Industry-specific impact assessment program: apple and pear

Impact assessment report for project *Extension AP05002: Alternaria Fruit Spot: New Directions* (AP06007)

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AgEconPlus and Agtrans Research

Project code:

MT18009

Date:

18 October 2019

Disclaimer:

Funding statement:

This project has been funded by Hort Innovation, using research and development levies and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

Published and distributed by: Hort Innovation

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What the report is about

This report presents the results of an impact assessment of a Horticulture Innovation Australia Limited (Hort Innovation) investment in project AP06007 titled "*Extension AP05002: Alternaria Fruit Spot: New Directions*". The project was funded by Hort Innovation over the period September 2006 to December 2013.

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 2017/18 dollar terms and were discounted to the year 2018/19 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 AP06007 has produced new management protocols to mitigate the impacts of *Alternaria* leaf blotch and fruit spot in the Australian apple industry. Consequently, AP06007 is likely to have contributed to reduction production losses (yield) and reduced quality downgrades for Australian apple growers resulting in a more productive and profitable Australian apple industry.

Investment Criteria

Total funding from all sources for the project was $2.75 million (present value terms). The investment produced estimated total expected benefits of $25.08 million (present value terms). This produced an estimated net present value of $22.42 million, a benefit-cost ratio of 9.1 to 1, an internal rate of return (IRR) of 22.9% and a MIRR of 11.9% over 30-years at a discount rate of 5%.

Conclusions

A number of environmental and social impacts were also identified but not valued as part of the current assessment. Thus, given the impacts not valued, combined with conservative assumptions made for the principal economic impacts valued, it is reasonable to conclude that the investment criteria reported may be an underestimate of the actual performance of the AP06007 investment.

Keywords

Impact assessment, cost-benefit analysis, AP06007, Extension AP05002, Alternaria Fruit Spot, Alternaria Leaf Blotch, disease management, apple

Introduction

All research and development (R&D) and marketing levy investments undertaken by Horticulture Innovation Australia Limited (Hort Innovation) are guided and aligned to specific investment outcomes, defined through a Strategic Investment Plan (SIP). The SIP guides investment of the levy to achieve each industry's vision. The current industry SIPs apply for the financial years 2016/17 – 2020/21.

In accordance with the Organisational Evaluation Framework, Hort innovation has the obligation to evaluate the performance of its investment undertaken on behalf of industry.

This impact assessment program addresses this requirement through conducting a series of industry-specific ex-post independent impact assessments of the apple & pear (AP), avocado (AV), mushroom (MU) and table grape (TG) RD&E investment funds.

Twenty-seven RD&E investments (projects) were selected through a stratified, random sampling process. The industry samples were as follows:

- Nine AP projects were chosen worth $15.46 million (nominal Hort Innovation investment) from an overall population of 19 projects worth an estimated $33.31 million,
- Seven AV projects worth $1.91 million (nominal Hort Innovation investment) from an overall population of 27 projects worth approximately $9.97 million,
- Five MU projects worth $1.75 million (nominal Hort Innovation investment) from a total population of 20 projects worth $7.94 million, and
- Six TG projects worth $2.84 million (nominal Hort Innovation investment) from an overall population of 11 projects worth $5.0 million.

The project population for each industry included projects where a final deliverable had been submitted in the five-year period from 1 July 2013 to 30 June 2018.

The projects for each industry sample were chosen such that the investments represented (1) at least 10% of the total Hort Innovation RD&E investment expenditure for each industry, and (2) the SIP outcomes (proportionally) for each industry.

Project AP06007*: Extension AP05002: Alternaria Fruit Spot: New Directions* was randomly selected as one of the 22 unique MT18009 investments 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 (RDCs), Cooperative Research Centres (CRCs), 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 actual and/or potential 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 used 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

Apples and pears are two of the main horticulture crops produced in Australia. Combined, the apple and pear industries produce more fresh fruit than any other fruit industry in Australia (APAL, 2019). The main production of apples and pears occurs in Victoria (at 45% and 88% of national production respectively), with major apple producers also located in all other states. Most Australian apples and pears are for fresh supply, but both also have significant production sent for processing (for juices and other value-added products).

In 2017/18, Australian apples had a farm gate value (FGV) of $418.3 million and production of 269,355 tonnes, while pears (including Nashi) had an FGV of $80.2 million and production of 103,748 tonnes (ABS, 2019). Domestic apple consumption has remained relatively stable over time, but per capita consumption has been falling (Hort Innovation, 2016). Fresh pear (excluding Nashi) per capita consumption has remained stable since 2002/03 (Hort Innovation, 2016).

Exports, while relatively small compared to domestic consumption, represent an important growth area for apples and pears. A total of 2,134 tonnes (or 1% of fresh production) of apples was exported in 2014/15 (Hort Innovation, 2016) with major markets being Papua New Guinea, United Kingdom, Sri Lanka, and Hong Kong S.A.R.

For pears, a total of 7,647 tonnes (7% of fresh production) was exported the same year (Hort Innovation, 2016), with major export markets being New Zealand, Indonesia, Canada, Singapore, and more recently India. Australia does allow imports of both apples and pears, but quantities are relatively small compared to domestic production.

There are both opportunities and challenges for the Australian apple and pear industry to improve in areas such as biosecurity, inconsistency of eating quality, export competition and market access, and an oversupply leading to lower prices (Hort Innovation, 2016).

The collective goal of the two industries is to increase the growth in domestic consumption of apples and pears, and to see growth in exports. The apple and pear industries have funded a number of projects, through Hort Innovation and industry RD&E investments, around improving access to the Asian export market, improved marketing of apples and pears, and improving industry productivity and quality (APAL, 2013).

Statutory levies are in place for both industries for Emergency Plant Pest Response, National Residue Testing, Plant Health Australia, Marketing and Research and Development (R&D). Marketing and R&D levies are managed by Hort Innovation. APAL is the apple and pear industries' representative body and non-profit membership organisation.

Rationale

The Hort Innovation Apple and Pear Strategic Investment Plan 2017-2021 (2017) identified that continued efforts to manage pest and disease challenges would be critical for Australian apples and pears. The SIP suggested Hort Innovation commit to an ongoing, prioritised and targeted program with the aim of cost effective monitoring and control of apple and pear pests and diseases that differ from region to region.

Alternaria species are a fungal pathogen that are known to cause leaf blotch and fruit spot disease in Australian apples and other nursery plants. Most *Alternaria* species are saprophytes that feed on dead organic matter, some only infect plant tissue weakened by stress, senescence or wounding, others are devastating primary pathogens (some of which produce potent plant toxins) (Nursery and Garden Industry Australia, 2014). Plant pathogenic *Alternaria* species also can survive between crops as the fungus occurs in infected plant residues or in and on plant seeds (Laemmlen, 2001). *Alternaria* diseases cause significant quality and yield losses in Australian apple orchards, particularly in Queensland (QLD) and New South Wales (NSW).

Previous *Alternaria* project AP02011 "*Managing Alternaria leaf and fruit spot in apples*", demonstrated that fungicides known to be effective against *Alternaria* species affecting apples overseas did not work in Australia. Furthermore, a literature review completed for the same project, revealed that no two countries reported the same fungicide to be the most effective in managing *Alternaria* diseases in apples. Field trials conducted in 2002 – 2005 in QLD and 2001 – 2003 in NSW showed a lack of adequate information on the disease cycles in the Australian production systems and the lack of an effective disease management strategy. Subsequently, project AP05002 "*Alternaria fruit spot: New Directions*" showed that a range of *Alternaria* species may be responsible for apple leaf and fruit infections in NSW and QLD orchards.

Project AP06007 (*Extension AP05002: Alternaria Fruit Spot: New Directions*) was funded as an extension of Project AP05002 to determine the identity of causal pathogens, epidemiology and disease cycle of Alternaria leaf blotch and fruit spot in Australian apples and provided a management strategy for both diseases for inclusion in the integrated fruit production manual.

Project Details

Summary

Project Code: AP06007
Title: *AP06007: Extension AP05002: Alternaria Fruit Spot: New Directions*
Research Organisation: Department of Agriculture, Fisheries and Forestry Queensland[1] (DAFF)
Principal Investigator: Nick Macleod (2011-2013)
Period of Funding: September 2006 to December 2013

Objectives

Project AP06007 was funded as an extension to original Project AP05002. The specific objectives of Project AP06007 were to:

1. Determine the *Alternaria* species involved in causing fruit spot and leaf blotch symptoms on Australian apples.
2. Elucidate the disease cycle of *Alternaria* on Australian apples, determining sources of inoculum, environmental conditions needed for infection, the infection process and disease development from infection to sporulation.
3. Refine methods for accurate assessment of disease incidence, severity and economic impact of *Alternaria* diseases in apple.
4. Assess efficacy of fungicides for *Alternaria* disease management.
5. Determine the most effective timing of fungicide applications, based on an understanding of the conditions needed for infection.
6. Develop an integrated approach to *Alternaria* management in Australian apple orchards, combining chemical, physical and cultural control methods.

Logical Framework

Table 1 provides a description of AP06007 in a logical framework.

Table 1: Logical Framework for Project AP06007

Activities and Outputs	<u>Fungicide Field Trials 2006-2008</u> • A number of field trials were performed between 2006 and 2008. • The trials involved the application of various fungicides, cultural control methods for reducing inoculum, observations of disease onset in commercial apple varieties, and various field trials in NSW. *Field Trial 1: The use of early, late and whole-of-season fungicide applications to manage Alternaria leaf blotch and fruit spot in apple.* • The first field trial was conducted to determine the most effective fungicides for the reduction of leaf blotches and fruit spots caused by *Alternaria* species on apple, and the time of season during which fungicide application was most effective in QLD. • 18 treatments of fungicide applications were examined during the 2006/07 season. *Field Trial 2: Late season fungicide applications to manage Alternaria leaf blotch and fruit spot in apple.*

[1] At the time of evaluation, DAFF was known as the Department of Agriculture and Fisheries (DAF) QLD.

	• The second field trial was designed to test the efficacy of different fungicides to control *Alternaria* leaf blotch and fruit spot using late season applications on Royal Gala apples in the Granite Belt of QLD in the 2007/08 season. • The fungicides were sprayed at about 3 litres per tree at fortnightly intervals from mid-December until harvest at the end of January. • After harvest the trees were sprayed once every 4 weeks until April. • Five mature leaves, closest to the trees' growing point, were rated for leaf blotch symptoms on the eastern aspect of the trees at the onset of symptoms, at harvest, three weeks after harvest, and prior to leaf fall. *Field Trial 3: Managing inoculum sources for Alternaria leaf blotch and fruit spot in apples. Effect of bud removal on Alternaria leaf blotch in apples.* • Trial 3 investigated the effect of dormant lime sulphur sprays, leaf removal and mulching, or debudding on overwintering inoculum sources in apple trees. • Field trials with Royal Gala trees at the Applethorpe Research Station were established. *Field Trial 4: Managing Alternaria leaf spot – NSW DPI trial 2006/07* • Results from field trials 1 and 2 in QLD indicated that late-season application of the fungicides dithianon, metiram and mancozeb may be a potential management strategy to reduce the impact of *Alternaria* in apple. • However, late-season applications may be limited because of chemical withholding periods. This type of situation can be exacerbated with varieties such as Royal Gala because they require multiple harvests. • In the 2006/07 season, trials in NSW tested mixtures of pyrimethanil and fluquinconazole and trifloxystrobin as early-mid season spray applications for *Alternaria* leaf blotch control. <u>Identifying *Alternaria* species causing leaf blotch and fruit spot of apple</u> • A lack of proper identification of the pathogen(s) responsible for leaf blotch and fruit spot of apple had prevented the development of effective *Alternaria* disease management practices. • Approximately 400 *Alternaria* isolates were obtained through the previous project (AP05002) and AP06007 from apple leaves with leaf blotch symptoms and fruit with fruit spot symptoms. • Each isolate was purified to produce monoconidial cultures. • Isolates were selected to represent different apple producing regions in each state and sourced from both leaf and fruit. • Reference strains of *A. alternata*, *A. arborescens*, *A. tenuissima*, *A. mali*, and *A. longipes* from Genebank accessions in the National Centre for Biotechnology Information were included for comparison. • Morphological and cultural characteristics including colony shape, colour and texture, conidiation and sporulation patterns of the isolates were then examined. <u>Determining the pathogenicity of isolates of *Alternaria* species</u> • The aim of this component of AP06007 was to determine if there was variation in pathogenicity among and within the *Alternaria* species causing leaf blotch and fruit spot of apple in Australia. • Specifically, the experiments were designed to determine if all four *Alternaria* species could cause both leaf spot and fruit diseases or if the isolates were specific to the tissue of origin. • Further, the study was to examine if the four *Alternaria* species groups were pathogenic on leaf and fruit of different apple cultivars. *Development and evaluation of pathogenicity assays* • Infection experiments were conducted to determine the stage at which unsprayed/ untreated fruit was most susceptible to infection.

	• The experiments were conducted at five different fruit stages using both detached fruit and *in planta* fruit (in the field at the Applethorpe Research Station) from Royal Gala and FB22-47 apple varieties. • At each stage, three fruit per variety were examined for size, sugar content and starch level. • Two inoculation protocols with three *Alternaria* isolates in three replicates per variety then were evaluated. • Fruit inoculated with sterile water served as a control. • Apples then were collected at three-week intervals between November and February and used in detached fruit assays. • Further, to investigate whether long-term storage had an effect on *Alternaria* fruit spot development, 90 Royal Gala and FB22-47 fruits (each at different developmental stages) were collected, inoculated and placed in a cold storeroom at 3 +/- 1 ^{o}C. • For leaf blotch, an experiment was conducted to evaluate the leaf stage and/or size at which leaves were most susceptible to infection. • Leaves at different stages (young to senescence) and from the top, middle and bottom of trees in glasshouse potted trees were used. • Royal Gala, FB22-47 and Galaxy apple varieties were used and six leaves from the potted trees were collected per leaf stage and position and inoculated separately with two *Alternaria* isolates. • Leaves inoculated with sterile water-soaked discs served as a control. • Leaf blotch incidence was then assessed at seven- and 14-days post inoculation. *Testing pathogenicity to leaf* • A total of 16 isolates representing the four *Alternaria* species were used in the studies. • The first five fully expanded leaves on terminal shoots used in the development of the inoculation assays were obtained from glasshouse potted trees using the Royal Gala variety. • The experimental design consisted of three replicates (leaves) per isolate. • After incubation, the occurrence of leaf blotch symptoms and severity were recorded. *Testing pathogenicity to fruit (in planta)* • The same set of 16 isolates was used for both detached leaf inoculation and *in planta* fruit inoculation assays. • The assay consisted of unwounded apples on Royal Gala trees at the Applethorpe Research Station (QLD). • Fruits were inoculated near maturity at about two to three weeks before harvest. • The trial was performed twice in the 2011/12 and the 2012/13 production seasons. • The incidence of fruit spot symptoms was recorded two weeks after inoculation. *Assessment of isolates* • To examine whether isolates from fruit spot caused leaf spot (and vice versa), cross-pathogenicity of the isolates was analysed in relation to the original source host tissue of the isolates. • Also, the reason for the high prevalence of *A. arborescens* in all apple growing states was evaluated by comparing the disease severity of the four *Alternaria* species on both leaf and fruit. *Testing pathogenicity on different apple varieties* • To determine if all four *Alternaria* species were pathogenic on different apple varieties, both detached leaf and *in planta* inoculation assays were performed on different apple varieties during the experiments. • The leaf inoculation assay was performed on Royal Gala, FB22-47, Galaxy, Red Delicious and Pink Lady™. • The fruit inoculation assay was performed on Royal Gala and FB22-47. • For each assay and each variety, disease severity was measured and recorded.

<table>
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<u>Exploring the timing of infection and development of Alternaria diseases under field conditions</u>

There are five distinct seasonal physiological stages of the apple season: green tip, flowering or bloom, fruit development, harvest and dormancy. It was thought that the beginning of each of these stages could be a period of high susceptibility for Alternaria infection.
Field trials were conducted on Royal Gala and FB22-47 trees at the Applethorpe Research Station (QLD). The trials were established in the 2010/11 and 2011/12 seasons.
The trees were separated with 10 to 15 ‘buffer trees’ between sample trees.
Alternaria leaf blotch incidence was monitored on each sample tree (in orchard) at two- to three-week intervals from the bloom stage until the tree dormancy stage. Disease incidence was recorded as percentage of leaves showing symptoms and observations were taken from three different heights of the tree canopy.
The percentage of leaves with symptoms was recorded before incubation, after incubation and then at fortnightly intervals for eight weeks.
The influence of weather conditions, including daily minimum and maximum temperature, daily mean relative humidity and daily rainfall, on disease incidence and development was explored using data collected throughout the trials between July 2010 and July 2012.

<u>Sources and availability of Alternaria inoculum</u>

The aim of this component of the AP06007 research was to determine the relative role of leaf residue, canopy leaves, twigs and buds to Alternaria inoculum in the orchard and establish the main source of inoculum through the tree dormancy stage.
Two commercial orchards at Applethorpe (QLD), and trees at the Applethorpe Research Station, were selected for the trials.
A total of nine trees per orchard were selected and samples of leaf residue, canopy leaves, buds and twigs were collected every three- to four-weeks from July 2010 to August 2012. Tree physiological stages also were recorded at sampling.
To determine if the Alternaria spores detected in the samples could cause leaf blotch, detached leaf inoculates were performed on a Galaxy cultivar. Leaves were examined for Alternaria leaf blotch symptom development after seven days.
The influence of climatic conditions, including minimum and maximum daily temperature, relative humidity and rainfall, on production of Alternaria inoculum in the trial orchards was examined.

<u>Suggested key areas for further research</u>

Further research was suggested to investigate the true distribution of Alternaria fruit spot in Australia and the extent of the overall economic impact of the occurrence of fruit spot to the Australian apple industry.
Also, as some species of Alternaria are known to produce toxic metabolites, it was suggested that future research be conducted to understand the risks associated with such mycotoxins.
The resistance of certain apple varieties to Alternaria species also should be explored in conjunction with the effect of rootstock selection on Alternaria diseases.
Fungicide resistance and efficacy and the significance of alternative host plants and cross-infectivity may be further examined.

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<tr><td>Outputs</td><td>
<u>Fungicide Field Trials 2006-2008</u>

Field Trial 1: results showed that Dithane® was the most effective fungicide at reducing Alternaria symptoms, resulting in incidence levels 10 times lower than the untreated control when applied late in the season or throughout the whole season.
In general, it was found that fungicides applied late in the season or throughout the whole season appear to confer better control of Alternaria symptoms than other strategies.

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	• Field Trial 2: attempts to assess *Alternaria* fruit spot symptoms were unsuccessful. • Overall, results showed that the percent of leaves with incidence of *Alternaria* leaf blotch was significantly reduced by the application of mancozeb and metiram fungicide, but not with diathianon. • Field Trial 3: the trials showed that the application of lime sulphur during winter dormancy had no significant impact on the incidence of *Alternaria* leaf blotch or fruit spot on the variety Royal Gala. • However, it appeared that mulching under the drip line of the trees reduced leaf blotch incidence but not fruit spot incidence. • Field Trial 4: results showed that the application of trifloxystrobin early in the season (without late season metiram, dithianon and mancozeb applications) did not provide sufficient disease control. <u>Identifying *Alternaria* species causing leaf blotch and fruit spot of apple</u> • The DNA sequencing showed very limited variation between isolates. Overall, 51% of the Australian isolates were *A. arborescens*, 26% were similar to *A. alternata,* 16% were similar to *A. tenuissima* and 8% were related to *A. longipes.* • All four *Alternaria* species were obtained from both fruit and leaf. However, most (60%) of the isolates obtained from leaf samples were *A. arborescens* wereas 50% of the isolates obtained from fruit samples were *A. alternata.* • *A. arborescens* was found to occur in all Australian apple producing states. • Only two *Alternaria* species were obtained from samples from Western Australia (WA), South Australia (SA) and Victoria (VIC). • Overall, the identity of 51 isolated selected from the original 400 was determined during project AP06007. • The results showed also that, in Australia, *Alternaria* species were not specific to leaf blotch or fruit spot or a specific geographical region. The study determined that the occurrence of common species obtained from both leaf and fruit in NSW and QLD and all other apple producing states suggests that both *Alternaria* leaf spot and fruit spot may become more widespread in Australia than has previously been reported. <u>Determining the pathogenicity of isolates of *Alternaria* species</u> • All four *Alternaria* species caused leaf blotch on Royal Gala in the detached leaf assay. No disease symptoms appeared in the control inoculations. • *A. alternata* and *A. tenuissima* were found to be more aggressive and cause a mean disease severity 75% higher than other *Alternaria* isolates. • In the *in planta* fruit inoculation assay on Royal Gala, at least one isolate of *A. alternata, A. tenuissima* and *A. longipes* caused fruit spot. • Overall, the mean fruit spot disease severity was highest in *A. tenuissima*, followed by *A. alternata*. • It was observed that, since all four *Alternaria* species caused leaf blotch, the severity of the disease was not dependent on the source of the isolate or the host tissue from where the isolates were obtained. • Also, although all the isolates obtained from fruit spot and leaf blotch symptoms caused leaf blotch, only 40% of the isolates obtained from leaf blotch or fruit spot caused fruit spot symptoms in the pathogenicity assays. • This indicated that a certain level of host tissue specificity exists in fruit spot infection which may contribute to why fruit spot disease is less prevalent compared to leaf blotch disease. • All four of the *Alternaria* species were pathogenic on the leaves of the five apple varieties tested. However, there were variations in severity and incidence of leaf blotch caused by each isolate among the varieties. • Results showed that the variation in susceptibility to leaf blotch among the cultivars was somewhat associated with isolate or species. • Comparison of the pathogenicity of the isolates on inoculated fruits of cultivars Royal Gala and FB22-47 showed that 38% of the isolates of *A. alternata, A. tenuissima* and *A. longipes* were pathogenic on Royal Gala and only 13% of the isolates of *A.*

	tenuissima were pathogenic on fruit of FB22-47. • The project team also noted that varying inter-seasonal results indicated that season variation may affect disease development. • Overall, the study demonstrated that all four *Alternaria* species obtained from leaf blotch and fruit spot symptoms of apple in Australia can cause leaf blotch on the five varieties tested. • In contrast, only three of the *Alternaria* species caused fruit spot on the two varieties tested. Exploring the timing of infection and development of *Alternaria* diseases under field conditions • The project team found that leaf blotch incidence (in orchard) increased from 5% at 40 DAB to approximately 41% at 125 DAB in FB22-47 and 2% to 25% at 110 DAB in Royal Gala in the 2010/11 season. • Both cultivars, extensive defoliation started after the highest disease incidence and continued until the tree dormancy stage. • Leaf blotch incidence occurred at similar DAB in both trial seasons, but further disease development was influenced by weather conditions. • Delayed disease progression was attributed to low (55-65%) relative humidity whereas rapid disease development occurred after rainstorm events. • Leaf blotch incidence was found to be significantly higher in the lower canopy than in the upper canopy which indicated that the primary source of inoculum may be from the orchard floor. • Results from the sequential exposure of the potted trees to natural *Alternaria* infection showed that the most significant infections occurred between 70 and 90 DAB and 90 to 110 DAB. • Comparison of the two varieties tested showed that leaf blotch incidence was significantly higher in Royal Gala. • In terms of timing of infection, under natural conditions, *Alternaria* fruit spot was first observed at 110 DAB in FB22-47 and 115 DAB in Royal Gala. • Results of the *in planta* fruit inoculation trials showed that, of the four *Alternaria* isolates tested, only two caused fruit spot on Royal Gala but no infection developed in FB22-47. • Fruit spot mostly occurred at the lower canopy height. The higher occurrence of fruit spot at the lower height followed the early occurrence of leaf blotch at the same height. • This suggested that the fruit infection may have arisen from inoculum from the diseased leaves in close proximity to the fruit and that, as a result, dense canopies close to the orchard floor should be avoided to reduce risk of infection, especially when warm and wet conditions prevail. Understanding the disease cycle of *Alternaria* leaf blotch and fruit spot of apple • The experiments described above provided a fundamental understanding of the disease cycle of *Alternaria* leaf blotch and fruit spot of apple in Australian orchards. • First appearance of leaf blotch may be expected from 40 DAB and fruit spot from 100 DAB at spring and summer seasons. • Fruit infection is expected to occur near maturity, and most likely at high levels of leaf blotch in the tree canopy near fruit maturity stage, in particular at two- to three-weeks before harvest. • Diseased leaves defoliate more readily near fruit maturity in the summer months and may remain on the orchard floor as residue through the dormancy stage. This serves as a reservoir for the *Alternaria* spores for the following seasons. • Leaf blotch epidemics occur when warm temperatures coincide with incessant rainfall. Fruit infection also is favoured at ambient temperatures close to 26°C in the presence of free water and/or high relative humidity.

	<u>Sources and availability of *Alternaria* inoculum</u> • The experiments found that *Alternaria* spores were present in all sample units (leaf residue, canopy leaves, buds and twigs) at all three trial sites and in all years. • Overall, the number of spores obtained from leaf residue was over one thousand times higher than those obtained from other sample units. • The number of spores obtained from canopy leaves was higher than twigs, followed by buds. • Peak numbers of spores were recorded from leaf residue in winter and early spring (late July to early September). This period corresponds to the bloom stage of tree development when leaves are prone to infection. • The most significant rate of increase in spore production during the apple production season occurred in leaf residue between the dormancy stage and the bloom stage. This signified that leaf residue may be a major source of *Alternaria* inoculum in the orchards. • The samples tested confirmed that the spores from leaf residues were *A. tenuissima* and *A. alternata* and that spores from the leaf residue caused leaf blotch on inoculated apple leaves. • The experiments also confirmed that the number of spores produced throughout the season was mostly influenced by temperature and rainfall. <u>Recommendations for disease management</u> The findings of project AP06007 led to the following disease management recommendations: • Integrated management strategy (four-step approach): 1. Removal of leaf residue using enhanced leaf decomposition agents (removal of main source of *Alternaria* inoculum). 2. Post-harvest cleanup of tree canopy with fungicide spray application using any registered protectant fungicide (reduce residual inoculum). 3. Time spray applications to reduce *Alternaria* leaf blotch disease progression above a critical limit in October-December (prevent extension leaf defoliation and reduce sources of inoculum for fruit infection). 4. Time fungicide applications to prevent fruit infection in mid-January to February (prevent fruit infection). • The critical control strategy identified for control of Alternaria leaf blotch and fruit spot was orchard hygiene. • Spray applications of fungicides at the bud burst period, to clean the tree canopy, is currently common practice in the Australian apple industry and may reduce incidence of Alternaria leaf blotch. • Also, routine fungicide spray applications to control other diseases (such as scab) are most likely to reduce Alternaria leaf blotch disease severity without the need for additional spray applications if the principles of orchard hygiene described above are adopted. • If necessary, fungicide spray applications should be applied from January to February at 90 DAB if leaf blotch incidence is more than 15% (approximately one out of every six leaves expressing symptoms three- to four-weeks before fruit maturity or harvest). Thus, regular monitoring for leaf blotch and fruit spot is a key management strategy. • Research findings from project AP06007 were communicated to industry throughout the project through visits to growers in local orchards, discussions and presentations at industry meetings and orchard walk events, communication with extension officers, interaction with Apple and Pear Australia Ltd (APAL) industry development officers, and published articles in growers' journals and newsletters. • Also, a number of scientific journal articles were published along with a number of conference presentations.
Outcomes	• The proposed, new *Alternaria* leaf blotch and fruit spot management strategy was first communicated to Australian apple growers in 2011.

	• The *Alternaria* leaf blotch and fruit spot management strategy has been largely adopted by Australian apple producers, particularly in QLD and NSW. • Reports of results in reduction of disease in orchards that adopted the control strategy have demonstrated that it is effective at significantly reducing the incidence of *Alternaria* leaf blotch, particularly when leaf residue was removed from under the canopy. • Further research has been funded to continue to add to the industry's understanding of *Alternaria* diseases and improve management of the pathogens.
Impacts	• Reduced production losses (yield loss) associated with incidence of *Alternaria* leaf blotch in Australian apple orchards. • Increased profitability for Australian apple growers through reduced losses from quality downgrades associated with the incidence of *Alternaria* fruit spot. • Potentially, increased farm operating costs associated with *Alternaria* management strategies (such as additional use of fungicides and removal of leaf residue to control *Alternaria* inoculum loads). However, these costs may be offset by the reduced impact of the disease on apple output and reduced sorting and processing costs post-harvest associated with *Alternaria* fruit spot. • It also is possible that improved management of *Alternaria* spp. in Australia may improve export market access and/or stability for Australian apple producers exporting Australian apples overseas. However, no specific information on market access risks associated with *Alternaria* spp. was identified during the current impact assessment. • Potentially, some contribution to increased negative environmental outcomes through increased chemical export-off farm because of increased fungicide use. • Increased knowledge and scientific capacity. • Potentially, some contribution to improved regional community well-being from spill-over benefits from more productive and profitable Australian apple producers.

Project Investment

Nominal Investment

Table 2 shows the annual investment (cash and in-kind) in project AP06007 by Hort Innovation and DAF QLD.

Table 2: Annual Investment in the Project AP06007 (nominal $)

Year ended 30 June	Hort Innovation ($)	DAF (QLD) ($)	Total ($)
2007	124,963	105,842	230,805
2008	119,518	105,842	225,360
2009	62,612	105,842	168,454
2010	135,323	105,842	241,165
2011	37,501	105,842	143,343
2012	37,494	105,842	143,336
2013	18,747	105,842	124,589
2014	56,258	105,842	162,100
Totals	592,416	846,735	1,439,151

Source: AP06007 Project Agreement and Variation documents supplied by Hort Innovation 2019

Program Management Costs

For the Hort Innovation investment the cost of managing and administrating the Hort Innovation funding was added to the Hort Innovation contribution for the project via a management cost multiplier (1.162). 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 (QLD) investment, it was assumed that the management and administration costs were already included in the nominal values reported in Table 2.

Real Investment and Extension Costs

For the purposes of the investment analysis, investment costs of all parties were expressed in 2017/18 dollar terms using the Gross Domestic Product deflator index (ABS, 2018). No additional costs associated with project extension were incorporated as the project included a high level of industry participation and a number of extension activities. Results were communicated to growers, APAL and the broader scientific community as part of the project.

Impacts

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

Table 3: Triple Bottom Line Categories of Principal Impacts from Project AP06007

Economic	• Reduced production losses (yield loss) associated with incidence of Alternaria leaf blotch and fruit spot in Australian apple orchards. • Increased profitability for Australian apple growers through reduced losses from quality downgrades associated with the incidence of Alternaria fruit spot. • Potentially, increased farm operating costs associated with Alternaria management strategies (such as additional use of fungicides and removal of leaf residue to control Alternaria inoculum loads).). However, these costs may be offset by the reduced impact of the disease on apple output and reduced sorting and processing costs post-harvest associated with Alternaria fruit spot. • It also is possible that improved management of Alternaria spp. in Australia may improve export market access and/or stability for Australian apple producers exporting Australian apples overseas. However, no specific information on market access risks associated with Alternaria spp. was identified during the current impact assessment.
Environmental	• Potentially, some contribution to increased negative environmental outcomes through increased chemical export-off farm because of increased fungicide use.
Social	• Increased knowledge and scientific capacity. • Potentially, some contribution to improved regional community well-being from spill-over benefits from more productive and profitable Australian apple producers.

Public versus Private Impacts

Impacts identified in this evaluation are predominantly private in nature. Private benefits are likely to be realised by Australian apple producers through reduced production losses and increased average value of production for Australian apples because of improved management of *Alternaria* leaf blotch and fruit spot resulting in a more productive and profitable industry.

Some public benefits also may occur and include increased scientific capacity as well as increased income in Australia apple growing communities/regions associated with a more profitable industry. However, some negative environmental outcomes may be associated with impacts from the investment through increased agricultural chemical use and export off-farm.

Distribution of Private Impacts

The impacts on the Australian apple industry from investment in project AP06007 will be shared along the apple supply chains with input suppliers, growers, processors, transporters, wholesalers, retailers and consumers all sharing impacts produced by the project according to relevant supply and demand elasticities.

Impacts on Other Australian Industries

Impacts on industries other than the Australian apple and pear industry may include potential gains to other industries affected by *Alternaria* diseases (e.g. stone and citrus fruit industries) via potential future spill-overs from the increase in knowledge and scientific capacity.

Impacts Overseas

No significant or direct impacts for countries outside of Australasia were identified. However, the knowledge created by the project and shared through international scientific and industry networks may result in some positive impacts for apple industries overseas (such as in Italy and Japan) where *Alternaria* disease of apples is a major industry problem.

Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 4. The project findings and related impacts will contribute to Rural RD&E Priority 1, with some contribution to Priority 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 6. Resources 7. Advanced Manufacturing 8. Environmental Change 9. Health

Sources: (Commonwealth of Australia, 2015) and (Australian Government, 2015)

Alignment with the Apple and Pear Strategic Investment Plan 2017-2021

The strategic outcomes and strategies of the apple and pear industry are outlined the Apple and Pear Strategic Investment Plan 2017-2021[2] (Hort Innovation, 2017). Project AP06007 addressed Outcome 2, Strategy 2.1.

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.

Two economic impacts were valued. First was the reduced production losses associated with the adoption of improved *Alternaria* management strategies attributable to the investment in AP06007. Second was reduced losses due to quality downgrades associated with the incidence of *Alternaria* fruit spot.

Impacts Not Valued

Not all of the impacts identified in Table 3 could be valued in the assessment. In particular, environmental and

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

social impacts were hard to value due to a lack of evidence/data on which to base credible assumptions, difficulty in quantifying the causal relationship and the pathway between AP06007 and the impact and/or the complexity of assigning magnitudes and monetary values to the impact.

The economic impact identified but not valued was:

- Potentially, increased farm operating costs associated with *Alternaria* management strategies (such as additional use of fungicides and removal of leaf residue to control *Alternaria* inoculum loads). However, these costs may be offset by reduced sorting and processing costs post-harvest associated with *Alternaria* fruit spot.
- Improved export market access and/or stability for Australian apple producers exporting Australian apples overseas. No specific information on market access risks associated with *Alternaria* spp. was identified during the current impact assessment.

Though not valued as a specific, separate impact, the potential additional costs associated with the implementation of new *Alternaria* management strategies in Australian apple orchards were considered as an adoption cost in the valuation of the two primary economic impacts noted above.

The environmental impact identified but not valued were:

- Potentially, some contribution to negative environmental outcomes through increased chemical export-off farm because of increased fungicide use.

The social impacts identified but not valued were:

- Increased knowledge and scientific capacity.
- Potentially, some contribution to improved regional community well-being from spill-over benefits from more productive and profitable Australian apple producers.

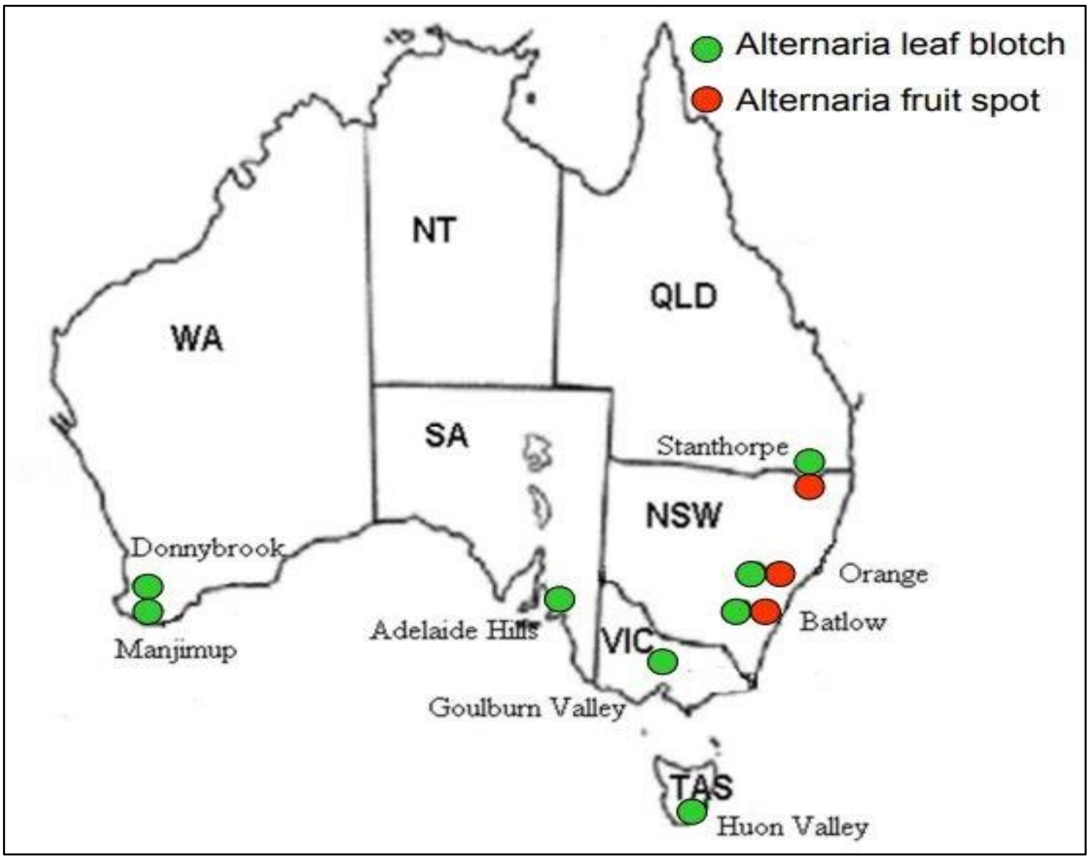
General Information and Background for Valuation of Impacts

Alternaria leaf blotch was first reported in Australian apples in Stanthorpe (QLD) in the 1990s while fruit spot was first reported, also at Stanthorpe, in 2003. Alternaria leaf blotch symptoms are small circular to irregular brown or blackish brown spots on leaves that enlarge to about 2-5 mm in diameter with a dark brown to purple margin. Diseased leaves defoliate readily from January onwards (Horlock, 2006).

Alternaria fruit spot symptoms are characterised by small slightly sunken, light to medium brown spots on mature fruit. The disease occurs regularly in the Granite Belt in QLD, the Sydney basin and Orange in NSW and there is some evidence that it occurs in other fruit growing regions of Australia (Brown, 2014).

Figure 1 shows the known distribution of *Alternaria* leaf blotch and fruit spot in Australia at the time of the project's completion.

Figure 1: Distribution of *Alternaria* leaf blotch and fruit spot in Australia



Source: (Harteveld, n.d.)

The impact of *Alternaria* on apple production has two components: direct impact on fruit quality due to fruit spot and reduced productive capacity (yield) of affected trees in the following seasons due to leaf blotch as a result of premature defoliation.

Alternaria diseases are of particular significance for the Australian apple industry because they affect high value varieties including Royal Gala, Pink Lady™, Fuji, and Red Delicious (Drenth, 2011) which represented approximately 50% of total Australian apple production in 2017/18 (Hort Innovation, 2018).

Yield losses reported by individual growers in the worst affected regions of QLD and NSW have been as high as 15-25% (Harteveld, Akinsanmi, Chandra, & Drenth, 2014).

Table 5 shows the national, Australian production statistics for the apple industry for the 10-year period from 2008/09 to 2017/18. Total production and the gross value of production (GVP) for Australian apples has remained relatively flat over the past decade. Figure 2 and show apple production by state and by year (for Australia and all apple produce states, and for NSW and QLD only). Figure 4 shows the total GVP for Australian apples by year for the same period.

Table 5: Australian Apple Production Statistics

Year ended 30 June	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	5-year Average
APPLES											
Area (ha)	5,782	5,295	6,708	6,733	6,747	6,778	6,799	6,860	7,365	n/a	**6,951**
No. of Trees (Bearing Age)	7,642,203	7,500,682	8,858,841	8,224,292	9,870,878	9,581,452	10,177,811	11,366,935	11,645,263	11,420,932	**10,838,479**
Production (tonnes)	295,134	264,401	299,778	289,064	288,878	266,771	295,196	308,298	313,730	268,355	**290,470**
Yield (t/ha)	51.0	49.9	44.7	42.9	42.8	39.4	43.4	44.9	42.6	n/a	**41.8**
GVP ($m)	542.7	402.3	595.3	464.5	441.4	433.7	555.9	540.5	511.7	490.8	**506.5**

Source: ABS Agricultural Commodities Statistics and ABS Value of Agricultural Commodities Statistics (2009-2018)
n/a: data not available

Figure 2: Production of Australian Apples by State (tonnes) 2008/09 to 2017/18

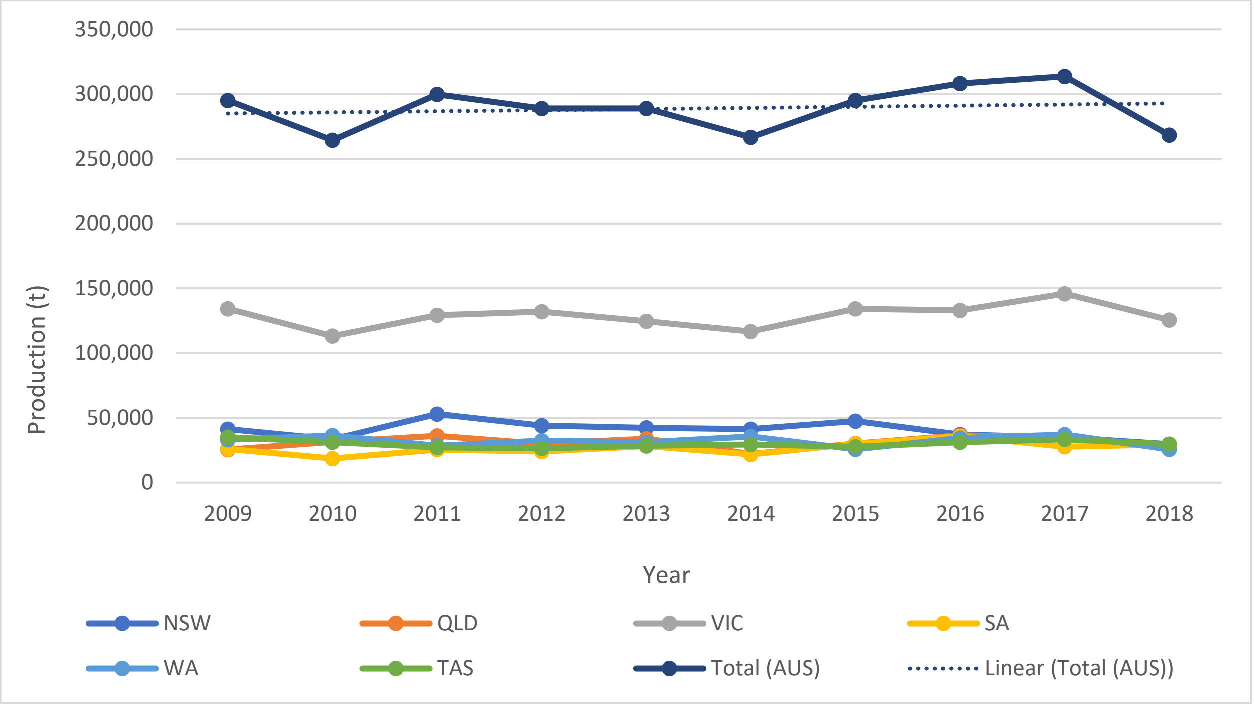


Figure 3: Production of Australian Apples for NSW and Queensland Only (tonnes) 2008/09 to 2017/18

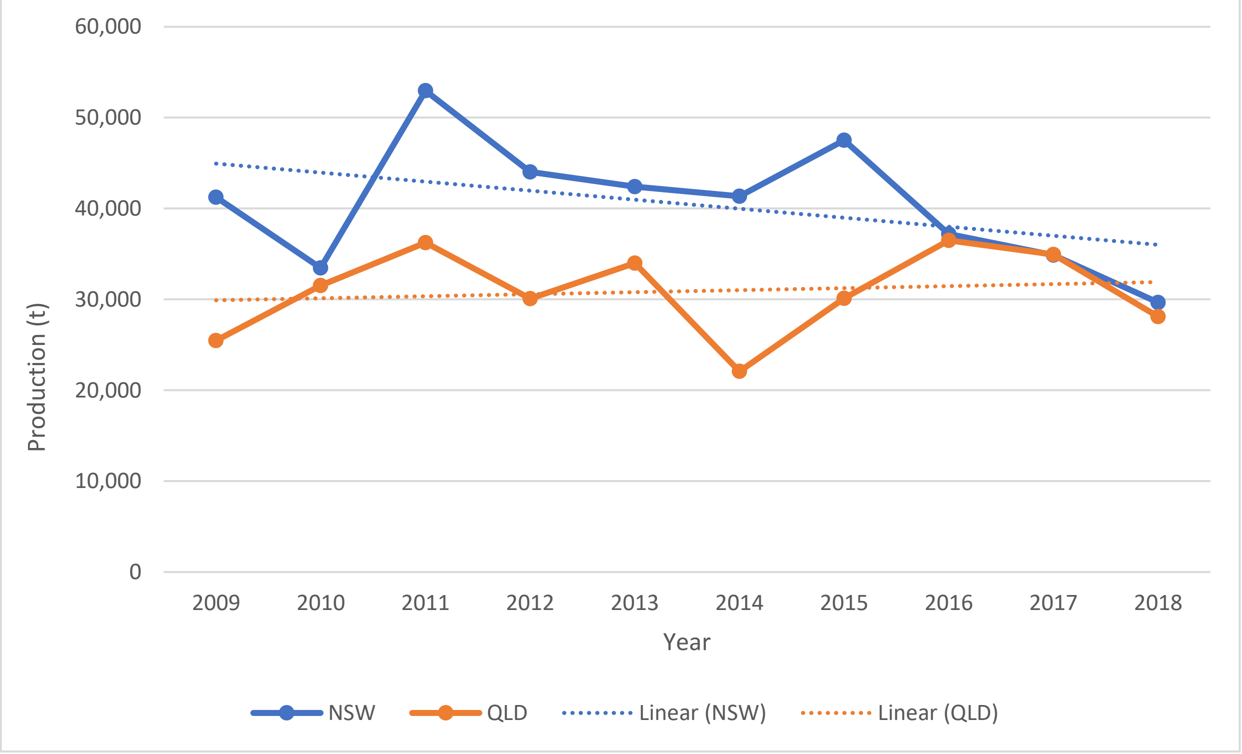
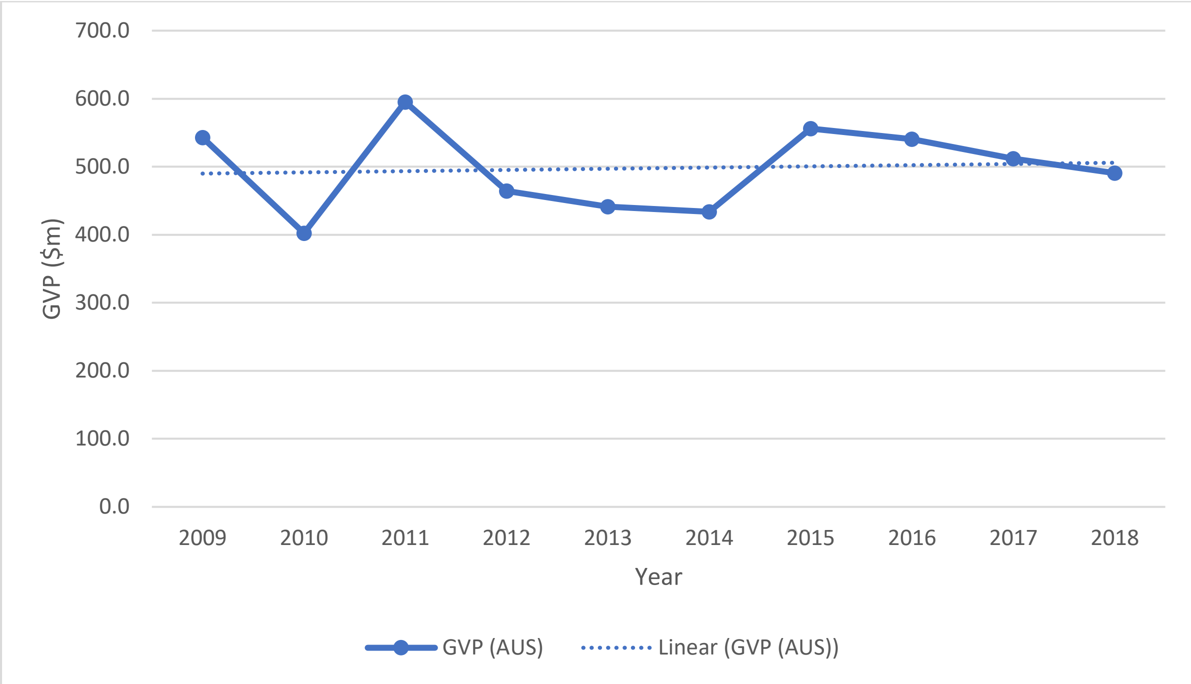


Figure 4: Total GVP ($m) for Australian Apples 2008/09 to 2017/18



Valuation of Impact 1: Reduced production losses from *Alternaria* leaf blotch

Through the Hort Innovation Apple and Pear Strategic Investment Plan (SIP) 2017 – 2021, the Australian pear industry aspires to create a more profitable industry by driving value growth, reducing costs and equipping industry to re-enter Asia's growing export markets.

The investment in AP06007 is likely to have resulted in the adoption of new and improved management strategies for *Alternaria* leaf blotch in Australian apple orchards leading to reduced production losses (yield), thus improving productivity and profitability for Australian apple producers.

Specific assumptions for the valuation of Impact 1 are described in Table 6.

Attribution

The *Alternaria* disease management strategies promoted to Australian apple growers through AP06007 were the result of several apple disease RD&E investments that built on each other. Both projects AP02011 "*Managing Alternaria leaf and fruit spot in apples*" and AP05002 "*Alternaria fruit spot: New Directions*" contributed to the knowledge that enabled the AP06007 research approach and its subsequent outputs to be produced. Thus, an attribution factor of 33.3% (one third) was applied to the benefits to estimate the impact of the investment in AP06007. The impacts estimated are therefore deamed to represent the benefits attributable to the specific investment in AP06007. To estimate the impact of any future investments, appropriate assumptions regarding level of impact, attribution and the counterfactual would need to be made.

Counterfactual

It was assumed that, in the absence of Hort Innovation investment in AP06007, given the relative significance and severity of *Alternaria* diseases to the Australian apple industry, some investment associated with management of *Alternaria* pathogens would have taken place (e.g. through state department and industry RD&E investments such as DAF QLD and APAL). However, it is likely that the level of investment would have been significantly less, and the resulting RD&E would have less efficient and/or effective (particularly if focused within a particular state boundary). Thus, it was assumed that only 70% of Impact 1 was driven specifically by the AP06007 investment.

Valuation of Impact 2: Reduced losses due to quality downgrades associated with *Alternaria* fruit spot

During project AP06007, an analysis of fruit rejects at a commercial apple orchard and packing shed at the Granite belt in QLD showed that, of every 10 bins (380kg fruit/bin) at least one bin was full of fruit rejects and approximately 42% of the total rejected fruit was due to *Alternaria* fruit spot (approximately 4.2% of production). Diseased fruit are downgraded to processing/juicing, reducing grower returns by up to 90% (Harteveld et al., 2014).

At the time of the current evaluation, *Alternaria* fruit spot was only confirmed as affecting apple production in NSW and QLD (see Figure 1). However, it is thought that the pathogens may be more widely spread than first thought.

The investment in project AP06007 has led to the adoption of improved management practices for *Alternaria* diseases leading to reduce disease incidence and has likely reduced the proportion of production rejected and downgraded to processing grade.

Specific assumptions for the valuation of Impact 2 are described in Table 6.

Attribution

As for Impact 1, the *Alternaria* disease management strategies promoted to Australian apple growers through AP06007 were the result of several apple disease RD&E investments that built on each other. Both projects AP02011 "*Managing Alternaria leaf and fruit spot in apples*" and AP05002 "*Alternaria fruit spot: New Directions*" contributed to the knowledge that enabled the AP06007 research approach and its subsequent outputs to be produced. Thus, an attribution factor of 33.3% (one third) was applied to the benefits to estimate the impact of the investment in AP06007.

Counterfactual

As for Impact 1, it was assumed that, in the absence of Hort Innovation investment in AP06007, given the relative significance and severity of *Alternaria* diseases to the Australian apple industry, some investment associated with management of *Alternaria* pathogens would have taken place (e.g. through state department and industry RD&E investments such as DAF QLD and APAL), however it is likely that the level of investment would have been significantly less and the resulting RD&E would have less efficient and/or effective (particularly if focused within a particular state boundary). Thus, it was assumed that only 70% of Impact 2 was driven specifically by the AP06007 investment.

Summary of Assumptions

A summary of the key assumptions made for valuation of the impacts is shown in Table 6.

Table 6: Summary of Assumptions

Variable	**Assumption**	**Source/Comment**
Baseline Data		
Average annual Australian apple production	AUS = 290,470 tonnes p.a. (100.0%) NSW = 38,126 tonnes p.a. (13.1%) QLD = 30,342 tonnes p.a. (10.4%)	See Table 6 (Note: assumes average annual production quantity listed above is net of *Alternaria* associated losses. That is, total annual Australian production is assumed to be 290,470 t p.a. after 12.5% production losses due to *Alternaria* diseases, therefore production without *Alternaria* disease impacts would be 331,966 t p.a. – see valuation assumptions with AP06007 below)
Average total area of Australian apple production	6,951 ha	See Table 6
Derived average apple yield	41.8 t/ha	290,470 / 6,951
Average proportion of total apple production utilised for processing/juicing	30%	Based on data available in the Australian Horticulture Statistics Handbook (Fruit) (Hort Innovation, 2018)
Average farm gate price for	$2.10/kg for non-processing quality	The Colere Group in consultation

fruit	$0.17/kg for processing quality	with APAL
Impact 1: Reduced production losses for Australian apple producers		
Valuation Assumptions		
WITHOUT AP06007		
Industry production losses (yield loss) from *Alternaria* leaf blotch (all apple producing regions)	15.0% p.a.	Conservative assumption based on estimated production losses of 15-25% p.a. (Harteveld et al. , 2014)
WITH AP06007		
Reduction in industry production losses from *Alternaria* disease because of adoption of improved management practices	2.5%	Analyst assumption
Production losses (yield loss) from *Alternaria* leaf blotch and fruit spot (with AP06007)	12.5% p.a.	15% - 2.5%
Total potential average annual apple production without *Alternaria* disease related losses	331,966 t p.a.	290,470 / 331,966 = 87.5% (100% - 12.5% losses)
First year of impact	2011/12	Based on new management protocols for *Alternaria* being shared with growers from 2011
Maximum level of adoption of new *Alternaria* management practices for the control of *Alternaria* leaf blotch	70% in QLD and NSW (QLD and NSW represent approximately 24% of total production) 40% in other apple producing states (VIC, SA, WA and TAS) Weighted average of approximately 47.2% for Australia (total)	Analyst assumption ~47.2% = 0.7 x 0.24 + 0.4 x 0.76 Takes into account non-adoption in cooler, drier regions where leaf blotch is less severe and/or prevalent
Time to maximum impact	7 years	Analyst assumption
Additional costs associated with adoption of new management practices for *Alternaria* leaf blotch	10% of the increased value of production	Analyst assumption based on evidence provided in the AP06007 final report. It was assumed that increased farm operating costs associated with *Alternaria* management strategies (such as additional use of fungicides and removal of leaf residue to control *Alternaria* inoculum loads) would be largely offset by reduced sorting and processing costs post-harvest associated with reduced *Alternaria* disease incidence.
Risk Factors and Other Variables		
Attribution of impact to AP06007	33.3%	Analyst assumption (see above)
Counterfactual – proportion of benefits driven by AP06007	70%	Analyst assumption (see above)
Probability of Output	100%	Analyst assumption – based on successful completion of AP06007

		and subsequent dissemination of improved management practices for *Alternaria* diseases in Australian apples
Probability of Outcome	100%	Analyst assumption – based on evidence of adoption of new management practices (noted in the final report of AP06007)
Probability of Impact	90%	Analyst assumption – accommodates the risk that exogenous factors may prevent the predicted impact from being achieved
Impact 2: Reduced losses because of quality downgrades from *Alternaria* fruit spot		
Valuation Assumptions		
Note: Valuation for Impact 2 is based on the assumption that the reduced production losses from improved management of *Alternaria* leaf blotch are achieved (Impact 1 is achieved).		
WITHOUT AP06007		
Proportion of production downgraded due to *Alternaria* fruit spot	6.2% p.a.	Analyst assumption – (4.2% + 2.0% → see below)
WITH AP06007		
Reduction in the proportion of production downgraded due to *Alternaria* fruit spot	2.0% p.a.	Analyst assumption
Proportion of QLD and NSW production downgraded due to *Alternaria* fruit spot	4.2% p.a.	See above (0.42*380/3,800)
Total potential average annual apple production for NSW and QLD without *Alternaria* disease related losses	78,250 t p.a.	(38,126 + 30,342) / 78,250 = 87.5% 100% of QLD and NSW production less 12.5% losses – assumes achievement of Impact 1 (see above)
First year of impact	2011/12	Based on new management for *Alternaria* being shared with growers from 2011
Maximum level of adoption of new *Alternaria* fruit spot management practices	70% in QLD and NSW only	Analyst assumption – takes into account non-adoption in cooler, drier regions where fruit spot is less prevalent
Time to maximum impact	7 years	Analyst assumption
Additional costs associated with adoption of new management practices for *Alternaria* fruit spot	10% of the increased value of production	Analyst assumption based on evidence provided in the AP06007 final report. It was assumed that increased farm operating costs associated with *Alternaria* management strategies (such as additional use of fungicides and removal of leaf residue to control *Alternaria* inoculum loads) would be largely offset by reduced sorting and processing costs post-harvest associated with reduced *Alternaria* disease incidence.
Risk Factors and Other Variables		

Attribution of impact to AP06007	33.3%	See above
Counterfactual – proportion of benefits driven by AP06007	70%	See above
Probability of Output	100%	Analyst assumption – based on successful completion of AP06007 and subsequent dissemination of improved management practices for *Alternaria* diseases in Australian apples
Probability of Outcome	100%	Analyst assumption – based on evidence of adoption of new management practices (noted in the final report of AP06007)
Probability of Impact	90%	Analyst assumption – accommodates the risk that exogenous factors may prevent the predicted impact from being achieved

Results

All costs and benefits were discounted to 2018/19 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 (2013/14) as per the CRRDC Impact Assessment Guidelines (CRRDC, 2018).

Investment Criteria

Table 7 shows the investment criteria estimated for different periods of benefit for the total investment. Table 8 shows the investment criteria estimated for different periods for the Hort Innovation only. The present value of benefits (PVB) for Hort Innovation was estimated by multiplying the total PVB by the proportion of Hort Innovation investment in project AP06007 (45.6%).

Table 7: Investment Criteria for Total Investment in Project AP06007

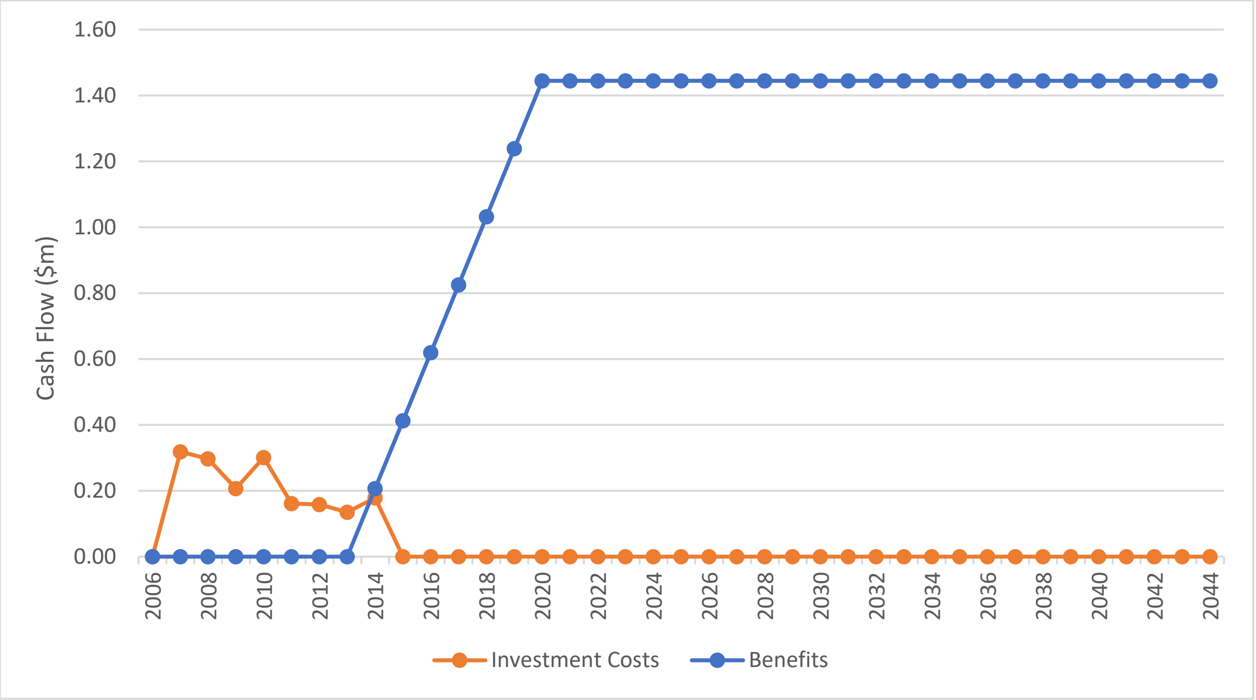
Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Benefits ($m)	0.26	4.71	10.97	15.87	19.71	22.72	25.08
Present Value of Costs ($m)	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Net Present Value ($m)	-2.49	1.96	8.22	13.12	16.96	19.97	22.32
Benefit-Cost Ratio	0.10	1.71	3.99	5.77	7.16	8.25	9.11
Internal Rate of Return (%)	negative	12.7	20.5	22.2	22.7	22.9	22.9
MIRR (%)	negative	negative	36.5	22.7	17.2	14.0	11.9

Table 8: Investment Criteria for Hort Innovation Investment in Project AP06007

Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Benefits ($m)	0.12	2.15	5.00	7.24	8.99	10.36	11.44
Present Value of Costs ($m)	1.47	1.47	1.47	1.47	1.47	1.47	1.29
Net Present Value ($m)	-1.34	0.69	3.54	5.78	7.53	8.90	10.15
Benefit-Cost Ratio	0.08	1.47	3.42	4.94	6.14	7.07	8.89
Internal Rate of Return (%)	negative	10.7	19.3	21.1	21.7	21.9	22.0
MIRR (%)	negative	negative	35.4	22.2	16.8	13.8	11.8

The annual undiscounted benefit and cost cash flows for the total investment for the duration of AP06007 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



Contribution of Benefits

Table 9 shows the contribution of each impact to the total Present Value of Benefits (PVB). Table 10 shows that, even if only one of the two impacts were to be achieved, either impact alone would have covered the Present Value of Investment Costs (PVC) of $2.75 million.

Table 9: Contribution to Benefits by Source

Impact	**PVB ($m)**	**% of Total PVB**
Impact 1: Reduced production losses	19.55	77.9
Impact 2: Reduced production downgrades	5.53	22.1
Total	25.08	100.0

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 10 present the results. The results were moderately to highly sensitive to the discount rate. This was largely because the benefits occur into the long-term future and future cash flows are subjected to more significant relative discounting.

Table 10: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5%**	**10%**
Present Value of Benefits ($m)	40.45	25.08	18.25
Present Value of Costs ($m)	1.76	2.75	4.27
Net Present Value ($m)	38.70	22.32	13.98
Benefit-cost ratio	23.04	9.11	4.27

A sensitivity analysis was then undertaken for the reduction in production (yield) losses attributable to AP06007 assumed for Impact 1. The results are presented in Table 11 and show a moderate to high sensitivity to the assumed reduction in production losses. This is largely because the valuation for both Impact 1 and Impact 2 rely on the yield assumed to prevail with the investment in AP06007.

Table 11: Sensitivity to Assumed Reduction in Production Losses (Yield) for Impact 1 (Total investment, 30 years)

Investment Criteria	**Benefits Attributable to AP06007**		
	0.5%	**2.5% (base)**	43.03
Present Value of Benefits ($m)	9.96	25.08	2.75
Present Value of Costs ($m)	2.75	2.75	40.28
Net Present Value ($m)	7.21	22.32	15.63
Benefit-cost ratio	3.62	9.11	43.03

Finally, a sensitivity analysis was undertaken for the reduction in the proportion of production downgraded due to *Alternaria* fruit spot attributable to AP06007 assumed for Impact 2. The results are presented in Table 12Table 11 and show a low sensitivity to the assumed reduction in the proportion of production downgraded. This is largely because the PVB of Impact 1 dominated the total benefits estimated for AP06007 at 77.9 % (see Table 9).

Table 12: Sensitivity to Assumed Reduction in the Proportion of Production Downgraded due to *Alternaria* Fruit Spot for Impact 2 (Total investment, 30 years)

Investment Criteria	**Benefits Attributable to AP06007**		
	0.5%	**2.0% (base)**	**5%**
Present Value of Benefits ($m)	20.65	25.08	33.92
Present Value of Costs ($m)	2.75	2.75	2.75
Net Present Value ($m)	17.90	22.32	31.17
Benefit-cost ratio	7.50	9.11	12.32

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 13). 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 13: Confidence in Analysis of Project

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

Coverage of benefits was assessed as Medium-High – the two primary economic impacts were valued; however, three potential environmental and social benefits were not able to be valued within the scope of the current assessment. The environmental and social benefits were considered secondary benefits and were likely small relative to the primary impacts valued.

Confidence in assumptions was rated as Medium-High. Data used in the analysis were mostly drawn from published and/or credible sources such as Hort Innovation, published scientific journal articles and the ABS. However, the level of adoption over time, the counterfactual and a number of assumptions associated with the magnitude of the likely change in a variable were analyst assumptions and are therefore somewhat uncertain.

Conclusion

The investment in AP06007 has produced new management protocols to mitigate the impacts of *Alternaria* leaf blotch and fruit spot in the Australian apple industry. Consequently, AP06007 is likely to have contributed to reduction production losses (yield) and reduced quality downgrades for Australian apple growers resulting in a more productive and profitable Australian apple industry.

Total funding from all sources for the project was $2.75 million (present value terms). The investment produced estimated total expected benefits of $25.08 million (present value terms). This produced an estimated net present value of $22.42 million, a benefit-cost ratio of 9.1 to 1, an internal rate of return (IRR) of 22.9% and a modified IRR of 11.9% over 30-years at a discount rate of 5%.

A number of environmental and social impacts were also identified but not valued as part of the current assessment. Thus, given the impacts not valued, combined with conservative assumptions made for the principal economic impacts valued, it is reasonable to conclude that the investment criteria reported may be an underestimate of the actual performance of the AP06007 investment.

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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Acknowledgements

AgEconPlus and Agtrans Research would like to thank all the project and program personnel associated with Horticulture Innovation Australia Limited that were involved in the evaluation process. Their cooperation and feedback throughout the evaluation process contributed significantly to this report.

Specific acknowledgments:
Brenda Kranz, Plant Health: Pathology/ Virology/ Nematodes Portfolio Manager, Hort Innovation
Adam Briggs, Senior Analyst, Hort Innovation
Nick Macleod, Director - Tropical Fruit & Market Access RD&E, Department of Agriculture and Fisheries Queensland

Abbreviations

ABS	Australian Bureau of Statistics
AIGN	Associated International Group of Nurseries
ANFIC	Australian Nurserymen's Fruit Improvement Company
AP	Apple and Pear
APAL	Apple and Pear Australia Limited
APFIP	Australian Pome Fruit Improvement Program Ltd
AV	Avocado
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
FGV	Farm Gate Value
Hort Innovation	Horticulture Innovation Australia Limited
MU	Mushroom
NZ	New Zealand
PFR	Plant and Food Research
R&D	Research and Development
RD&E	Research, Development and Extension
RDC	Research and Development Corporation
TG	Table Grape
WGS	Whole Genome Selection