Final Report

Project title:

Horticulture Impact Assessment Program:

Appendix 3: Fusarium wilt Tropical Race 4 Research Program (BA14014 Impact Assessment)

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Delivery partner:

AgEconPlus and Agtrans Research

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MT18011

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Executive Summary

What the report is about

This report presents the results of an impact assessment of a Horticulture Innovation Australia Limited (Hort Innovation) investment in *BA14014: Fusarium wilt Tropical Race 4 Research Program.* The project was funded by Hort Innovation over the period June 2015 to June 2020.

Methodology

The investment was first analysed qualitatively within a logical framework that included activities and outputs, outcomes, and impacts. Actual and/or potential impacts then were categorised into a triple bottom line framework. Principal impacts identified were then considered for valuation in monetary terms (quantitative assessment). Past and future cash flows were expressed in 2019/20 dollar terms and were discounted to the year 2019/20 using a discount rate of 5% to estimate the investment criteria and a 5% reinvestment rate to estimate the modified internal rate of return (MIRR).

Results/key findings

The investment in BA14014 has contributed to improved on-farm and off-farm biosecurity against *Foc* TR4 reducing the risk of future incursions or spread of the disease. Further, the investment has likely contributed to the development and future adoption of *Foc* TR4 resistant banana cultivars and to improved efficiency and/ or effectiveness of resource allocation associated with *Foc* TR4 RD&E and banana breeding.

Investment Criteria

Total funding from all sources for the project was $9.43 million (present value terms). The investment produced estimated total expected benefits of $94.98 million (present value terms). This gave a net present value of $85.55 million, an estimated benefit-cost ratio of 10.08 to 1, an internal rate of return of 24.9% and a modified internal rate of return of 13.8%.

Conclusions

Investment in Project BA14014 produced outputs that have created, and continue to create, positive impacts for the Australia banana industry. As a number of economic and social impacts identified were not valued, the investment criteria estimated by the evaluation are likely to be an underestimate of the actual performance of the investment in Project BA14014.

Keywords

Impact assessment, cost-benefit analysis, banana, Fusarium wilt, Fusarium wilt Tropical Race 4, TR4, Panama disease, biosecurity

Introduction

Horticulture Innovation Australia Limited (Hort Innovation) required a series of impact assessments to be carried out annually on a number of investments in the Hort Innovation research, development, and extension (RD&E) portfolio. The assessments were required to meet the following Hort Innovation evaluation reporting requirements:

- Reporting against the Hort Innovation's current Strategic Plan and the Evaluation Framework associated with Hort Innovation's Statutory Funding Agreement with the Commonwealth Government.
- Annual Reporting to Hort Innovation stakeholders.
- Reporting to the Council of Rural Research and Development Corporations (CRRDC).

Under the impact assessment program (Project MT18011), three series of impact assessments were conducted in calendar 2019, 2020 and 2021. Each included 15 randomly selected Hort Innovation RD&E investments (projects). The third series of impact assessments (current series) was randomly selected from an overall population of 56 Hort Innovation investments worth an estimated $38.9 million (nominal Hort Innovation investment) where a final deliverable had been submitted in the 2019/20 financial year.

The 15 investments were selected through a stratified, random sampling process such that investments chosen represented at least 10% of the total Hort Innovation RD&E investment in the overall population (in nominal terms) and was representative of the Hort Innovation investment across six, pre-defined project size classes.

Project *BA14014: Fusarium wilt Tropical Race 4 Research Program* was randomly selected as one of the 15 investments under the third series for MT18011 and was analysed in this report.

General Method

The impact assessment follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations, Cooperative Research Centres, State Departments of Agriculture, and some universities. The approach includes both qualitative and quantitative descriptions that are in accord with the impact assessment guidelines of the CRRDC (CRRDC, 2018).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, outcomes, and impacts. The principal economic, environmental, and social impacts were then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. Where impact valuation was exercised, the impact assessment uses cost-benefit analysis as its principal tool. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, a high degree of uncertainty surrounding the potential impact, or the likely low relative significance of the impact compared to those that were valued. The impacts valued are therefore deemed to represent the principal benefits delivered by the project. However, as not all impacts were valued, the investment criteria reported for individual investments potentially represent an underestimate of the performance of that investment.

Background & Rationale

Background

The Australian Banana Industry

Horticulture is Australia's second largest rural production industry after wheat, with fruit and nuts comprising 52%, vegetables 31% and nursery/ornamental crops 17% of the gross value of production (GVP). (Australian Society of Horticultural Science, n.d.).

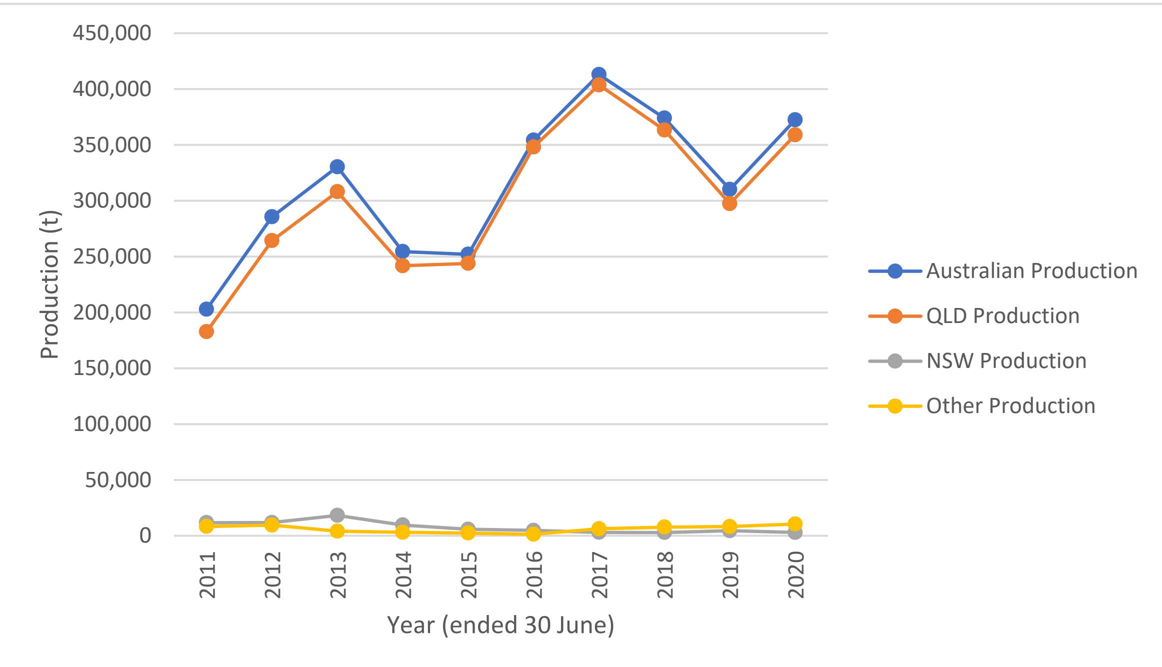
In the fruit category, bananas are Australia's number-one selling supermarket product (by volume) (Australian Banana Growers' Council Inc. (ABGC), 2021a). In the year ended 30 June 2020, Australia produced over 372,000 tonnes (t) of bananas, grown over a total area of 13,148 hectares (ha) with a GVP of approximately $647.1 million (ABS, 2021).

The vast majority of Australian bananas are sold as fresh fruit, with less than 1% of total production going to processing (e.g. dried fruit). Australia does not import or export fresh bananas. Queensland (QLD) accounts for 94% of Australia's banana production, with almost all of that in North QLD. Banana farming is centered around the Cassowary Coast region (Tully, Innisfail and Kennedy), the Atherton Tablelands, and at Lakeland, north of Cairns. The remainder of Australian banana production occurs in in New South Wales (NSW) (4%), Western Australia (WA) (2%) and the Northern Terriroty (NT) (less than 1%) (ABGC, 2021b).

Bananas are grown year round with the peak growing season between May and August. Although there are more than 500 varieties of banana plants wordwide (Hort Innovation, 2021), Cavendish bananas account for 97% of production. Lady Finger account for 3% with other varieties including Red Dacca, Goldfinger, Sucrier, Ducasse and Plantains accounting for much less than 1% (ABGC, 2021b).

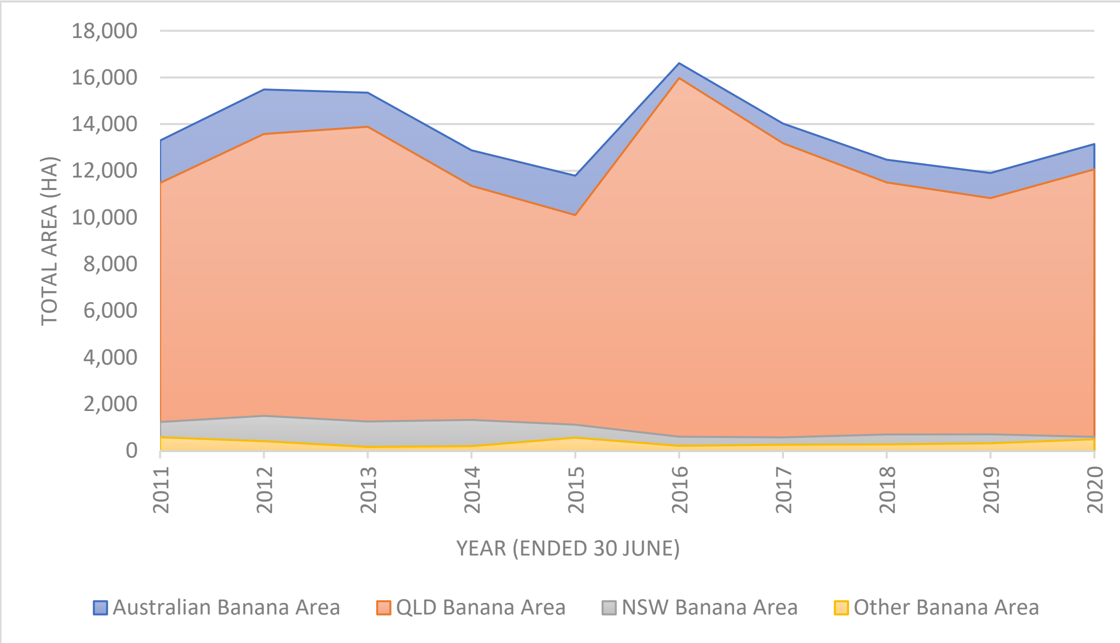
Figures 1 to 3 show the production, area, average yield and gross value statistics for the Australian banana industry over the period 2010/11 to 2019/20. The data show that production of Australian bananas has increased from approximately 200,000 tonnes in 2010/11 to close to 375,000 tonnes in 2019/20. This increase was largely due to the increase in the QLD production area, although average yields also have increased marginally over the same period.

Figure 1: Australian Banana Production (2010/11 to 2019/20)



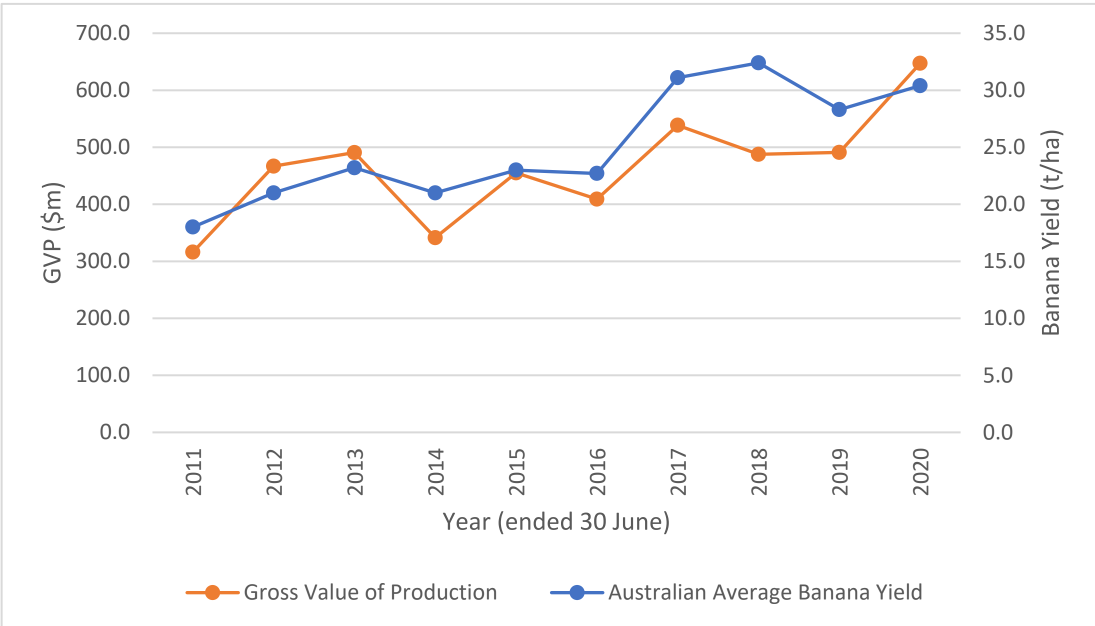
Source: Derived from ABS Catalogue 7121.0 Agricultural Commodities

Figure 2: Production Area for Australian Bananas (2010/11 to 2019/20)



Source: ABS Catalogue 7121.0 Agricultural Commodities

Figure 3: Average Australian Banana Yields (t/ha) and Gross Value of Production ($m) (2010/11 to 2019/20)



Source: ABS Catalogue 7121.0 Agricultural Commodities and ABS Catalogue 7503.0

Disease Risks to the Australian Banana Industry

The banana industry worldwide is subject to serious disease events, with Australia being no exception despite the fact that no fresh bananas are currently imported into the country. Biosecurity risks to Australian bananas are recognised by the industry in the Australian Banana Strategic Investment Plan (Hort Innovation, 2017). Pest and disease management (including broader industry biosecurity issues) is recognised as a key strategic outcome under the current Plan.

National RD&E investment for the Australian banana industry also is guided by the National Primary Industries RD&E Framework for Horticulture (National Horticulture Research Network, 2019) where biosecurity is recognised as a major investment priority.

The Framework states:

> *"Reducing the threat of pest and disease incursions is a high priority for the horticultural industry. Maintaining Australia's reputation of a supplier of pest and disease free produce is critical to market access and provides new opportunities for Australian exports. From a production perspective, the costs of control or eradication on farm profitability, make preparedness and awareness a priority."*

As of 2019, Plant Health Australia (PHA) identified two major biosecurity threats challenging the Australian banana industry (PHA, n.d.). These threats were:

1. Fusarium wilt Tropical Race 4 (*Foc* TR4, also known as Panama disease), and
2. Banana bunchy top virus in northern NSW and south-east QLD.

Fusarium wilt

Fusarium wilt (*Foc*) is a destructive fungal disease of banana plants. It is caused by the fungal plant pathogen *Fusarium oxysporum f. sp. cubense*. It first became epidemic in Panama in 1890 and proceeded to devastate the Central American and Caribbean banana industries that were based on the 'Gros Michel' variety in the 1950s and 1960s.

There are four recognised races of the *Foc* pathogen which are separated based on host susceptibility (Daly & Walduck, 2006):

- Race 1 (*Foc* R1), was responsible for the epidemics in 'Gros Michel' plantations, and also attacks 'Lady Finger', 'Silk', and 'Ducasse' varieties.
- Race 2 (*Foc* R2) affects cooking bananas such as 'Bluggoe'.
- Race 3 (*Foc* R3) affects Heliconia spp., a close relative of banana, and is not considered to be a banana pathogen.
- Race 4 (*Foc* R4) is capable of attacking 'Cavendish' as well as the other varieties of banana affected by R1 and R2. Races 1, 2 and 4 have been present on the east coast of Australia for many years and R1 also is present in WA. R4 is further divided into 'sub-tropical' (SR4) and 'tropical' (TR4) strains.

Foc TR4 is a more virulent form of the pathogen and is capable of causing disease in Cavendish bananas growing under any conditions. *Foc* TR4 was first identified in Taiwan in 1989 and has since spread rapidly. Soilborne, the *Foc* TR4 fungus enters the plant through the roots and blocks the plant's vascular system, causing it to wilt and die. *Foc* TR4 cannot be eradicated and can survive dormant in the soil for decades without host plants. It is easily spread by movement of contaminated soil and water and infected planting material (Queensland Government, 2021).

TR4 was discovered in Darwin's rural area in 1997 and has since spread to most banana growing areas of the NT. In March of 2015, *Foc* TR4 was also identified on a property in the Tully area (QLD) where a large percentage of Australian bananas are grown (O'Neill, et al., 2016).

Very few varieties are resistant to the *Foc* TR4 strain of the pathogen and despite years of breeding no commercially acceptable varieties have proven to be fully resistant, although certain selections of Cavendish (Giant Cavendish Tissue Culture Variant) have been used in Taiwan since the early 1990s (Hwang & Ko, 2004). With 94% of Australian production based in QLD, the spread of *Foc* TR4 (or other *Foc* races) has the potential to devastate the Australian banana industry.

Rationale for the Current Investments

In 2015, the Department of Agriculture and Fisheries (DAF) QLD, in partnership with Hort Innovation funded a series of projects, collectively known as the *Fusarium wilt Tropical Race 4 Research Program*, to support successful containment of the disease and prevent further spread of the pathogen. The Program also was funded to investigate options to facilitate the development of economically viable production systems capable of minimising inoculum build up, that are suitable for use on infected or 'at risk' farms. This evaluation specifically assesses component project BA14014: *Fusarium wilt Tropical Race 4 Research Program*.

Project Details

Summary

Project Code: BA14014
Title: *Fusarium wilt Tropical Race 4 Research Program*
Research Organisation: DAF QLD
Project Leader: Tony Pattison
Period of Funding: June 2015 to June 2020

Objectives

The overall aim of the project was to provide new science, information and practices that address key areas of need in the Australian banana industry, with a medium to long-term view of developing management practices for banana growers affected by *Foc* TR4.

The three themes that were addressed by this project were:

1. Development of genetic material suitable for production in TR4 affected areas and an understanding of the genetic basis for resistance to TR4.
2. Development of production systems that improve banana plant resilience through an understanding of the epidemiology of TR4 and the soil environment.
3. Tools to facilitate the adoption of biosecurity systems with particular focus on the development and implementation of a clean planting scheme for bits and suckers to complement tissue culture.

Logical Framework

Table 1 provides a detailed description of the project in a logical framework.

Table 1: Logical Framework for Project BA14014

Activities	**Activity 1.1: Generation of improved banana survival to TR4** • Five banana cultivars (Goldfinger, GCTCV119, GCTCV215, CJ19, and Dwarf Nathan) were selected for mutation breeding. • All plants from the five cultivars targeted for mutagenesis were transferred to field sites for evaluation for diseases and agronomic characteristics. Cultivars were transferred together with unirradiated control plants and additional plants were screened for agronomic characteristics and fruit quality in QLD. **Activity 1.2: Selection of improved banana survival to Panama disease** • Inoculum production procedures were refined to ensure plants produced would be uniformly infected with the *Foc* TR4 pathogen. • 791 plants were planted in-field in 2017 for testing (10 Williams, 50 non-irradiated GCTCV119 and 731 mutant GCRCV119). • Each plant was inoculated with 200 mL of *Foc* TR4 inoculated millet. • Eight months post planting (February 2018) there were 50 plant deaths recorded with *Foc* TR4 observed in inoculated Williams plants, but no disease detected in GCTCV119 plants (controls or mutant). • Mutagenesis of the five cultivars was a continuous process, with representatives of all irradiated plants undergoing assessment at different stages

	• A selection of 21 improved GCRCV119 from the NT and a selection of 20 Goldfinger plants were chosen for second generation screening for *Foc* TR4 resistance, improved agronomic characteristics or improved fruit quality. • Also, approximately 650 mutated CJ19 plants (plus controls) were planted in the NT and on a commercial farm in far northern QLD. **Activity 1.3: Marker assisted screening of germplasm for potential resistance to Panama disease** • Banana cultivars were selected and multiplied to test for genetic markers. • Assays with *Foc* SR4 showed that the following accessions were resistant with no rhizome discolouration: i) Malaccensis (851), ii) Calcutta 4 (IV9), iii) Pahang SH3362, and iv) Madang (655 from Guadeloupe). **Activity 2.1: Epidemiology of *Foc*** • Inoculum studies of *Foc* SR4 in Williams and Malaccensis cultivars were conducted to investigate the epidemiology of *Foc*. • Polymerase Chain Reaction (PCR) tests were conducted to confirm the presence of the pathogen. • Banana plants were screened to determine the survival of *Foc* following treatment of the plants with a herbicide. • Cavendish plants were inoculated with *Foc* SR4 and were stem-injected with glyphosate, paraquat, atrazine, and kerosene to determine the survival of the fungus. **Activity 2.2: Survival of Panama disease on alternative hosts** • A survey of plants co-habiting banana plantations in the NT, north QLD and the sub-tropics was conducted. • The survey was used to identify alternative hosts to *Foc* R1, SR4 and TR4. A preliminary list of the most common weed species in banana plantations was created for each region surveyed. • Identified species were sampled and fungal isolations performed. • Twelve weed species were selected to be used in an alternative host pot trial that commenced in November 2017. • Weeds were established in pots and then inoculated with 5 mL of *Foc* TR4 infested millet. • At the conclusion of the trial the root systems of surviving plants were sampled. • After the host survey and trials were completed, and results analysed, development of a guide on the host status of plants co-habiting bananas was commenced. **Activity 2.3: Rotation crops to reduce inoculum of Panama disease** • A 1.6 ha trial site near Darwin (NT) was identified. Due to no bananas having been grown at the site for two years, the site was planted to bananas to increase the inoculum in the soil before implementing rotation crops for testing. • Six rotation treatments were identified for investigation: i) Sugar graze sorghum, ii) Sweet jumbo sorghum, iii) Cavalcade (*Centrosema pascuorum*),

	iv) Envirogro Jarrah grass (*Digitaria milangiana*), v) Seca stylo (*Stylosanthes hamata*), and vi) weedy fallow. • Trials were conducted where the treatment was grown/applied for 150 days. After the treatment period, a susceptible banana cultivar (cv. Williams) was planted. • The rotation and ground cover treatments were planted on January 16, 2018. Bananas were then replanted on the site in June 2018. • Prior to the planting of the rotation crops, soil samples were taken to determine *Foc* inoculum levels and soil nutrient characteristics. **Activity 2.4: Banana microbiome** • A survey was conducted of the north QLD banana producing region. The survey sampled 17 of the most dominant soils used in banana production, which represented 77% of soils used in overall banana production. • Soil samples were collected from five banana fields showing differing degrees of plant growth. • Biological screening was conducted to determine if in-plant growth was related to differences in the soil microbiome community. • The bacteria, archaea, fungi, and other microeukarya associated with the area were characterised using phylogenetic marker gene sequencing. • Also, the microbiomes of three banana varieties (Cavendish, Gold Finger and Lady Finger), grown in five of the most dominant banana production soils, were characterised. • Twenty potential cover crops were sampled from a pasture trial in north QLD and also were screened for differences in soil microbial community composition. • *Foc* suppressive isolates were identified and trialled in pot experiments. • The project was then progressed to explore *Foc* at greater taxonomic resolution and over a larger geographical range to better understand *Foc*'s ecology and to highlight what controls the distribution of *Foc* and its diverse subspecies. • A novel risk system was established that considered the roles of plant and soil microbiomes in the management of *Foc*. **Activity 2.5: Banana nutrition** • Nutrition glasshouse trials were conducted to assess the *Foc* severity in Cavendish bananas pre-conditioned to a range of nutrient treatments. • The trials were used to determine the effect of deficient, adequate and high levels of nutrient supply on the banana plant defence mechanisms. • Soil samples were collected for analysis from sites in the NT and north QLD. • Nutrient manipulation studies were undertaken, focusing on boron and iron (Fe). **Activity 2.6: Banana soil physico-chemical properties** • A list of physico-chemical protocols was compiled. • A greenhouse pot trial was conducted using six key north QLD banana growing soil types planted with Lady Finger with and without inoculation with *Foc* R1. • Soil and plants were monitored during and at harvest. • A further investigation was conducted to determine whether Fe availability influences suppressiveness to *Foc*.

	• Fe availability was manipulated using chelating ligands with different strengths which have been shown to suppress *Foc* in other crops. **Activity 3.1: Developing and implementing a new, clean planting material system for the Australian banana industry** • A QBAN (Quality Approved Banana Nursery) committee was established to provide oversight of the activity. • Translation of the QBAN system of certification for clean banana planting material to the Nursery Industry Accreditation Scheme Australia (NIASA) / BioSecure Hazard Analysis and Critical Control Points (HACCP) was undertaken. • This involved a technical and administrational review of the QBAN Guidelines against the Nursery and Garden Industry Australia (NGIA) Nursery Production Farm Management System (FMS) programs, including the NIASA and the BioSecure HACCP Guidelines. • Two QBAN transition reference committee meetings were held, and progress on the transition was communicated to banana and production nursery industries via industry publications and industry events conducted during July 2018. • Extension services were planned to for production nurseries to support implementation of the new QBAN scheme. This was to be achieved through development of a market access tool under the BioSecure HACCP Guidelines. However, the mobile up ultimately was not developed as there was no demand for it by industry. Resources were instead used to improve the online BMP that continues to be used by industry (Tony Pattison, pers. comm., 2021). **Activity 3.2: Digital tools to assist farm biosecurity for banana producers** • A project team member was selected to sit on the project reference group (PRG) for the ABGC's 'Better Bunch' record keeping mobile app. to ensure that the app could be built upon to add features that may increase adoption of on-farm biosecurity practices. • An online biosecurity best management practice (BMP) system was developed. Validation of the online BMP tool is continuing through industry feedback as the system is rolled-out to banana growers. **Activity 3.3: TR4 capacity building** • A number of project personnel presented at conferences, workshops and other information sharing events both domestically and abroad. **Activity 4: Project governance** • A PRG was established, and a shared understanding of project priorities and objectives developed. • Throughout the project, the PRG reviewed project progress against the proposed project outputs and milestones, annual work plans, monitoring and evaluation plan, and a communication and stakeholder engagement plan. • A mid-project review was conducted by Dr Brett Summerell from the Royal Botanic Gardens (Sydney) in March 2018.
Outputs	**Activity 1.1: Generation of improved banana survival to TR4** • 1,000 GCTCV119 plants, 960 Dwarf Nathan plants, 728 Goldfinger plants, and 1,100 CJ19 plants were distributed for screening.

	• Irradiation and stabilisation of approximately 1,000 GCTCV215 plants was completed. • The project found that generating mutations has been successful in changing banana cultivar appearance. **Activity 1.2: Selection of improved banana survival to Panama disease** • A selection of 21 GCTCV119 plants from the NT for second generation screening was carried out. The new screening component will investigate *Foc* TR4 resistance, improved agronomic characteristics or improved fruit quality (Tony Pattison, pers. comm., 2021). • The Dwarf Nathan trial showed initial yellowing and wilting symptoms in Williams control plants within five months of planting, but with some recovery. • No elite plants were identified from the Dwarf Nathan trial. • Harvesting and fruit quality assessments were conducted for the Goldfinger trial and 20 Goldfinger plants have been selected for second generation screening for either *Foc* TR4 resistance, improved agronomic characteristics or improved fruit quality. • Twelve selections of irradiated plants of CJ19 were identified that had potential for the Australian banana industry. • Fifteen selections of GCTCV215 were made of plants that fulfilled the selection criteria. • For further information on improved banana variety research, see https://betterbananas.com.au/2018/01/15/banana-variety-research/ • Elite banana selections were carried over to BA16001 for further development and screening after BA14014. Further selection and refinement of cultivars has taken place and is continuing under new projects post-BA14014 (Tony Pattison, pers. comm., 2021). **Activity 1.3: Marker assisted screening of germplasm for potential resistance to Panama disease** • Both Malaccensis and Calcutta 4 were confirmed as resistant to *Foc* SR4 and TR4 in pot trials. This indicated that Calcutta 4 offers a possible alternative source of resistance to *Foc* TR4. • Resistance appears to be conferred through containment mechanisms that prevent the fungi from spreading to other parts of the plants. • Work is continuing through the International Institute of Tropical Agriculture to fine map the marker and assessments will continue to be made using any variants of the marker as they are developed. • A manuscript was published in Frontiers in Microbiology that has been viewed 6,550 times and cited seven times in other publications (Tony Pattison, pers. comm., 2021). **Activity 2.1: Epidemiology of *Foc*** • Confocal microscopy showed the presence of *Foc* in the roots, corm and lower area of the Cavendish pseudostem from 10 dpi (days post inoculation) prior to the development of external symptoms. • The presence of *Foc* in the lower area of the Lady Finger pseudostem was not observed until 40 dpi, however, it was present in the roots at 10 dpi and the corm at 20 dpi. This also was prior to the development of external symptoms.

	• A manuscript on the epidemiology studies was submitted to the journal 'Frontiers in Microbiology' (titled *The Movement of Fusarium oxysporum f.sp. cubense (Sub-Tropical Race 4) in Susceptible Cultivars of Banana)* and subsequently published in 2018. • This article has been viewed 15,136 times and cited 27 times putting it in the top 89% of articles published in the Frontiers journals (Tony Pattison, pers. comm., 2021). • A second article titled *Effect of in Planta Treatment of 'Cavendish' Banana with Herbicides and Fungicides on the Colonisation and Sporulation by Fusarium oxysporum f.sp. cubense* was published in the open access journal, titled Journal of Fungi in February 2021 (Tony Pattison, pers. comm., 2021). **Activity 2.2: Survival of Panama disease on alternative hosts** • From north Queensland, the following species were found to host *Foc* R1: i) *Youngia japonica*, ii) Summer grass (*Digitaria ciliaris*), iii) Crowsfoot grass (*Eleusine indica*), and iv) Spiny spider flower (*Cleome aculeate*). • From northern NSW, *Foc* was detected from: i) Paragrass, ii) Weeping grass, iii) Horse weed, iv) Miniature stonecrop, and v) Clover sour. • In the NT two species tested positive for *Foc* TR4: i) *Euphorbia hirta*, and ii) *Cyanthillium cinereum*. Other *Foc* species were detected in two other weed species, but further testing found that they were *F. solani* and *F. equiseti*. • All weed species showed some level of infection by TR4, with some species showing a lower frequency of *Foc* TR4 from root isolation than others. • A grower manual, depicting weeds of bananas and their host status for *Foc*, was developed. Currently, 30 potential alternative hosts have been included with two weeds (*Euphorbia heteophylla* and *Cyanthillium cinereum*) rated as high host potential to TR4. • Five weeds were rated as medium-high, five as medium, nine as low, five as very low, and five as non-hosts based on the field and pot trial surveys. • Fifty alternative host species were found in banana plantations and characterised based on their ability to host *Foc* R1, *Foc* SR4 and *Foc* TR4 from the field surveys and glasshouse experiments. • All experiments were completed and 500 copies of the grower guide were produced and circulated to industry. Circulation of remaining guides has continued at industry events such as the Australian Banana Industry Congress (Tony Pattison, pers. comm., 2021). **Activity 2.3: Rotation crops to reduce inoculum of Panama disease** • Eighteen different potential rotation crops were ultimately screened for their ability to supress *Foc* TR4. • In the first trial it was shown that none of the trialled rotation crops was significantly better at reducing *Foc* than bare soil or having disease levels similar to uninoculated soil.

	• Bananas (cv. Williams) grown after rotation crops started showing *Foc* TR4 symptoms from December 2018. • However, two legumes *Macroptilium bracteatum (*Burgundy bean) and *Leucaena leucocephela* (Leucaena), and two grasses *Paspalum dilatum* and *Digitaria didactyla* had *Foc* recovery levels similar to uninoculated soil and underwent further evaluation. • The experiments were extended, and sugarcane lines were sourced for further investigation to determine growth and persistence of *Foc* in their roots using *Foc* SR4. **Activity 2.4: Banana microbiome** • Results of the microbiome experiments indicated that fungal and bacterial community composition differed strongly between soils. • The difference in infection rates between soils, which may be considered representative of differences in *Foc* suppressiveness, was significantly associated with shifts in the composition of both bacterial and fungal communities. • A significant influence of banana genotype was also found for fungal, but not bacterial, communities, and found that there were distinct communities associated with different plant compartments. • A publication titled *Sampling Microbiomes Associated with Different Plant Compartments* has been downloaded 598 times since being published on November 8, 2020 (Tony Pattison, pers. comm., 2021). • *Fusarium oxysporum* was found to be among the most dominant fungal taxa in all soils and plants studied. • The BA14014 research team demonstrated that elimination of the soil microbiome can increase *Foc* colonization rates of soil by up to x10,000. This highlighted the importance of soil microbiomes in mitigating *Foc* risk. **Activity 2.5: Banana nutrition** • 81 different soil and plant characteristics were determined. • Bioassays of soils from field trials with different nitrogen rates showed that tolerance of bananas was enhanced in soil with low application of nitrogen compared to a high rate of nitrogen. This was demonstrated by a lack of external symptom development with increasing rhizome necrosis in soils that had a history of low nitrogen application. • Further, there was some evidence that high applications of nitrogen reduced the tolerance of bananas to *Foc* by changing the microbial community within the soil. • Recommendations on nutrient application from aeroponics trials found that a deficiency in boron may increase plant susceptibility to *Foc,* possibly through loss of cell wall strength. **Activity 2.6: Banana soil physico-chemical properties** • A published review on soil physiochemical properties relating to Fusarium wilt was published in December 2018 and has since been cited 21 times (Tony Pattison, pers. comm., 2021). • The study found that a significant reduction in disease severity was achieved by addition of the strong chelating agents Fe-EDDHA and Fe-FHBED, which reduce the availability of Fe. However, the effect was small (approximately 10% reduction in discoloration of corm). A further experiment was conducted to determine the effects of chelator application rate.

	• Experiments manipulating the physiochemical properties of soil using Fe-chelating agents had no consistent effect on growth of bananas and severity of *Foc*. • Further work was planned to examine the effect of nitrogen application rate, the effect of soil pH, and the effect of optimising several soil parameters at once. • A number of papers were submitted and published in several academic journals (e.g. Applied Soil Ecology). **Activity 3.1: Developing and implementing a new, clean planting material system for the Australian banana industry** • The review concluded that the NGIA Nursery Production FMS provides a stable platform for inclusion of the QBAN Scheme within its Guidelines. • Progress on the transition of the QBAN Accreditation Scheme into NIASA and BioSecure HACCP scheme requirements continued to meet project milestones. • NIASA High Health Banana Plantlet Production requirements have been translated into the NIASA Guidelines and software updates were completed. Requirements were included as 'Appendix 14' to the Guidelines. • The appendix provides banana high health best practice guidance in relation to collection of banana material from mother blocks, tissue culture production, and nursery production of banana plantlets. • Further, it was determined that the existing BioSecure HACCP Guidelines would not need amendment or addition of specific project related procedures to facilitate market access related movement control requirements. • The majority of QBAN accredited businesses expressed strong support for the continuation of a scheme to provide an ongoing source of clean banana planting material for the Australian banana industry. • The transition of the QBAN into NIASA/BioSecure HACCP was finalised in August 2019. **Activity 3.2: Digital tools to assist farm biosecurity for banana producers** • The online biosecurity BMP system was developed to mirror the existing environmental BMP used in the banana industry and utilise the questions in the self-assessment checklist and information resource of the on-farm biosecurity BMP. • The system was designed to auto-populate a current management plan based on the answers that growers provide and based on current biosecurity practices they have in place. **Activity 3.3: TR4 capacity building** • David East (DAF), attended a *Foc* workshop hosted by Forestry and Agricultural Biotechnology Institute, University of Pretoria, South Africa. • Tony Pattison and Anna McBeath travelled to Montpellier, France for the ProMusa conference focusing on agroecological management of banana plantations (October 2016). • A Panama disease field day was undertaken in May, 2017 (109 attendees) with smaller field days for banana growers in November 2017 and February 2018. A full list of events and activities, including attendance figures, was included in the BA14014 final report.

	• Eighteen articles were published in 'Australian Bananas' magazine with a summary of the mid-project achievements. • Components of the project were disseminated to 140 banana industry personnel through the Banana Roadshows in July and August of 2018. • Presentations were made at the 22nd ACORBAT International Banana Congress in Miami (USA, May 2018), the 11th International Congress of Plant Pathology in Boston (USA, July-August 2018), and the 10th Australasian Soilborne Disease Symposium (Adelaide, September 2018). • Steward Lindsay attended the World Banana Forum and had discussions with the Food and Agriculture Organisation of the United Nations (Rome, Italy) and CIRAD[1] researchers (Montpellier, France) about accessing global TR4 research. • Negotiations were undertaken with Dr Philppe Tixier of CIRAD for international collaboration on developing modelling systems to investigate how an integrated approach to managing *Foc* TR4 can best be deployed for the Australian banana industry. **Activity 4: Project governance** • A mid-project review was produced and stated that: "*the project was proceeding well and meeting all expected outputs and associated key performance indicators. The project governance and management is excellent and all the documentation provided of a high quality. The science and research methodology is appropriate and effective but expectations must be tempered to reflect the difficulty of working with this pathogen and the time scales necessary to achieve industry goals. It can be expected that the project will deliver a range of excellent science, a number of management practices to recommend to the industry, and an excellent cohort of scientists to lead and develop future research on this pathogen and the disease that it causes*".
Key Outcomes	• Scientific interest in the project was high due to the multi-disciplinary approaches used that incorporated plant-pathology, plant science, soil science, microbiology, soil ecology and horticulture science. • The selection and breeding of banana cultivars for *Foc* resistance, improved agronomic characteristics and improved fruit quality has been improved. No formal banana improvement program existed in Australia prior to project BA14014. • There was a shift in how banana cultivars are screened based on the initial outcomes from the first cultivar that underwent mutagenesis (GCTCV119). This cultivar maintained its resistance to *Foc* TR4 after irradiation, therefore greater emphasis was placed on agronomic characteristics. • Currently, available cultivars with resistance to *Foc* TR4 are 20% less productive than other commercially available cultivars. New cultivars developed through the banana improvement program have the potential to close this gap (Tony Pattison, pers. comm., 2021). • The epidemiology work allowed a re-focus of research on when *Foc* spores are being produced in banana plants which, in turn, may allow a refinement in activities used to suppress the production of *Foc* spores.

[1] CIRAD: the French agricultural research and international cooperation organisation working for the sustainable development of tropical and Mediterranean regions. For more information see: https://www.cirad.fr/en

	• Researchers and industry stakeholders now are more aware of which soils are likely to have *Foc* develop at a rapid rate if allowed to go unmanaged and there is increased awareness of the value of vegetated ground cover to reduce soil movement and the spread of disease. • A end-of-project impact opinion survey that assessed the effectiveness, relevance, engagement, appropriateness, and efficiency rated BA14014's impact in terms of TR4 capacity building at 3.8, 4.0, 3.8, 3.8, and 3.4 out of 5 respectively. • Australian banana growers have and continue to adopt *Foc* TR4 Research Program outputs (such as the grower manual on weeds and their *Foc* host status, information regarding rotation crops, and the biosecurity BMP app/online system) to improve the on-farm biosecurity practices and improve the containment of existing *Foc* TR4 infestations. • Evidence of the effectiveness of Australia's adoption of new and improved biosecurity measures can be seen by comparing a known outbreak in Colombia where 10 farms were infected. Despite implementing biosecurity measures, over 1,200 plants have been infected since 2019. Farms in NQ implementing biosecurity and farm management practices as recommended have recorded under 10 infected plants since 2017 (Tony Pattison, pers. comm., 2021). • The project built significant links with international researchers working in *Foc* TR4, particularly in France and the United States of America. • The research team also continued work to identify which microbes live in association with bananas, what they do, and how they can be controlled to manage *Foc* in the future. • The BA14014 team also identified a core set of bacterial and fungal taxa that are associated with Musa spp. across different soils, genotypes and plant ages.
Potential Impacts	• [Economic] Avoided future banana production losses from *Foc* TR4 for some Australian growers because of: a) A reduction in the risk of incursion (new incursions) and/or spread (existing infestations) of *Foc* TR4 for the Australian banana industry, particularly the north QLD production region b) Some contribution to the development and future adoption of *Foc* TR4 resistant cultivars through the banana improvement program c) More efficient/ effective implementation of on-farm biosecurity practices (e.g. through use of the biosecurity BMP online system). d) Increased industry capacity through biosecurity education and training. • [Economic] Improved efficiency and/or effectiveness of resource allocation associated with investment in banana breeding through improved prioritisation. • [Economic] Improved efficiency and/or effectiveness of resource allocation for *Foc* TR4 RD&E investment. • [Social] Increased scientific knowledge and research capacity through the creation of new knowledge (e.g. knowledge of the banana microbiome), biosecurity education and training, and facilitation of international collaborative networks. • [Social] Potentially, maintained regional community wellbeing through spillover benefits of a more secure banana industry.

Project Investment

Nominal Investment

Table 2 shows the annual investment made in Project BA14014 by Hort Innovation and other funding partners.

Table 2: Annual Investment in Project BA14014 (nominal $)

Year ended 30 June	HORT INNOVATION[(a)] ($)	DAF QLD ($)	OTHERS[(b)] ($)	TOTAL ($)
2016	1,111,310	250,000	358,127	1,719,437
2017	1,111,310	250,000	358,127	1,719,437
2018	1,111,310	250,000	358,127	1,719,437
2019	1,111,310	250,000	358,127	1,719,437
2020	54,759	29,965	0	84,724
Total	**4,500,000**	**1,029,965**	**1,432,508**	**6,962,472**

Source: BA14014 Executed Research Agreement and Contract Variation documents supplied by Hort Innovation 2021

(a) Based on total Hort Innovation managed funds of $4.5 million (nominal dollars) from R&D strategic co-investment funds. Allocated by financial year on the basis of the proportion of annual investment by others for each year.

(b) Other project partners included: the Northern Territory Department of Agriculture and Fisheries, the University of Queensland, and James Cook University.

Program Management Costs

For the Hort Innovation investment the cost of managing the Hort Innovation funding was added to the Hort Innovation contribution for the project via a management cost multiplier (x1.162). This multiplier was estimated based on the share of 'payments to suppliers and employees' in total Hort Innovation expenditure (3-year average) reported in the Hort Innovation's Statement of Cash Flows (Hort Innovation Annual Report, various years). This multiplier was then applied to the nominal investment by Hort Innovation shown in Table 2.

For the DAF investment, the management and administration costs for the project are already built into the nominal dollar amounts appearing in Table 2. A salary multiplier of 2.85 was used (Wayne Hall, pers. comm., 2017).

Finally, a 10.0% management and administration cost was included to account for overheads associated with the contribution of others to the total project investment. This cost is in addition to the other contribution amounts shown in Table 2.

Real Investment and Extension Costs

For purposes of the investment analysis, the investment costs of all parties were expressed in 2019/20 dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP) (ABS, 2020). No additional costs of extension were included as the project encompassed a range of communication and extension components.

Impacts

Table 3 provides a summary of the principal types of impacts delivered by the project, based on the logical framework. Impacts have been categorised into economic, environmental, and social impacts.

Table 3: Triple Bottom Line Categories of Principal Impacts from Project BA14014

Economic	• Avoided future banana production losses from *Foc* TR4 for some Australian growers because of: a) A reduction in the risk of incursion (new incursions) and/or spread (existing infestations) of Foc TR4 for the Australian banana industry, particularly the north QLD production region. b) Some contribution to the development and future adoption of Foc TR4 resistant cultivars through the banana improvement program c) More efficient/ effective implementation of on-farm biosecurity practices (e.g. through use of the biosecurity BMP online system). d) Increased industry capacity through biosecurity education and training. • Improved efficiency and/or effectiveness of resource allocation associated with investment in banana breeding through improved prioritisation. • Improved efficiency and/or effectiveness of resource allocation for *Foc* TR4 RD&E investment.
Environmental	• Nil.
Social	• Increased scientific knowledge and research capacity through the creation of new knowledge (e.g. knowledge of the banana microbiome), biosecurity education and training, and facilitation of international collaborative networks. • Potentially, maintained regional community wellbeing through spillover benefits of a more secure banana industry.

Public versus Private Impacts

The primary impacts identified from the investment were private in nature. Private impacts are likely to accrue to Australian banana growers through reduced future production losses and increased efficiency/ effectiveness of resource allocation associated with banana breeding and *Foc* TR4.

However, increased efficiency/ effectiveness of resource allocation for banana breeding and *Foc* TR4 RD&E will impact both private and public stakeholders that fund such research (e.g. banana levy payers and state government departments). Other public benefits may be produced in the form of increased scientific knowledge and research capacity.

Distribution of Private Impacts

The primary beneficiaries of the Fusarium wilt TR4 Research Program are Australian banana growers. Particularly those growers in the QLD production region and/or those growing Cavendish banana varieties.

Private impacts will be distributed along the banana supply chain and the share of impact realised by each component of the banana supply chain will depend on both short- and long-term supply and demand elasticities in the banana market.

Impacts on Other Australian Industries

With further/ additional research, it is possible that impacts from the project will be relevant to growers in related Australian industries such as the nursery industry and the sugar industry. This is particularly true for RD&E related to biosecurity BMPs.

Impacts Overseas

No significant impacts to overseas parties were identified. However, improved international scientific and industry networks that improve *Foc* information sharing may have some impact on foreign banana industries dealing with *Foc* infestations.

Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 4. The project outcomes and impacts are likely to contribute primarily to Rural RD&E Priority 2, with some contribution to Priorities 3 and 4, and to Science and Research Priority 1.

Table 4: Australian Government Research Priorities

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

Sources: (DAWE, 2019) and (Australian Government, 2015)

Alignment with the Banana Strategic Investment Plan 2017-2021

The strategic outcomes and strategies of the Australian banana industry are outlined in the Banana Industry's Strategic Investment Plan 2017-2021[2] (Hort Innovation, 2017). Project BA14014 primarily addressed Outcome 1 through:

- Strategy 1.1: Conduct research into new disease-resistant varieties that also have consumer appeal,
- Strategy 1.2: Collaborate with the international community to accelerate the identification and development of disease-resistant varieties, and
- Strategy 1.3: Continue research to improve pest and disease management and biosecurity.

Further, BA14014 also addressed Outcome 2 through Strategy 2.1 (Continue to drive adoption of BMP for on-farm biosecurity to ensure biosecurity risks are minimised) and Strategy 2.2 (Strategically communicate the industry's biosecurity and environmental BMP to the community).

[2] For further information, see: https://www.horticulture.com.au/hort-innovation/funding-consultation-and-investing/investment-documents/strategic-investment-plans/

Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some 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.

One key economic impact was valued in monetary terms:

- Avoided future banana production losses from *Foc* TR4 for some Australian growers driven by:
  a) A reduction in the risk of incursion (new incursions) and/or spread (existing infestations) of Foc TR4 for the Australian banana industry, particularly the north QLD production region.
  b) Some contribution to the development and future adoption of Foc TR4 resistant cultivars through the banana improvement program.
  c) More efficient/ effective implementation of on-farm biosecurity practices (e.g. through use of the biosecurity BMP online system).
  d) Increased industry capacity through biosecurity education and training.

Impacts Not Valued

Not all of the impacts identified in Table 3 could be valued in the assessment. Those not valued included:

- Improved efficiency and/or effectiveness of resource allocation associated with investment in banana breeding through improved prioritisation.
- Improved efficiency and/or effectiveness of resource allocation for *Foc* TR4 RD&E investment.
- Increased scientific knowledge and research capacity through the creation of new knowledge (e.g. knowledge of the banana microbiome), biosecurity education and training, and facilitation of international collaborative networks.

These impacts were not valued largely due to lack of data to support credible assumptions. More specific reasons for non-valuation are described below:

<u>Improved efficiency of investment in banana breeding and improved efficiency of *Foc* TR4 RD&E investment</u>

The coordination, collaboration and sharing of R&D through the investment in the Fusarium wilt TR4 Research Program was a strong element of banana disease R&D investments including breeding for disease resistance.

The general dissemination of information regarding banana disease research and the interactions of an international network of banana experts are likely to generate benefits through improved prioritisation and working towards the best use of available research monies.

These impacts were not valued primarily due to difficulties in forming the counterfactual, that is, what would have been the characteristics of investments and their impacts if the Fusarium wilt TR4 Research Program had not been funded (e.g. lesser impacts or the same impact but requiring a higher level of investment). Further, data on the total investment in *Foc* RD&E and banana breeding for Australia was not readily available and information on which to base credible assumptions was limited to expert opinion.

<u>Increased scientific knowledge and research capacity</u>

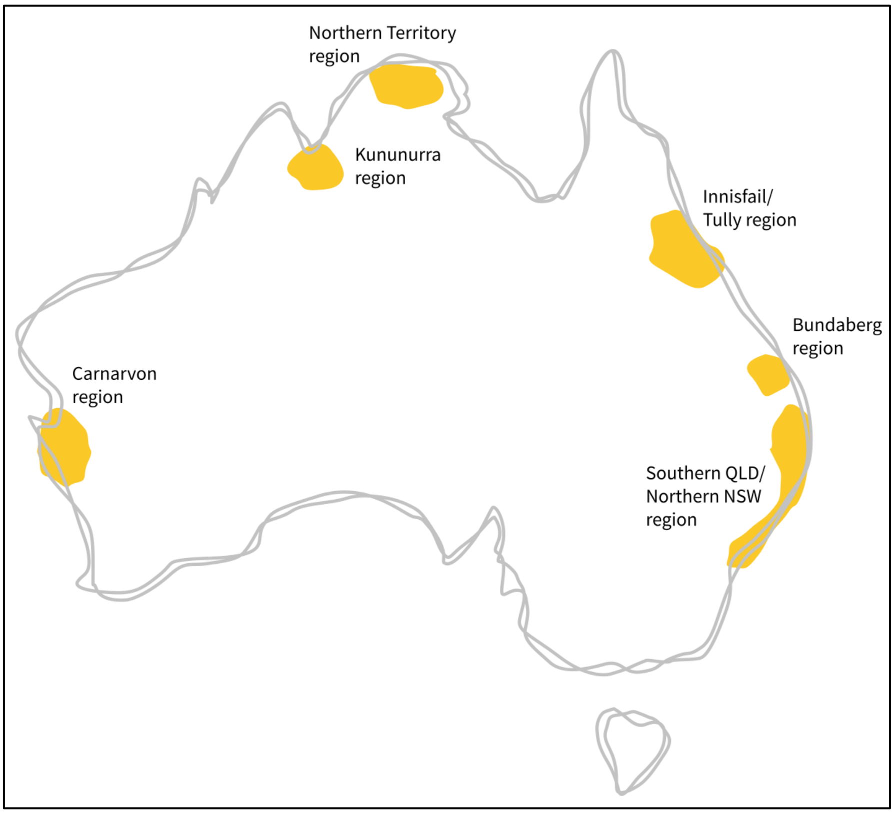
The Fusarium wilt TR4 Research Program supported various PhD projects, international scientific and industry collaborations and networks, and contributed to the wider body of scientific knowledge. The investments have also consistently worked towards developing general scientific capacity (e.g. developing new, validated research methodologies and conducting researcher training), some of which will enhance the availability of expertise in future responses to *Foc* outbreaks.

It is difficult to quantify the magnitude of such capacity enhancement because the initial level of capacity was unknown and placing a monetary value on human capacity requires the application of non-market valuation techniques that were beyond the scope of the current impact assessment.

Valuation of Impact 1: Avoided future banana production losses from *Foc* TR4

Foc TR4 is named 'tropical race 4' because the TR4 strain of the fungus is capable of infecting Cavendish banana varieties growing in tropical conditions (Biosecurity Queensland, 2016). The wet tropical coast of northern QLD between Babinda and Cardwell (shown in Figure 3) is Australia's main banana growing area, accounting for between 70% and 80% of the Australia's national production (Deuter, White, & Putland, 2012; Steward Lindsay, pers. comm., 2019).

Figure 4: Map of Australian Banana Growing Regions



Source: https://australianbananas.com.au/Pages/all-about-bananas/the-banana-story

Once a plantation becomes infected with *Foc* TR4, prevention of spread can only be achieved by the destruction of infected plants, maintenance of a surrounding buffer zone with no banana plants, limiting water run-off and restricting access using fences and long-term fallow of affected land. There are no known long-term chemical options for management of *Foc* TR4 (Cook, Taylor, Meldrum, & Drenth, 2015).

Potential industry losses WITHOUT the investment (counterfactual)

It was assumed that, without the investment in the Fusarium wilt TR4 Research Program there would be a greater risk of future *Foc* TR4 incursions becoming established and spreading to a proportion of the tropical QLD banana industry causing significant economic losses. Without the investment, it also was assumed that quarantine efforts for future incursions would be less effective, therefore the potential spread of *Foc* TR4 would be faster than it would with the investment.

Industry losses WITH the investment

It was assumed that, with the investment in BA14014, the risk of future incursion, establishment and spread of *Foc* TR4 would be lower and that quarantine efforts would be more effective therefore slowing the spread of the disease by half.

Attribution

Project BA14014 was a significant investment (approximately $6.96 million in nominal terms). However, BA14014 was only one investment in a series of RD&E investments made since 2015 targeting *Foc* TR4 for the Australian banana industry. The total expenditure on *Foc* TR4 RD&E and biosecurity measures was uncertain and credible data were not readily available. To accommodate this uncertainty and the contribution of other RD&E to the impacts identified in Table 4, an attribution factor of 50% was applied to the estimated benefits.

Specific assumptions used in the valuation are detailed in Table 5.

Summary of Assumptions

A summary of the key assumptions made for the valuation of Impact 1: Avoided future banana production losses from *Foc* TR4 for some Australian growers is reported in Table 5.

Table 5: Summary of Assumptions for Impact Valuation

Variable	**Assumption**	**Source[(a)]**
General Assumptions		
Australian banana production (3-year average, 2018-2020)	380.72 kt	Australian Horticulture Statistics Handbook – Fruit (2018-2020)
Australian banana production area (3-year average, 2018-2020)	11,589 ha (bearing age)	ABS Agricultural Commodities Statistics Series 7121.0 (various years) Derived yield = 380.72 x 1,000 / 11,589 ha
QLD production and area as a proportion of the total Australian banana industry	996.5% production 92.7% bearing area	
QLD banana yield (3-year average, 2018-2020)	32.9 t/ha	
Australian banana industry value – gross value of production (3-year average, 2018-2020)	$548.3 million	Australian Horticulture Statistics Handbook – Fruit (2018-2020)
Impact 1: Avoided future banana production losses from *Foc* TR4		
WITHOUT the investment		
Probability of *Foc* TR4 spreading to the rest of the tropical QLD banana industry	10% in any year	Chudleigh, Hardaker, Abell, & Clarke, 2019
Proportion of QLD production potentially affected by the spread of *Foc* TR4	45% (approximately 60% of the production occurring in the tropics at 75% of total Australian production)	
Time to reach maximum spread and impact	10 years	

Impact cost of *Foc* TR4 to the Australian banana industry should the disease become widespread	$152.7 million p.a. (2019/20 dollar terms – updated using the Implicit Price Deflator for GDP)	Based on $138 million p.a. in 2015 dollar terms (Cook *et al.*, 2015)
WITH the investment		
Probability of *Foc* TR4 spreading to the rest of the tropical QLD banana industry	9% in any year (reduction of 1% compared to the without scenario)	Analyst assumption
First year of impact of reduced risk of spread	2016/17	Assumes early BA14014 outputs begin to be adopted quickly (e.g. on-farm biosecurity measures and BMPs) due to the severity of potential losses from *Foc* TR4
Proportion of QLD production potentially affected by the spread of *Foc* TR4	45% (approximately 60% of the production occurring in the tropics at 75% of total Australian production)	Chudleigh, Hardaker, Abell, & Clarke, 2019
Time to reach maximum spread and impact	20 years (investment contributes to slowing spread by half)	
Risk Factors		
Probability of output	100%	Based on successful completion of Project BA14014
Probability of outcome (usage)	80%	A large number of growers and industry stakeholders have already adopted biosecurity practices to improve the containment and control of *Foc* TR4. This probability takes into account those yet to adopt BMPs, those who will not adopt, and any dis-adoption.
Probability of impact	50%	Allows for uncertainty regarding future control methods used to contain and control *Foc* TR4 in the tropical Australian banana industry (e.g. new technologies, resistant (non-Cavendish) banana varieties).
Attribution of benefits to the specific investment in BA14014	50%	Analyst assumption

Results

All costs and benefits were discounted to 2019/20 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 level of uncertainty for many of the estimates. All analyses ran for the length of the project investment period plus 30 years from the last year of investment (2019/20) as per the CRRDC Impact Assessment Guidelines (CRRDC, 2018).

Investment Criteria

Tables 6 and 7 show the investment criteria estimated for different periods of benefits for the total investment and the Hort Innovation investment alone. The present value of benefits (PVB) for the Hort Innovation investment was estimated by multiplying the total PVB cash flow by the proportion of Hort Innovation managed real investment (66.7%).

Table 6: Investment Criteria for Total Investment in Project BA14014

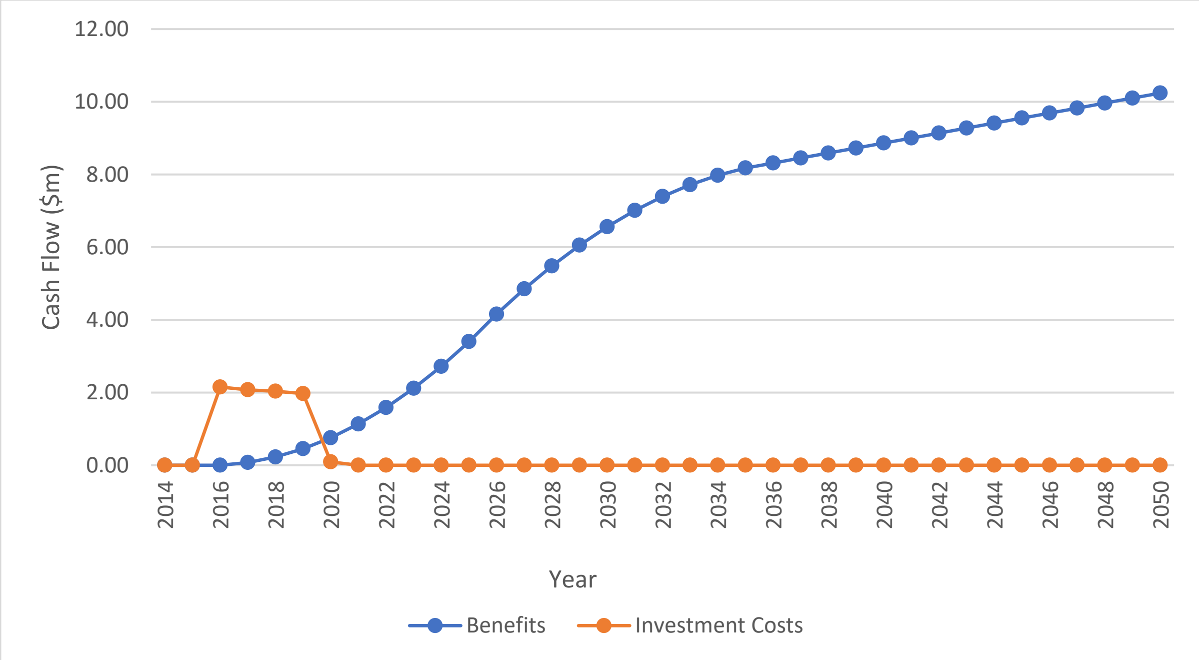
Investment Criteria	Years after Last Year of Investment						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	1.57	10.82	29.01	49.28	67.14	82.26	94.98
Present Value of Costs ($m)	9.43	9.43	9.43	9.43	9.43	9.43	9.43
Net Present Value ($m)	-7.86	1.40	19.59	39.86	57.72	72.83	85.55
Benefit-Cost Ratio	0.17	1.15	3.08	5.23	7.12	8.73	10.08
Internal Rate of Return (%)	negative	7.7	20.6	23.7	24.6	24.8	24.9
MIRR (%)	negative	8.2	18.3	17.9	16.3	14.9	13.8

Table 7: Investment Criteria for Hort Innovation Investment in Project BA14014

Investment Criteria	Years after Last Year of Investment						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	1.05	7.22	19.36	32.89	44.81	54.90	63.39
Present Value of Costs ($m)	6.29	6.29	6.29	6.29	6.29	6.29	6.29
Net Present Value ($m)	-5.24	0.93	13.07	26.60	38.52	48.61	57.10
Benefit-Cost Ratio	0.17	1.15	3.08	5.23	7.12	8.73	10.08
Internal Rate of Return (%)	negative	7.7	20.6	23.7	24.6	24.9	24.9
MIRR (%)	negative	8.2	18.3	17.9	16.3	14.9	13.8

The annual undiscounted benefit and cost cash flows for the total investment for the duration of the BA14014 investment plus 30 years from the last year of investment are shown in Figure 5.

Figure 5: Annual Cash Flow of Undiscounted Total Benefits and Total Investment Costs



Sensitivity Analyses

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 8 presents the results. The results show sensitivity to the discount rate reflecting the lag between project cost and the generation of maximum project benefits.

Table 8: Sensitivity to Discount Rate (Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present Value of Benefits ($m)	217.00	94.98	49.59
Present Value of Costs ($m)	8.33	9.43	10.64
Net Present Value ($m)	208.67	85.55	38.95
Benefit-cost ratio	26.06	10.08	4.66

The key driver of the valuation of Impact 1 was the assumption of a reduced probability of *Foc* TR4 spreading to the rest of the tropical QLD banana industry. Therefore, a sensitivity analysis was undertaken on the reduction in the probability of spread assumed. Results are provided in Table 9. The investment criteria showed only a moderate to low sensitivity to the assumed reduction in the probability of spread. This may indicate that the return on investment in BA14014 (and similar *Foc* TR4 RD&E) that contribute to reducing the risk of spread of *Foc* TR4 in QLD, given the estimated impact costs of *Foc* TR4 should it become endemic, may be highly positive.

Table 9: Sensitivity to Probability of Foc TR4 Spreading
(Total investment, 30 years, 5% discount rate)

Investment Criteria	**Probability of *Foc* TR4 spreading to the rest of the Tropical QLD banana industry**		
	Reduction of 0.1%	**Reduction of 1.0% (base)**	**Reduction of 2.5%**
Present Value of Benefits ($m)	79.71	94.98	120.43
Present Value of Costs ($m)	9.43	9.43	9.43
Net Present Value ($m)	70.28	85.55	111.00
Benefit-cost ratio	8.46	10.08	12.78

Confidence Rating

The results produced are highly dependent on the assumptions made, some 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 10). 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 10: Confidence in Analysis of Project

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

Coverage of benefits valued was assessed as High as the primary economic impact, avoided future production losses from reduced probability of spread of *Foc* TR4, was valued in the assessment.

Confidence in assumptions was rated as Medium. This rating was given because, though most of the data and assumptions used were from credible sources and expert opinion, there is uncertainty about how much the investment in Project BA14014 may have reduced the probability of *Foc* TR4 spreading. However, the investment criteria showed a moderate to low sensitivity to the assumption associated with the risk of *Foc* TR4 spreading (Table 9).

Conclusion

The investment in BA14014 has contributed to improved on-farm and off-farm biosecurity against *Foc* TR4 reducing the risk of future incursions or spread of the disease. Further, the investment has likely contributed to the development and future adoption of *Foc* TR4 resistant banana cultivars and to improved efficiency and/ or effectiveness of resource allocation associated with *Foc* TR4 RD&E and banana breeding.

Total funding from all sources for the project was $9.43 million (present value terms). The investment produced estimated total expected benefits of $94.98 million (present value terms). This gave a net present value of $85.55 million, an estimated benefit-cost ratio of 10.08 to 1, an internal rate of return of 24.9% and a modified internal rate of return of 13.8%.

As a number of economic and social impacts identified were not valued, the investment criteria estimated by the evaluation are likely to be an underestimate of the actual performance of the investment in Project BA14014.

Glossary of Economic Terms

Cost-benefit analysis:	A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs), regardless of to whom they accrue.
Benefit-cost ratio:	The ratio of the present value of investment benefits to the present value of investment costs.
Discounting:	The process of relating the costs and benefits of an investment to a base year using a stated discount rate.
Internal rate of return:	The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs.
Investment criteria:	Measures of the economic worth of an investment such as Net Present Value, Benefit-Cost Ratio, and Internal Rate of Return.
Modified internal rate of return:	The internal rate of return of an investment that is modified so that the cash inflows from an investment are re-invested at the rate of the cost of capital (the re-investment rate).
Net present value:	The discounted value of the benefits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs.
Present value of benefits:	The discounted value of benefits.
Present value of costs:	The discounted value of investment costs.

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Abbreviations

ABGC	Australian Banana Growers' Council (Incorporated)
ABS	Australian Bureau of Statistics
AuSHS	Australian Society of Horticultural Science
BBTV	Banana Bunchy Top Virus
BMP	Best Management Practice
CBA	Cost-Benefit Analysis
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries (QLD)
DAWR	Department of Agriculture and Water Resources (Commonwealth)
dpi	days post inoculation
DPIR	Department of Primary Industry and Resources (NT)
DST	Decision Support Tool
FAO	Food and Agriculture Organisation (UN)
Fe	Iron
FMS	Farm Management System
Foc	Fusarium oxysporum g. sp. cubense
GVP	Gross Value of Production
HACCP	Hazard Analysis and Critical Control Point
HIA	Horticulture Innovation Australia Limited (also known as Hort. Innovation)
IITA	International Institute of Tropical Agriculture
NBI	Nitrogen Balance Index
NDP	National Diagnostic Protocols
NDVI	Normalised Difference Vegetation Index
NGIA	Nursery and Garden Industry Australia
NIASA	Nursery Industry Accreditation Scheme Australia
NSW	New South Wales
NT	Northern Territory
PCR	Polymerase Chain Reaction
PHA	Plant Health Australia

PRG	Project Reference Group
QA	Quaternary Ammonium
QBAN	Quality Approved Banana Nursery
QLD	Queensland
R&D	Research and Development
RAT	Risk Assessment Tool
RD&E	Research, Development and Extension
RDC	Research and Development Corporation
TR4	Tropical Race 4 (a race of the Fusarium wilt pathogen)
WA	Western Australia