDC scholarship contribution of \$32,000 + additional \$6,000 operational funding per annum

2: Based on CRDC scholarship maximum contribution of \$35,000 - \$23,728 APA scholarship + \$4,000 additional operational funding per annum

Table 4: Investment by Researchers and Industry for Years Ending June 2008 to June 2016 (nominal \$)

Project ID	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
CGA1405	0	0	0	0	0	0	0	0	0	0
CRC139	22,664	22,664	22,664	22,664	22,664	0	0	0	0	113,320
CRC1115	0	0	0	257,543	269,920	0	0	0	0	527,463
CRC1117	0	0	0	89,168	106,769	106,355	0	0	0	302,292
DAQ1001	0	0	846,584	867,676	889,219	0	0	0	0	2,603,479
FTRG1601	0	0	0	0	0	0	0	0	40,446	40,446
UNE1501	0	0	0	0	0	0	0	41,635	0	41,635
UQ1302	0	0	0	0	0	633,600	658,073	668,901	0	1,960,574
US1301	0	0	0	0	0	51,272	51,272	51,272	0	153,816
Totals	22,664	22,664	869,248	1,237,051	1,288,572	791,227	709,345	761,808	40,446	5,743,025

Table 5: Total Annual Investment by Year
(nominal \$)

Year ending June	CRDC	Researchers, Industry and Others	Total
2008	38,000	22,664	60,664
2009	38,000	22,664	60,664
2010	187,225	869,248	1,056,473
2011	593,757	1,237,051	1,830,808
2012	613,393	1,288,572	1,901,965
2013	605,080	791,227	1,396,307
2014	478,369	709,345	1,187,714
2015	541,126	761,808	1,302,934
2016	60,706	40,446	101,152
Total	3,155,656	5,743,025	8,898,681

Program Management and Extension Costs

The average cost of managing the nutrition cluster projects was added to the total project costs via a management cost multiplier (1.13:1); this was estimated based on the reported share of ‘employee benefits’ & ‘supplier’ expenses in total CRDC expenditure (CRDC, 2015). No additional costs of extension were included as the majority of projects were either extension-focussed or had encompassed an extension component.

5. Impacts

From the project descriptions, the principal potential impacts for the nutrition cluster were identified. Table 6 summarises the key potential impacts identified and the contribution to each potential impact by each of the nine projects.

Table 6: Contribution by Project to Principal Potential Cluster Impacts

Project Code	Increased profits due to increased N use efficiency	Increased profits due to improved P and K fertiliser management	Reduced off-farm impacts from nutrient losses to terrestrial and aquatic areas	Reduced GHG emissions	Increased future scientific & industry capacity	Community spillovers
CGA1405	✓		✓	✓	✓	✓
CRC139	✓			✓	✓	✓
CRC1115	✓		✓	✓	✓	✓
CRC1117	✓		✓	✓	✓	✓
DAQ1001		✓			✓	✓
FTRG1601	✓		✓	✓		✓
UNE1501		✓			✓	✓
UQ1302		✓			✓	✓
US1301					✓	✓

Table 7 provides, in a triple bottom line framework, a summary of the principal types of impacts associated with the outcomes of the overall investment in the nine projects.

Table 7: Triple Bottom Line Categories of Actual and Potential Impacts from the Project Investments

Economic	<ul style="list-style-type: none"> Increased profits due to increased nitrogen use efficiency. Increased profits due to improved P and K fertiliser management.
Environmental	<ul style="list-style-type: none"> Reduced greenhouse gas emissions. Reduced nutrient losses to environment contributing to improved water quality off-farm.
Social	<ul style="list-style-type: none"> Increased scientific and industry capacity. Increased community well-being through the spill-over effects of increased farm productivity and profitability.

Public versus Private Benefits

The largest proportion of benefits identified in this evaluation will accrue to the cotton and grains industries and therefore are considered private benefits. Some environmental impacts were reported in Tables 6 and 7 (e.g. reduction in greenhouse gases). Some indirect social benefits were delivered also, including increased community incomes, the result of spillovers from increased/maintained cotton and grain industry incomes.

Distribution of Impacts along the Supply Chain

The majority of benefits are initially delivered at farm/producer level. Some benefits and costs will likely be passed along the input and output supply chains in proportion to the elasticities of supply and demand at different stages along the chain. For example, if changes in farm nutrition practices lead to a significant decrease in the volume of fertiliser applied, this may lead to minor decreases in income for fertiliser producers and suppliers.

Impacts on other Industries

While most projects focussed specifically on cotton, the impacts of project DAQ1001 are expected to be delivered largely to the grains industry and its rotations. Dryland cotton, as grown in rotation with cereal grain, will be an indirect beneficiary of DAQ1001.

Impacts Overseas

There are not expected to be any significant overseas impacts from this research.

Match with Research Priorities

The Australian Government's Science and Research Priorities and Rural Research, Development & Extension (RD&E) priorities are reproduced in Table 8. The cluster contributes primarily to Rural RD&E priorities 3 and 4, and to Science and Research priority 2 with some minor contributions to priorities 1 and 7.

Table 8: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	Science and Research Priorities (est. 2015)
1. Advanced technology	1. Food
2. Biosecurity	2. Soil and Water
3. Soil, water and managing natural resources	3. Transport
4. Adoption of R&D	4. Cybersecurity
	5. Energy and Resources
	6. Manufacturing
	7. Environmental Change
	8. Health

Sources: DAWR (2015) and OCS (2016)

6. Valuation of Impacts

Impacts Valued

Six projects from the total population of nine that were identified to have contributed to significant impacts. Those projects were:

- **CGA1405** - Understanding Soils and Plant Nutrition for Cotton Growers
- **CRC139** - Nutrient Redistribution Within Cotton Plants
- **CRC1115** - Developing N-efficient Cotton Systems that Produce Low GHG Emissions and Promote Healthy Soil
- **CRC1117** - Understanding Greenhouse Gas Emission from Broadacre Irrigated Cropping Systems
- **DAQ1001** - Defining Critical Soil Nutrient Concentrations in Soil Supporting Irrigated Cotton and Grains in Northern NSW and Queensland
- **FTRG1601** - Identifying Practical Solutions to Optimising Nitrogen Use Efficiency (NUE) and Water Use Efficiency (WUE) in Cotton Production

From these six projects, three benefits were selected for valuation:

1. Increased profits due to increased N use efficiency
2. Increased profits due to improved P and K fertiliser management
3. Reduced GHG emissions.

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when a high degree of uncertainty was involved. Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria.

Two separate analyses were carried out. In the first analysis, the present value of all benefits valued was compared to the total investment in all nine projects. As there are likely to be some positive benefits from the projects where impacts were not explicitly valued, the results from this analysis are likely to represent a lower bound set of investment criteria for the cluster.

The second analysis refers to the same set of valued benefits but compared them only to the investment in the six projects where benefits were valued. These investment criteria are likely to represent an upper bound set of investment criteria for the cluster.

Impacts Not Valued

Not all impacts identified in Table 6 can be valued in an assessment such as this. This is for various reasons including time and resources, availability of baseline data, understanding of causal relationships between the research outputs and their specific impact, and the difficulty of placing credible monetary values on the social benefits.

The benefits identified but not valued were one environmental and two social benefits, being:

- Reduced nutrient losses to environment contributing to improved water quality off-farm.
- Increased scientific & industry capacity
- Community spillovers resulting from increased farm profitability.

Valuation of Benefit 1: Increased Nitrogen Use Efficiency

Projects in this cluster have contributed to increased efficiency of fertiliser nitrogen applications in Australian cotton production. This impact has been valued by accounting for the reduction in volume of fertiliser applied without affecting cotton yields. This reduction in applied nutrients has been achieved through several pathways, primarily:

- Reduction in nutrient losses via denitrification and volatilisation.
- Reduction in nutrient applications above economically efficient levels.
- Improved soil health (soil organic carbon), leading to reduced fertiliser requirements.

Management of nitrogen (N) inputs is a key component of profitability in broad-acre cropping. A common issue is that of excessive application, where nitrogen is applied at levels where the costs of additional N may be well greater than the marginal yield benefits. This inefficient practice typically results from inadequate understanding of the specific nitrogen requirements for a particular crop, or the application of additional N as ‘insurance’ against low yields.

Valuing Nitrogen Savings

The primary economic benefit delivered by these projects is a reduction in N use above optimal levels. Prior to the projects valued it was suggested that a substantial number of cotton growers were using in excess of 250 kg/ha. It has been estimated that due to the outputs and outcomes of the projects considered, adopting growers will reduce their nitrogen applications by an average of 20 kg/ha. This saving has been valued at \$1.35/kg of N, based on a urea price of \$620/tonne and 46% N content (Impact Fertilisers, 2016).

Adoption

It was reported that in 2012 45% of cotton growers were applying nitrogen in excess of 250 kg/ha (CRDC, 2014). In valuing the reduced N benefit it has been assumed that 25% of these growers will achieve significant N use reductions due to the projects. For this evaluation, maximum adoption has been estimated to be achieved by 2020, with first adoption occurring in 2017.

Attribution

Five projects from this cluster have been assessed as contributing to this benefit:

- CGA1405 - Understanding Soils and Plant Nutrition for Cotton Growers
- CRC139 - Nutrient Redistribution Within Cotton Plants
- CRC1115 - Developing N-efficient Cotton Systems that Produce Low GHG Emissions and Promote Healthy Soil
- CRC1117 - Understanding Greenhouse Gas Emission from Broadacre Irrigated Cropping Systems
- FTRG1601 - Identifying Practical Solutions to Optimising Nitrogen Use Efficiency (NUE) and Water Use Efficiency (WUE) in Cotton Production.

Two additional projects (CLW1102 and DAN1502) that were funded outside the nutrient cluster also were considered to have contributed to reduced N fertiliser usage. These additional projects have been considered as a necessary step on the pathway to impact, therefore an attribution factor to this benefit has been applied based on the five projects’ share of the total costs of all seven N projects identified.

Investment in the five projects in this cluster total \$2.2m, approximately 85% of the combined investment in the seven projects (\$2.5m), therefore an attribution factor of 85% has been applied to the benefit valued in the current evaluation. The two additional N projects are evaluated in an Agtrans Research impact assessment of CRDC water use efficiency RD&E investment.

Further detail regarding specific assumptions can be found in Table 9.

Valuation of Benefit 2: Reduced Greenhouse Gas Emissions

Valuation of this benefit follows from the N reductions calculated in Benefit 1, which will lead to reductions in nitrous oxide emissions. Benefits have been valued by converting N fertiliser applications to CO₂ equivalent values via the following process:

*Applied N savings → N2O reductions → proportion N emitted as N2O
→ N2O in CO2 equivalent terms
→ economic value of CO2 equivalent emissions*

Specific values for the different steps in this process are presented in Table 9. The value for CO₂ equivalent emissions was estimated using the previously mandated Australian carbon price of \$24.15/tonne.

Valuation of Benefit 3: Improved Utilisation of Deep Nutrient Reserves in Grain Production

Research in this cluster, particularly project DAQ1001, represents an important step towards the adoption of deep placement of P fertiliser in Australian grains crops. This project helped to increase awareness of the importance of deep P reserves and developed improved methods for increasing availability for plant uptake.

Valuation of this benefit is based around the increased rotational gross margin available to growers adopting the new methods. Benefits are expected to accrue to grain growers in the main as cotton growers have not yet shown indications of significant adoption (Mike Bell, pers. comm., 2016).

Average annual benefits will depend on the length of rotation, and need to account for the cost of the technology investment by growers. With these factors in mind, an average gross margin increase of \$60/ha was identified (Zull et al, 2015). It was estimated that these new practices will be applicable to 33% of the approximately 4 m ha of crop area in the northern grains region (Mike Bell, pers. comm., 2016). Specific assumptions for the valuation are presented in Table 9.

Counterfactual

It has been assumed that the benefits valued in this cluster are incremental in nature and would have been unlikely to occur without CRDC investment.

Summary of Assumptions

Table 9: Summary of Assumptions

Variable	Assumption	Source
<i>Benefit 1: Fertiliser use efficiency</i>		
Value of elemental N	\$1.35/kg	Based on urea price of \$620/tonne @ 46% N (Impact Fertilisers, 2016)
Nitrogen saving	20 kg/ha	Agtrans Research based on CRDC, 2014
Industry applicable area – irrigated cotton	306,684 ha	ABS (2011-2016a), average of years 2011, 2013, 2014 & 2015
Irrigated cotton area using excessive N	45% of 306,684 = 138,008 ha	CRDC, 2014
Growers adopting N reductions	25% of 138,008 = 34,502 ha	Agtrans Research after discussions with research personnel
Year of first adoption	2017	Agtrans Research, based on completion of project FTRG1601 in 2016
Year of maximum adoption	2020	Agtrans Research
N saved at maximum adoption	690,039 kg	20 kg/ha x 34,502 ha

Attribution to nutrition cluster projects	85%	Five projects' share of total investment in N research considered
<i>Benefit 2: Greenhouse gas reductions (from nitrogen fertiliser reductions)</i>		
Reduction in N fertiliser applications	As per Benefit 1	As above
Factor to convert N to N ₂ O	3.14	Halvorson & Del Grosso, 2003
Proportion of N emitted as N ₂ O	0.4%	IPCC, 2013
CO ₂ equivalent of N ₂ O (100 years)	298 times	Clean Energy Regulator, 2015
Value of CO ₂ equivalent	\$24.15/tonne	As above
Adoption timeframes	As per Benefit 1	Same attribution as for Benefit 1 above
Attribution	85%	
<i>Benefit 3: Improved Utilisation of Deep Nutrient Reserves</i>		
Average annual crop area in northern region	4m ha	Agtrans Research, includes cereals, pulses and oilseeds
Applicable crop area for deep placement of P in northern region	33% of northern region crop area	Agtrans Research based on discussions with Mike Bell
Average annual net benefit from technology	\$60 per ha	Zull et al (2015), Average of long and short rotations. (\$43+\$76)/2 and accounting for the cost of the technology investment by growers. While these are net discounted values, the average is used as a conservative estimate of an undiscounted value in the current analysis
First year of adoption	2016	Agtrans Research based on discussions with Mike Bell
Expected maximum adoption of technology as of 2024/2025	20% of applicable area	
Attribution of benefit to DAQ1001 (investment of \$3.06 m from 2010 to 2012)	25%	

7. Results

All past costs and benefits were expressed in 2015/16 dollar terms using the Implicit Price Deflator for GDP. The CRDC components of project investment costs were all multiplied by a factor of 1.13 to accommodate project management costs. All benefits after 2015/16 were expressed in 2015/16 dollar terms. All costs and benefits were discounted to 2015/16 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a high level of 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 (2015/16) to the final year of benefits assumed.

Tables 10 and 11 show the investment criteria estimated for the different periods of benefits for both the total investment and for the CRDC investment respectively. These investment criteria account for the cost of all nine projects but benefits from only the six projects where benefits were valued. These investment criteria therefore represent the lower bound for return on investment in the population of projects evaluated.

The present value of benefits (PVBs) for the CRDC investment, shown in Table 11, are estimated by multiplying the total PVB (\$61.15 million) by the CRDC proportion of investment (35.3%).

Table 10: Lower Bound Investment Criteria for Total Investment in the Nine Projects
(Discount rate 5%, Re-investment rate 5%)

Investment criteria	Years from year of last investment						
	0	5	10	15	20	25	30
Present value of benefits (\$m)	0.50	9.70	24.32	37.11	47.14	54.99	61.15
Present value of costs (\$m)	11.32	11.32	11.32	11.32	11.32	11.32	11.32
Net present value (\$m)	-10.82	-1.61	13.00	25.79	35.82	43.68	49.83
Benefit-cost ratio	0.04	0.86	2.15	3.28	4.17	4.86	5.40
Internal rate of return (IRR) (%)	negative	2.7	13.6	16.4	17.3	17.6	17.8
MIRR (%)	negative	1.8	13.4	13.7	12.8	11.9	11.1

Table 11: Lower Bound Investment Criteria for CRDC Investment in the Nine Projects
(Discount rate 5%, Reinvestment rate 5%)

Investment criteria	Years from year of last investment						
	0	5	10	15	20	25	30
Present value of benefits (\$m)	0.19	3.71	9.30	14.19	18.02	21.03	23.38
Present value of costs (\$m)	4.27	4.27	4.27	4.27	4.27	4.27	4.27
Net present value (\$m)	-4.08	-0.56	5.03	9.92	13.75	16.75	19.11
Benefit-cost ratio	0.04	0.87	2.18	3.32	4.22	4.92	5.47
Internal rate of return (%)	negative	2.8	14.0	16.8	17.7	18.0	18.2
MIRR (%)	negative	2.0	13.6	13.8	12.9	12.0	11.2

Tables 12 and 13 show the investment criteria estimated for the different periods of benefits for the investment in the six projects where benefits were valued but include the costs of only the six projects. These results therefore represent the upper bound of investment criteria for cluster investment.

Table 12: Upper Bound Investment Criteria for Total Investment in the Six Projects Where Impacts Valued (Discount rate 5%, Re-investment rate 5%)

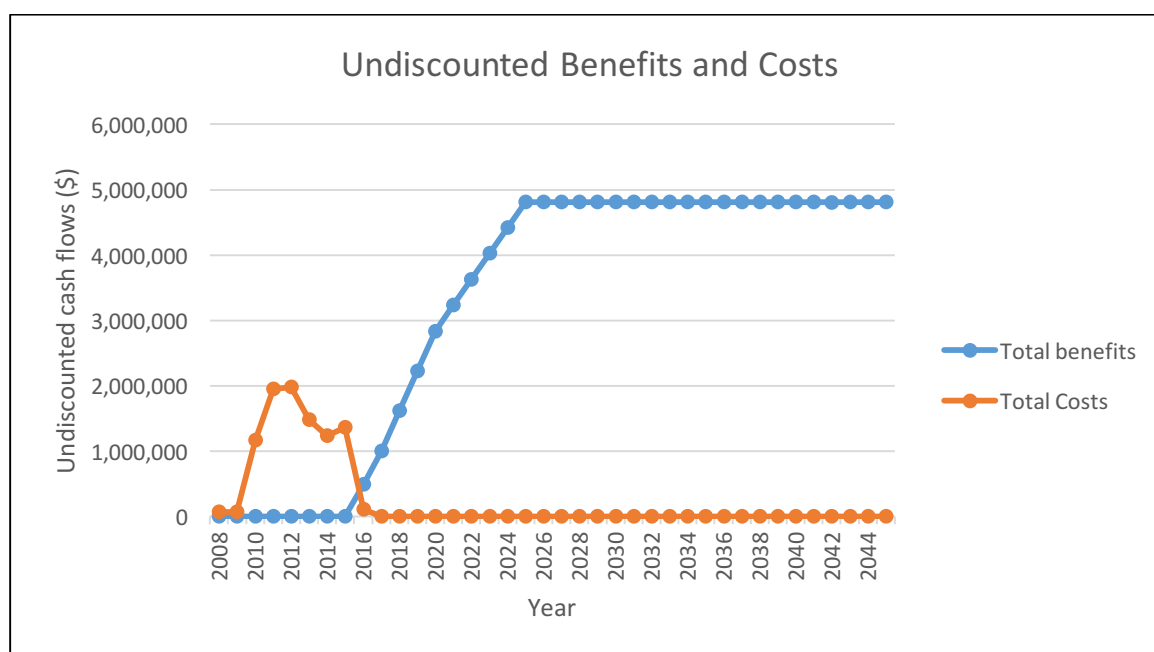
Investment criteria	Years from year of last investment						
	0	5	10	15	20	25	30
Present value of benefits (\$m)	0.50	9.70	24.32	37.11	47.14	54.99	61.15
Present value of costs (\$m)	7.11	7.11	7.11	7.11	7.11	7.11	7.11
Net present value (\$m)	-6.62	2.59	17.20	30.00	40.03	47.88	54.04
Benefit-cost ratio	0.07	1.36	3.42	5.22	6.63	7.73	8.60
Internal rate of return (%)	negative	9.1	18.0	20.1	20.8	21.0	21.1
MIRR (%)	negative	11.8	18.9	17.3	15.5	14.0	12.9

Table 13: Upper Bound Investment Criteria for CRDC Investment in the Six Projects Where Impacts Valued (Discount rate 5%, Reinvestment rate 5%)

Investment criteria	Years from year of last investment						
	0	5	10	15	20	25	30
Present value of benefits (\$m)	0.19	3.71	9.30	14.19	18.02	21.03	23.38
Present value of costs (\$m)	2.43	2.43	2.43	2.43	2.43	2.43	2.43
Net present value (\$m)	-2.24	1.28	6.87	11.76	15.59	18.60	20.95
Benefit-cost ratio	0.08	1.53	3.83	5.84	7.42	8.65	9.62
Internal rate of return (%)	negative	9.3	18.3	20.4	21.1	21.3	21.4
MIRR (%)	negative	12.1	19.1	17.5	15.6	14.1	12.9

The annual undiscounted benefit and cost cash flows for the total investment for the duration of investment period plus 30 years from the last year of investment are shown in Figure 1.

Figure 1: Annual Cash Flow of Total Benefits and Total Costs in the Nine Investments



Sources of Benefits

Given the assumptions made, the benefits from the deep placement nutrient intervention contributed a higher level (80.5%) of total discounted benefits than the projects addressing nitrogen use efficiency and GHG emissions. Estimates of the relative contributions, given the assumptions made and after application of attribution factors, are shown in Table 14.

Table 14: Sources of Benefits by Category

Source of Benefits	Contribution to PVB (\$m)	Share of benefits (%)
Increased NUE	11.08	18.1
Reduced GHG emissions	0.87	1.4
Improved utilisation of deep nutrient reserves	49.20	80.5
Total	61.15	100.0

This investment cluster represents a somewhat unusual case in that substantial benefits were delivered outside the cotton industry. This is due to project DAQ1001, which received substantial funding from, and thus delivered substantial benefits to, the grains industry. It should be noted that the lower bound benefit-cost ratio (BCR) for the CRDC investment of 5.40 does not apply to specific cotton industry benefits and specific cotton industry investment. The benefits accrue to both cotton and grains as well as environmental benefits. The industry benefits are dominated by dryland grain rotations and not irrigated cotton. In so far as dryland grain rotations can include dryland cotton, cotton growers will share in some increased rotational benefits via higher grain yields.

If only irrigated cotton industry benefits and cotton industry investment are included, the BCR will be lower at 2.80 to 1 (\$11.08m from nitrogen reduction benefits, plus \$0.87m for environmental benefits, divided by the total CRDC investment of \$4.27m).

Sensitivity Analysis

A sensitivity analysis was carried out on the discount rate. The analysis was performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values. Table 15 presents the results. Note that this analysis is for the six projects where benefits were valued but includes the investment for all nine projects (lower bound). The results showed a moderate sensitivity to the discount rate.

Table 15: Sensitivity to Discount Rate (Lower Bound Analysis)
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits (\$m)	129.38	61.15	34.23
Present value of costs (\$m)	9.46	11.32	13.52
Net present value (\$m)	119.93	49.83	20.71
Benefit-cost ratio	13.68	5.40	2.53

A sensitivity analysis was conducted on the key variables of the level of adoption of reduced N applications and the extent of the reduction (Table 16). The results in Table 16 show that the overall investment criteria exhibit a low sensitivity, likely due to the N saving benefit contributing only 18% to the overall benefit, as it was dwarfed by the deep nutrient intervention benefit delivered to grain rotations.

Table 16: Sensitivity to Change in Assumptions on Adoption and Level of Reduction of N (Lower Bound Analysis)
(Total Investment, 30 years)

Investment Criteria	Adoption rate (%), Average N saving (kg/ha)		
	50% of base	Base case (25, 20)	50% increase of base
Present value of benefits (\$m)	52.19	61.15	76.08
Present value of costs (\$m)	11.32	11.32	11.32
Net present value (\$m)	40.87	49.83	64.77
Benefit-cost ratio	4.61	5.40	6.72

A sensitivity analysis was also conducted on the assumptions on the adoption and impact levels driving the benefits from the deep nutrient interventions captured by the grains industry. As may have been expected, the results for the total investment criteria show a high level of sensitivity.

Table 17: Sensitivity to Change in Key Deep Nutrient Intervention Assumptions (Lower Bound Analysis)
(Total Investment, 30 years)

Investment Criteria	Maximum adoption (%), gross margin increase (\$/ha)		
	Worst case (10, 30)	Base case (20, 60)	Best case (30, 90)
Present value of benefits (\$m)	24.37	61.15	122.27
Present value of costs (\$m)	11.32	11.32	11.32
Net present value (\$m)	13.06	49.83	110.96
Benefit-cost ratio	2.15	5.40	10.80

Confidence Ratings

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

Table 18: Confidence in Analysis of Cluster

Coverage of Benefits	Confidence in Assumptions
Medium-high	Medium

Coverage of benefits was assessed as medium-high as the majority of benefits were considered to be economic in nature relating to increased input efficiency. While a number of benefits were not valued, these benefits were assessed as being minor relative to those valued.

Confidence in assumptions was rated as medium. While feedback has been sought from industry personnel, many of the key assumptions relate to future or expected benefits; these represent an inherent uncertainty.

Confidence in assumptions could be improved by greater availability of information on grower practices, particularly regarding adoption of RD&E outputs driven by specific projects or groups of projects. While the cotton industry does produce more information on grower practices than many other industries, the drivers of change are often not readily identified. Time series data on practice change would be useful as would more detailed grower feedback on extension activities. In particular, perceived information on value to individuals and future intentions regarding practice change could be most valuable to economic evaluation. Such a requirement could be built into project specifications. The current qualitative information is useful in developing approximate assumptions; however, an increase in the availability of quantitative data, especially time series data, would improve the validity of future impact assessments.

8. Conclusions

Funding for the nine projects in the cluster totalled \$11.32 million (present value terms) and produced aggregate total expected benefits of \$61.15 million (present value terms). This gave a net present value of \$49.83 million, a benefit-cost ratio of 5.4 to 1, an internal rate of return of 17.8% and a modified internal rate of return of 11.1%.

Funding for the six projects where impacts were valued totalled \$7.11 million (present value terms) and produced aggregate total expected benefits of \$61.15 million (present value terms). This gave a net present value of \$54.04 million, a benefit-cost ratio of 8.6 to 1, an internal rate of return of 21.1% and a modified internal rate of return of 12.9%. The six projects valued represented approximately 63% of total funding for the nine projects in the project population.

It can be concluded, given the assumptions made, that the benefit-cost ratio for the investment in the nine nutrition projects lies somewhere between 5.4 to 1 (considered a lower bound estimate) and 8.6 to 1 (considered an upper bound estimate). Overall these results suggest that the projects in this cluster are providing a high return on investment.

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