Final Report

A review of knowledge gaps and compilation of R and D outputs from the Australian Potato Research Programs

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Horticulture Australia Ltd

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PT13013

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Summary

The purpose of this report is two-fold;

1. to extract science supported information that can be used by industry and form the basis of an extension program (Part A),
2. and at the same time identify gaps in our knowledge and suggest possible areas of further research which can then be considered as part of the Industry Research Advisory process (Part B).

This has been a somewhat ambitious project and represents for the first time a synthesis of HAL funded potato R&D in agronomy/soil health and also provides a reference point for further work which can be used as a resource when assessing new research projects/programs

The Extendable Outputs report provides a synthesis of all HAL funded Potato R&D in agronomy and soil health for the past 20yrs.

The data is presented in a form to be used both as is (with addition of photographic material) or with supplemental material for an extension/communication program for the Australian Industry. It can also be used by individuals or other groups/companies etc.

All the data contained herein has peer reviewed by those who participated in the R&D as well as the APRP2 Technical Oversight Committee, in order to ensure robustness.

This document also provides a source document for future reference.

The Gap Analysis report is a review of all production related R&D funded through the HAL (now HIA) mechanism over the past two decades and has revealed that whilst research has generally been of a high calibre it has often suffered from poor outcomes with limited or no adoption/uptake by industry.

This Gap Analysis is primarily focussed on the APRP2 Program but has also considered the broader research portfolio which covers production/agronomy etc.

As part of this analysis some systemic issues in the general R&D formulation process were identified and a mechanism is proposed to address these issues.

This mechanism is envisaged as being of broader application across the HIA R&D portfolio.

Several sub-sets of recommendations are provided;

- General Recommendations that cover activities that need to be enacted across the Potato R&D portfolio and many may also apply to other areas within HIA
- Areas for continued Research and Investment and suggested timelines

- Areas where if further investment is proposed far greater rigour needs to be exercised
- Areas where no investment is warranted at this stage

Whilst many recommendations are made from a technical perspective it is acknowledged that the ultimate determination of investment rests with the Group charged with that responsibility. This report is to help inform that process.

Keywords

Potato, research, extension, disease, pest, soil, nutrition, amendment, biosecurity, seed, tuber

Introduction

As APRP2 was drawing to an end, an opportunity existed to review the key findings of this multidisciplinary R&D program, to collate the technical findings of the program, along with those from APRP1 and other relevant prior R&D projects and package this into a format that can be extended effectively to the Australian Processing Potato Industry and to assist to identify any gaps in knowledge in areas that remain a priority for the industry.

The Australian Processed Potato Industry Strategic Investment Plan 2012-2017, highlights the need to seamlessly complete and evaluate APRP2, along with a need to identify the top four "game changing" practical research outcomes from APRP2, APRP1 and/or other available research programs. It is also recommended that there is a need to get the full and earliest benefits from APRP2, a role that the Potato Industry Extension Program was identified as being pivotal in.

One of the greatest constraints to productivity and profitability for any primary producer is managing risk. Much of the R&D flowing from APRP2 deals with assisting growers to "know their risk" and or manage and reduce their risk. This project collated the technical messages from APRP1, APRP2 and other relevant projects that are ready for extension to the Australian Processing Potato Industry and assisted to identify knowledge gaps to assist in the identification of future R,D&E funding priorities.

Methodology

The scope of this project was to cover the following;

1. Conduct a review of current APRP2 research, prior research from APRP1 (PT04016 - Potato Processor R&D Program) and other R&D projects relevant to potato productivity improvements in Australia. Initially HAL (now HIA) funded projects commenced since 2002 for the potato industry were reviewed in this process, in addition to the APRP2 R&D nearing completion. The review identified outputs ready for adoption that can be compiled and packaged for delivery to the Australian Processed Potato Industry in the area of addressing risk, as well as assisting to identify knowledge gaps that could be assessed for suitability as future funding priorities by the HIA and the Australian Potato Industry.

2. The Across Industry Committee AH11005 (Horticulture Environmental Desk Audit) report and APRP2 Review Report was reviewed and considered for direction in the process of compilation of APRP2 outputs and identification of R&D knowledge gaps.

3. The compiled potato R&D messages will then be available for packaging and delivery by the Australian Processed Potato Industry. There is also likely to be clear benefits from these outputs for the Australian Fresh Potato Industry which would assist to demonstrate the value of a collaborative activity between these two sectors of the broader Australian Potato Industry as identified in the Australian Processed Potato Industry Strategic Investment Plan 2012-2017.

4. The May 2014 APRP2 Technical Operations Committee Meeting offered the opportunity to assess the current knowledge gaps from the APRP2 participants. These proposed knowledge gaps were critically assessed by the PT13013 project leader and compiled along with the knowledge gaps identified in activity 1) above and these have been delivered via draft report to the PPIAC, along with an update on the progress of the compilation of R&D outputs from activity 2) above and expected timelines for finalisation of project PT13013.

Recommended Experts to Consult

APRP2 Project and Sub-project Leaders, the APRP2 Technical Oversight Group, the Potato Extension Program Special Projects Coordinator, the Potato Industry Communications Team, relevant PPIAC members, potato growers and processor representatives, relevant industry consultants and HIA are industry stakeholders that were consulted during this process.

Outputs

The primary outputs of this project were compilation and packaging of R&D output messages related to grower risk from prior R&D projects and APRP2 as it concludes, in addition to identification of knowledge gaps in R,D&E, considering the longer term goal of productivity improvements for the Australian Processed Potato Industry. These two outputs are presented as Appendix 1 & 2 in this report.

Outcomes

This project constitutes an important step in progressing the adoption of prior R&D from the APRP investment by the processing potato industry. Recommendations from this project may guide future R,D&E on productivity improvements for the Australia Processed Potato Industry in the short term and within the life of the current Industry Strategic Investment Plan. This project also progresses a number of the strategies in Objective 2 of the Australian Processed Potato Industry Strategic Investment Plan 2012-2017 and will also provide benefit to the Fresh Potato sector of the industry.

Evaluation and Discussion

Evaluation and discussion of extendable outputs and gap analysis of R,D&E are covered in detail in Appendix 1 & 2.

Recommendations

Extendable Outputs – Recommendations

- KPIs are developed to measure impact of the extension program (see Appendix 1 section 1.1.1)

- That a general soil health communication be developed utilising the findings and data from this report and various vegetable levy funded work (see Appendix 1 section 1.1)

- Pre-existing materials be updated for re-use (see Appendix 1 section 2.1)

- That formal assessment be requested from APVMA and funded before embarking on any communication relating to soil amendments (see Appendix 1 section 2.2.1)

- That the previous HAL site be reactivated with a re-direct function to enable Research reports to be accessed online again.

- That a document control system be instituted for all HIA publications to ensure currency and legacy

- Clarification be sought from APVMA re the use of fertilizer amendments for disease control

Gap Analysis - Summary of Funding Recommendations

The following briefly summarizes the recommendations listed in Section 2 and in the general body of the report. These should be consulted for more detailed information.

Immediate Funding

- Commence an extension/Tech transfer program based upon the findings in Part A of PT13013 and with PreDicta Pt as a major platform
- Commence a baseline survey of current awareness (see Appendix 2 2.2.1,1)
- Continue investment in PreDicta Pt to become a cornerstone of Soil-borne disease extension/information. To do this it needs to;
  - extend to other regions in Australia
  - extend to other nematodes especially PCN (if possible)
  - develop peel tests for common, powdery scab, Rhizoctonia, Verticillium, Black dot,
  - integrate decision trees into the manual
  - improve varietal susceptibility ratings
  - include a pink rot test
- Develop a Biosecurity R&D sub-program and where relevant incorporate findings of PT13006

- Desktop study to determine factors limiting yield in Australian potato production regions

Funding Subject to Caveats

- A stocktake of Australian Soil Disease Research
- Strategic Investment in;
  - Soil microbiology and characterisation of disease suppressive soils
  - Endophytes as a means of disease control
  - Work on biofumigants to determine modes of action
  - Determine role of other soil/tuber diseases in crop loss including Rhizoctonia strains and also organisms such as Erwinia.
  - Develop a better understanding of non-vector borne viruses
  - Review if there is any appetite within industry (including Chemical companies) for a chemical treatment to assist in Powdery Scab control

No Further Funding

- Research on fertilizer amendments as a means of soil-borne disease control be discontinued
- General levy expenditure on Bacterial wilt detection
- Use of foliar treatments for common scab without some commercial involvement and a path to registration (unless this is part of a research program to understand mechanisms
- On plant nutrition unless there is a compelling case and principles with broad application cane be established

General Recommendations

General Recommendations are also provided in Appendix 2 and their implementation is seen as a precursor to the specific ones also provided in Appendix 2. Thus they require immediate attention. It is the author's view that unless substantial changes are made to the R&D process then little change can be expected from the current situation. These recommendations are to inform this process.

Scientific Refereed Publications

None to report

Intellectual Property/Commercialisation

No commercial IP generated

References

See Appendices 1 & 2 for relevant references utilized during this project.

Acknowledgements

To compile a report of this nature required substantial consultation with a number of people who provided valuable feedback for both Part A and Part B. In no particular order I acknowledge the help of the researchers, particularly with Part A from Mike Rettke, Kathy Ophelkeller, Brendon Rodoni, Dolf de Boer, Tonia Wiechel, Brenda Coutts, Paul Taylor, Richard Falloon, Calum Wilson, Robert Tegg, Anne Ramsay and Leigh Sparrow. Ben Callaghan and Dave Moore provided valuable comments and Ben's help in proofing is greatly appreciated. I also thank Peter O'Brien for his comments and appreciated the valuable discussions with Alan Smith, Peter Hardman and fellow tech Committee members Graeme Henman, and Frank Mulcahy.

Appendices

Appendix 1 – Extension Potential Report

Appendix 2 – Gap Analysis Report

Appendix 1 – Extension Potential Report

Horticulture Innovation Australia

Extension Potential and Gap Analysis of Australian Potato Research

Part A
Extension Potential

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PR 13013

December 2014

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Executive Summary

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The data is presented in a form to be used both as is (with addition of photographic material) or with supplemental material for an extension/communication program for the Australian Industry. It can also be used by individuals or other groups/companies etc.

All the data contained herein has peer reviewed by those who participated in the R&D as well as the APRP2 Technical Oversight Committee, in order to ensure robustness.

This document also provides a source document for future reference.

Recommendations pertaining to the conduct of the communications program are in the box below listed below.

- KPIs are developed to measure impact of the extension program (see section 1.1.1)
- That a general soil health communication be developed utilising the findings and data from this report and various vegetable levy funded work (see section 1.1)
- Pre-existing materials be updated for re-use (see section 2.1)
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1 Introduction

The purpose of this report is two-fold;

1. to extract science supported information that can be used by industry and form the basis of an extension program (Part A),

2. and at the same time identify gaps in our knowledge and suggest possible areas of further research which can then be considered as part of the Industry Research Advisory process (Part B).

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1.1 Part A

As noted above the purpose of Part A was to both inform Part B but also to consolidate all the R&D to-date into a form that can be used for extension communication activity and act as an industry resource. A sentiment existed in a number of quarters that there was much that could be done with current and previous HAL funded R&D for which the uptake or usage to date had been very patchy.

In compiling Part A it is important to note that it is not intended to be a ‘How to Manual’. As described above its purpose is to summarize the results produced out of the HAL funded R&D program around which an extension/Tech Transfer program can be constructed. This does not mean however that the work presented does not have relevance elsewhere. Care has been taken to ensure that the data does not conflict with other work elsewhere and complements other work.

To complete this task, the report, commissioned by the former HAL, has examined the past twenty years of HAL funded research relating to potato production particularly that relating to both the APRP1 and APRP2 Programs. By definition therefore this analysis does not include non-agronomy related R&D such as marketing and conferences.

This is the first time that such an analysis has been performed by the potato industry and at the very least provides a single resource in which all production related R&D up until Dec 2014 has been consolidated. It also complements similar initiatives performed through the HAL Vegetable Levy where there have also been similar reviews particularly around soil health. Of particular note in this regard are;

VG 11034 Benchmarking Uptake of Soil Health Practices

VG 13076 Gaps Analysis to Identify Technical Knowledge Gaps for each Region, Crop and Soil Issue

VG 13078 Extension of Integrated Crop Protection Information

Together with this report, the vegetable R&D reviews provide the basis for comprehensive extension and communication activities for the potato and vegetable sectors. The rationale behind this recommendation is that many growers crop other vegetables as part of their potato production program and a single crop cannot be considered in isolation from associated activities.

At the time of writing (December 2014), the Horticulture Australia website lists 242 Potato specific research reports which have been published over more than 20yrs. This research is from both the fresh and processed potato sector and includes the APRP1 program. The scope of these reports ranges from the very specific (eg study tours) to the very broad and comprehensive (eg soil disease and crop rotations). For the purposes of this report a total of 104 reports were identified of possible relevance to the fields of agronomy and soil health, including the APRP1 program (treated as a single report) plus the reports to be produced under the APRP2 umbrella (a further 12 individual reports). These reports are listed in Part B, Appendix1,

Whilst most of these reports were funded through the levy process some were also through the VC mechanism and both types have been considered in this report.

Examination of the selected reports showed approximately 2/3 could be considered for further extension activities. The rest were discarded because they were for study tours, formed the basis for further study, were no longer relevant (ie the science had moved on) or in some cases were based on faulty or poorly understood science. In one case a project was not completed due to the project leader leaving his employment.

Of the remaining reports two had produced extensive publications which had been distributed or made available to industry. These are the PreDicta Pt Manual (SARDI) and The Seed Potato Handling and Storage – best practice Manual.

Three studies were identified that are of importance to the industry's Biosecurity status and have been or will be incorporated into the Potato Industry Biosecurity Plan (eg. work on psyllids and late blight type 2).

A number of others have formed the basis of fact sheets which have also been distributed to industry and/or are available online. This includes information on black dot, pink rot, virus Y, controlled traffic, tomato potato psyllid and white fringed weevil.

It is intended that the data sheets which form the bulk of the report will be seen as a first point of reference and a resource upon which further knowledge can be gleaned from both the references suggested therein and elsewhere. It is for this reason that supporting documentation has been provided so that those who wish, can consult further.

The data sheets are thus stand-alone. As R&D is an ongoing process it is important that when these documents are utilised that a document control system be utilised so that they can be updated and also ensure that the latest documents are those which are being used.

1.1.1 Recommendation

As part of the extension process it is recommended that some KPI measures be developed to assess the efficacy of the extension program and to inform further Tech Transfer, research formulation etc. As noted in part B successful outcomes are the cornerstones upon which R&D programs should be based. This has been discussed in some detail in Part B "Gap Analysis". For the extension program a useful KPI could be developed by repeating the study by Leigh Sparrow from APRP1 (see recommendation 2.2.1 of Part B "Gap Analysis".

1.2 Part B

Part B will be discussed in more detail in that sub-report.

2 Methodology

In compiling this set of extension materials the following quotations from VG 13076 are of particular relevance:

> *"In spite of the relatively large amount of R&D conducted on soil borne disease management over the past 10 years, the adviser survey completed for this project again highlighted the need for more practical information on this topic. This means that our extension services for VG13076 have to link with VG13078 (Integrated Crop Protection extension project), to ensure growers and their advisers receive the practical information and resources they need to better control soil borne diseases.*
>
> *We believe that currently the gap in using information is greater than a gap in information."*
>
> *"Much of the available information is presented in the style of textbooks, scientific papers/reports or promotional material. It is often lengthy, too complex or too simple, and focuses on certain production aspects, solutions or disciplines only. This makes it difficult for time-poor people (growers and advisers) to synthesise and use the information to make decisions on farm."*

To address these issues the data has been condensed and placed into a 'Fact Sheet' format which in some cases includes FAQs.

The research is grouped under four broad headings in the Appendices;

Soil borne disease	**Appendix 1**
Plant related Research	**Appendix 2**
Seed Related Research	**Appendix 3**

Each sheet contains a summary and also references to the documents sourced in its compilation. They also provide web addresses where further information can be gleaned.

The material available under each heading is reflection of the research input, i.e. The vast majority of the work presented is based around soils and this is reflected in the number of sheets in this section.

Much of the plant R&D that has been performed was nutrition related and after examination this was found to be of little use.

Seed research is in the same format and covered in Appendix 3. This research covers work on P-age, seed health and seed disease assessment.

Furthermore a glossary of terms is provided in Appendix 4 which defines those used in this report in that are often cause for confusion, eg Organic matter.

It is also recognised that the face of communication is rapidly changing and thus the data format has been selected such that it may be used in both the traditional printed medium or in an electronic format including URLs (see Note below), all of which were functional at time of final report completion.

Note. The exception to this are the URL's for the former HAL website. With the restructure of the organisation into HIA all the R&D reports are no longer accessible. In the hope that linkage/redirections to any new website are put in place the original URLs have been left in the report. At the time of writing past reports can only be accessed by contacting HIA on the following:

Tel 02 8295 2300
Email contact@horticulture.com.au
Or ordering online http://www.horticulture.com.au/wp-content/uploads/2014/12/HIA-Final-Report-Order-Form.pdf

Lastly as noted in the introduction there have already been many publications produced over the years and many of these are still relevant and these are covered below.

2.1 Pre-Existing Material

In looking through the reports there were a number that have already produced communication sheets/outputs which would be quite suitable for resurrection, updating and reuse. Those in italics are seen as the most important.

These are listed below:

Tomato Potato Psyllid Ute Guide - produced as part of PT10026 "Zebra Chip Awareness" and distributed by AUSVEG through potatoes Australia in 2010

PT423	A Management Strategy and Guide for Cadmium
PT98018	Cleaning and Disinfestation practices for potato farms-produced a hygiene protocol which can be reproduced.
PT99022	Gross margin analysis for round seed production in Tasmania
PT01030	*Seed Storage handling Manual*
PT432	Improved Inland Potato Production – produced a checklist for SE SA, but needs to be checked for current relevance
PT01041	Crop management tools for the French fry industry in the SE of South Australia-produced a good synthesis of issues relating to potassium nutrition
PT01008	Produced a list of recommendations for managing soil pests in all states except Tasmania (this needs updating and to include all potato production regions)
Black Dot	http://www.sardi.sa.gov.au/__data/assets/pdf_file/0009/46593/black_dot.pdf

2.1.1 Other Resources

The web is a powerful source of information, however most of it is not subject to critical review therefore information on this source needs to be treated with caution unless it comes from a reputable source such as a university, Government Department etc.

Within Australia the former HAL website and AUSVEG provide access to a considerable body of information.

See http://www.AUSVEG.com.au/

The issue of web access to research reports produced for the former HAL is still unresolved at this point,

There are also a number of industry websites in other countries which provide valuable resources on all aspects of potato production and marketing. An example is the Potato Council in Great Britain; http://www.potato.org.uk/knowledge-hub

2.1.2 Using the Data Sheets

The data presented in the Appendices is designed to approach the problem of management from an holistic integrated management approach and thus the various fact sheets flow from a series of overarching questions down to notes about specific diseases. As such they can be used either individually or part of a larger compendium.

It is hoped that with this approach it will enable users of the data to quickly determine which areas apply to their individual situation. Each fact sheet will provide a summary of what is known and workable management options. For soil borne diseases however it will be seen that for most of them there are often not that many options. This underlines the intractable nature of many of these soilborne diseases.

There is also a glossary provided for a number of terms commonly used when discussing soil health. This is done to ensure that the reader is using the same definition as this author. Note that definition of organic matter used herein is specific. It is important that this glossary be used in conjunction with these sheets otherwise confusion may result.

Note The provision of photographs of the various diseases and their symptoms/expression was not part of the brief. It is recommended that these be incorporated into the data sheets. These will need to be sourced from the relevant researchers.

2.2 Soil Research

As will be seen from the reference table the majority of potato research has focussed on this area either from a disease or a nutrition perspective. A large proportion of the research work on soil diseases was encapsulated within the APRP1 and APRP 2 research program.

These two large projects and the individual research reports within form the basis for much of what is presented in Appendix 1. The distillation of these two reports into the data presented has been complex. These two substantial research programs have made significant advances in our understanding of soil borne diseases especially powdery scab. It is also incumbent to point out that a lot of APRP 1 formed the basis and groundwork for what was produced in APRP 2. The consequence is that although a large document (>700 pages) much of APRP1 produced few direct extension deliverables.

2.2.1 Soil Amendments

Considerable effort and expense has been made over the years in researching the use of elements and compounds typically used as fertilizers as a means of reducing some soil-borne diseases such as powdery scab. This is an area that warrants clarification as it is likely that in some (perhaps all) cases their use for phytosanitary purposes may require an APVMA approval and registration. This applies for all crops and is not just an issue for potato R&D.

The distinction is in what is being claimed. If the claim is general association with plant health ie that use of X will improve the growth and general health of plants then a fertilizer supplement probably does not require APVMA approval. However if the claim is that the application of fertilizer X in amounts other than normally accepted practice, will prevent, alleviate or cure a disease(s) then APVMA approval will probably be required.

The APVMA provides a self-assessment tool on its website which can assist in answering this question.

See: : https://portal.apvma.gov.au/rap/dmprr-ag

Within the scope of the research and results from APRP1 & 2, the elements in question are sulphur and Zn. Although Sulphur is a fertilizer and thus its use is permitted one needs to exercise caution when making claims about its use as an instrument for disease reduction. This would be particularly the case if the application rates are outside what would be typical for normal agronomic practice.

The assessment tool was utilized (Appendix 5) and it suggests registration maybe required. Informal discussions with APVMA suggest that clarification is advisable. However for a formal determination this will require an application and the payment of a fee. It is recommended that this be performed.

2.2.2 Related HAL Work on Soils

The Introduction notes the extensive investment made by the vegetable industry in soil health and soil-borne diseases including a gap analysis, knowledge surveys and compilation of lists of relevant research. Many potato growers also crop other vegetables as part of their operations. It would thus make sense that wherever relevant, the findings and outputs from the three projects listed earlier are also utilised as well as the references therein. VG 13076 lists 30 Australian based websites which cover topics on soil health and soil-borne diseases.

In addition, these three projects contain links to other soil work performed within HAL and as such are also a very useful resource.

2.3 Plant Research

Most of this work has concentrated on viruses although there have been a couple of studies which have considered post-harvest factors in particular After Cooking Darkening (ACD).

The virus work has considered the role of viruses in seed schemes especially in WA and Tasmania and a set of recommendations were produced for Tasmania. These have been reproduced on one of the sheets in Appendix 2. There are a number of fact sheets in circulation and also a “Spudcast’ about virus Y on the AUSVEG website. These existing materials are adequate and merely need to be reproduced within the format of this report. Consequently they are merely referenced for access purposes. Where non-levy money has been used in their production then permission will need to be sought for their use.

Factsheets have also been produced on the Tomato Potato Psyllid and these should be refreshed and reprinted.

Appendix 1

Soil Borne Disease Fact Sheets

3 General Principles of Soil Management Particularly for Soil-borne Diseases

In this section specific diseases are discussed and some specific management techniques for each are offered.

The most important thing to remember is that if you have clean soil –ie free of common soil-borne diseases this should be protected at all costs as experience shows that once these diseases enter a soil they are impossible to get rid of.

There are also some general management principles which when applied will help in minimising the impact of soil-borne diseases.

These are:

- Maintain plant vigour – healthy growing plants are less susceptible to disease and also have shorter windows for infection if growing well
- Control of volunteer potatoes and other Solanaceous weeds.
- Avoid nutrient imbalances – critical elements here are N, Ca, P, K and micro nutrients
- Avoid practices that restrict root volume – eg Water logging, compaction
- Practice and have in place a Farm Biosecurity Policy
- Be aware of the potential risk for disease introduction posed by contractors and their equipment
- Studies have shown that in many cases disease pressure is highest around paddock entry points see HAL project PT319:

Further Reading
The following HAL reports;

2000 PT97026 Developing soil and water management systems for potato production on sandy soils in Australia – *(this provides some guidelines on ripping)*

1996 PT319 Development and extension of potato hygiene strategies

2004 PT98018 Cleaning and disinfestation strategies for potato farms is also a very useful reference

Reference Book;
1998 Insects & Diseases of Australian Potato Crops by P Horne and R deBoer, Melb. Univ. Press.

The following websites are also good sources for;
Farm biosecurity resources;
http://www.farmbiosecurity.com.au/toolkit/update-your-farm-biosecurity-profile/
http://www.farmbiosecurity.com.au/biosecurity-basics-utility-service-contractors/

Some Information for control of potato disease is provided by crop care - See;
http://www.cropcare.com.au/Assets/1703/1/BRHorticulture-2014PotatoProductGuide.pdf

3.1 General Soil Health

Q People talk about healthy soils how do I know what a healthy soil is? Is there a measure of soil health?

A Whilst most people can identify a poor soil or poor soil condition, there is no single measure of soil health. Soil health is not just its nutritional status but also encompasses physical and biological factors. Soil is a living system and needs to be thought of as such, irrespective of where potatoes are grown.

A good resource is the Soil Quality website;
http://www.soilquality.org.au/.
This site provides a number of fact sheets

There are a number of management practices that can greatly increase the likelihood of better productivity.

These are:

- Building up organic matter in the soil.
- Ensuring that plant residues are completely broken down prior to planting as undecomposed plant material can provide a habitat for some soil diseases such as Rhizoctonia
- Avoid practices that encourage compaction (working wet soils)
- Avoid volunteer plants from crops (and related species) that are part of cropping cycle
- Focus on practices that are best for the primary crop.
- Be aware that cropping cycles for multiple crops will inevitably mean that compromises will need to be made on soil management.
- Soil fumigants such as Metam Sodium kill both beneficial and pathogenic micro-organisms. Use of fumigants may actually make soil diseases worse when pathogens are introduced via seed or tubers as there is no competition from beneficial or antagonistic micro-organisms.
- Practice good weed control – if host plants for a disease are present then there is effectively no rotation in place!
- Compost can be a source of weeds if not done correctly See;
- http://www.farmbiosecurity.com.au/tips-about-compost-use-on-farm/

Further Reading
http://www.horticulture.com.au/reports/search_final_reports.asp
2013 MT09040 Development and demonstration of controlled traffic farming techniques for production of potatoes and other vegetables.

Note:

Most of the diseases covered in this report are among the most intractable of soil pathogens and contamination of clean ground should be avoided. Once in the soil they are almost impossible to remove and there is no easy fix.

3.2 Rotations

Rotations are practised for two reasons:

- To reduce the ability of pathogens to build up in soil which occurs under continuous cropping or short rotations of the same plant
- To provide for additions of organic matter to maintain the soils organic matter or build it up.

Factors to consider

- In multi-crop systems there will always be a compromise on the result from rotation as what is good for one particular type of cash crop may not suit another that one wishes to grow.
- Exercise caution if looking at results from overseas – they are often from areas with more severe winters and the winter itself maybe acting as a 'disinfectant'
- The cropping break is usually more important than the type of crop used
- Avoid having un-decayed plant material in soil otherwise it may make some diseases worse (eg Rhizoctonia)
- When using biofumigants they need to be mulched when green and to almost a pulp to be effective
- Data suggests that killing crop with herbicide renders the biofumigant less effective
- Use caution and wait 3-4 weeks before planting as some biofumigants can be very effective herbicides.
- Fallowing generally makes little impact on soil disease
- Some rotation species host pathogens eg Brassicas such as mustards can host club root.
- When considering root crops, potatoes and carrots are probably best considered as the same crop – they host many of the same diseases
- Levels of Rhizoctonia AG 3 have been shown to increase after carrots, rye grass and poppies in Tasmania
- Poppies have been shown to also increase the levels of the AG 2.1 strain of Rhizoctonia

Further Reading

Useful HAL reports/references on rotations include:

1997 PT315	Rhizoctonia control in fresh market potatoes
2000 PT447	Integrated management with biofumigation to control soil pests and diseases
2003 PT96032	Influence of rotation and biofumigation on soil-borne diseases of potatoes
2008 PT04001	Understanding the implications of pastures on the management of soil-borne diseases of seed potatoes
2005 PT01001	Control of black dot in potatoes
2014 PT09026(ii)	Impact of rotations

4 Management Options

In determining how to approach management of soil borne diseases in potato crops probably the most important question is that of:

Where do potatoes as a crop fit in the farming operation?

(1) It is the only cash crop

(2) They are part of a broader cropping program

The answer will bring about quite different approaches to management.

1) It is the only cash crop

In this situation soil management can be tailored around potatoes. Weed and host plant management is easier and practices between successive crops can be such that disease risk is greatly reduced.

If pasture is part of the cropping cycle then care needs to be exercised in management. A number of soil borne diseases can continue in a pasture phase. (see 3.2 Rotations)

Certain management techniques become easier such as Controlled Traffic as this only needs to be for one crop. (see Controlled Traffic)

Different planting and bed structures may also be possible which may have benefits for water use. ie beds instead of mounds.

2) They are part of a broader cropping cycle

This situation will demand compromises and thus practices may need to be pursued that would not otherwise be employed.

Nutrition and pH management may be compromised (important for common scab control).

The position of other root crops in the cropping program needs careful evaluation. For most soil borne diseases crops such as carrots are equally as important as potatoes in maintaining inoculum in the soil.

As with (1) above, the role of pasture and organic matter needs to be considered. Cultivation reduces organic matter and thus replenishment needs to be considered.

4.1 Identifying Risk

Know your risk

This is a three step process involving the following three factors in order
Customer,
Paddock selection
Seed source (will be covered under seed)

Customers

For what purpose are the potatoes being grown?
This will determine cultivar and presentation (ie washed, brushed, process, storage etc.) and is important because every cultivar will have a different response to soil disease(s).

If the cultivar needs to be planted that is highly susceptible to a disease which has been identified through paddock testing (i.e. PreDicta Pt) or past paddock history as being present at high levels then it may be appropriate to review whether to go ahead and plant at all. (See; Decision Trees)

Paddock Selection

What is my likelihood of having a problem and what is it likely to be from?

The following list provides some cues which may help define risk more closely. More detailed risk factors peculiar to each disease are covered in the separate fact sheets for each pathogen.
The presence of any of these factors does not mean that a particular pathogen may arise but they may help in determining the potential risk for a crop, particularly if a number of factors are present.

Risk Factors

General (for all soil borne diseases)

- Ensure you have correctly identified the disease (obtain a proper diagnosis from a plant health diagnostician)
- Poor Drainage
- Compaction
- Short rotations and volunteer weed potatoes
- A paddock history of the disease(s) listed below
- Volunteer potatoes or host weeds (see Table 1)
- Cultivar susceptibility
- Seed Health

Powdery Scab

- Presence of Solanaceous weeds and volunteer potatoes (e.g. nightshade).
- Poor drainage
- Cold soil at planting
- Irrigation practice

(Further assistance in identifying the potential risk of powdery scab maybe gained by utilising the Powdery Scab Decision Tree in PT09039)

Rhizoctonia

- Unbroken down pasture or other potential host crops (ie still intact plant parts)

(Further assistance in identifying the potential risk of Rhizoctonia may be gained by utilising the Rhizoctonia Decision Tree in PT09039)

Common Scab

- Rotation with susceptible crops
- Undecomposed pasture – ie lumps of turf and root mats
- Soil temperature/planting date

(Further assistance in identifying the potential risk of common scab maybe gained by utilising the Common Scab Decision Tree in PT09039)

Black dot

- Host weeds (See weed host list)
- Infected seed tubers

Bacterial Wilt

- An infected water source
- An infected crop in past 4-5years

Verticillium

- Important to know the species for control (ie *V. dahliae* infects mostly from soil whilst for *V. albo-atrum* seed infection appears to be more important)
- A threshold level of inoculum in the soil is likely
- past history of paddock

Root Knot Nematodes

- Can be very unevenly distributed in paddocks
- Weed species such as blackberry nightshade
- Hosted by carrots
- Many pasture species are hosts so that long term pastures can carry high levels of some root knot nematodes

Pink Rot

- Previous history combined with host weed species being present
- Seed from a particular source in the past has produced crops with the disease
- Planting window of highest risk is when soil temperatures are between 15-25^{O}C

Some FAQs

Q I have one or more of these issues is there anything I can do?

A The PreDicta Pt test will help you identify the degree of the problem particularly for Powdery scab, black dot and root knot nematode. For the other diseases (excluding Pink Rot & Bacterial Wilt which are not included in the PreDicta Pt suite of tests) PreDicta Pt will also provide some guidance because when high levels of inoculum are present, it may indicate a potential problem.

Q Why do I need a PreDicta Pt test?

A Identifying the correct pathogen present in the paddock is important for determining the level of risk and a potential management strategy. Some pathogens can be very difficult to predict from any other method and are long lasting in soil. Management strategies can vary between pathogens and appear to be almost conflicting (e.g. common versus powdery scab). If the paddock is leased or history is unknown the test is probably mandated.

Q Is there anything I can do to reduce these risk factors

A There are some things that can be done but in some cases the choice is extremely limited. There is no simple easy fix for these diseases. Management will need to be over the medium to long term. This is covered more fully under management options.

Q Testing for all these diseases is expensive and in the end I may be able to do nothing anyway.

A The cost of testing needs to be considered in the light of the cost of disease. Soil and pathogen tests are a tiny fraction of the gross value of the crop usually than the cost of 1-2t of potatoes. In this context they are not expensive.

At the very least the data derived from these tests at least provides a benchmark against which one can measure management improvements.

If one does not measure then one has no way of knowing what is changing.

Testing may also in some cases suggest that alternative crops be considered.

Q I do not believe I have any of these risk factors do I need to do anything further?

A PreDicta Pt test is advised as this will provide a base level against which ongoing management practices can be evaluated. If this also shows no disease then particular care needs to be exercised in seed purchasing to ensure you do not bring these diseases onto your property. However remember that PreDicta Pt doesn't test for all diseases.

Table 1: Table of known weed hosts for soil diseases covered in this report. ***Cautionary Note; This table needs caution when interpreting. The absence of colour does not necessarily always denote that the plant is not a host. In many cases there is no evidence one way or the other.***

Common Name	Botannical Name	CScab	PScab	Rhizo	Vert	Pink	B'Dot	Nem	B'Wilt	PVY	TSWV	PVS	PVX
Barley	*Hordeum vulgare*												
Bindweed	*Convolvulus erubescens*												
Black or blackberry Nightshade	*Solanum nigrum*												
Broad bean	Vicia faba												
Cape gooseberry	*Physalis peruviana*												
Capsicum	*Capsicum annum*												
Carrot	*Daucus carrota*												
Cereal ryegrass	*Secale cereale*												
Clover species	*Trifolium spp.*												
Fat Hen	*Chenopodium album*												
Green beans	*Phaseolis vulgaris*												
Hairy/green nightshade	*Solanum physalifolium*												
Kale/cabbage	*Brassica oleracea*												
Oats	*Avena sativa*												
Perennial rye grass	*Lolium perenne*												
PhaLaris	*Phalaris*												
Pigweed	*Portulaca oleracea*												
Quena	*Solanum esuriale*												
Selfsown potatoes	*Solanum tuberosum*												
Shepherds purse	*Capsell bursa-pastoris*												
Short term ryegrass	*Lolium multiflorum*												
Skeleton weed	*Chondrilla juncea*												
Spring vetch	*Vicia sativa*												
Swedes/turnips	*Brassica napus*												
Thornapple	*Datura spp.*												
Tomatoes	*Lycopersicon esculentum*												

Vetch	*Vicia dasycarpa*
Wheat	*Triticum vulgare*
Wild tomato	*Citrullus colocynthis*
Wire weed	*Polygonum aviculare*
Yellow mustard	*Brassica campestris*

Notes

Nightshade family (Solanaceace) should be regarded as hosts of potato diseases

Legend

Abbreviations other than viruses

CScab	Common scab
PScab	Powdery scab
Rhizo	Rhizoctonia solani
Vert	Verticillium
B'dot	Black dot
Pink	Pink rot
B'Dot	Black dot
Nem	Nematodes
B'Wilt	Bacterial wilt

Known host

likely/weak host, or pathogen will survive as a saprophyte on plant material in the soil

view with suspicion

4.2 *Disease Data Sheets*

4.2.1 BLACK DOT

The Pathogen and Disease

- Caused by fungus *Colletotrichum coccoides*
- Causes skin blemishes and internal discolouration of stem ends
- Can cause yield loss of up to 30%
- Develops from both infected seed and soil
- Mostly spread by seed and infected seed leads to infected daughter tubers, is a very common soil-borne pathogen
- Can be carried internally in seed
- Lasts a long time in soil (up to 8years)
- Has many host species and many plants host latent infections
- Unlike silver scurf it does not spread in storage
- In the USA it was found that it can infect foliage after damage from abrasion (eg after sandstorms)
- Diseased stolons can provide an entry point for other diseases such as *Fusarium*

Management

- At high inoculum levels fungicides may not provide adequate control
- Keep weed hosts at bay the disease survives on fat hen, black nightshade and skeleton weed
- Avoid planting at risk seed or ground when soil temperatures are greater than 25^{o}C
- Seed and/or soil treatments with registered fungicides (Fludioxonil + Metalxyl - M and Azoxystrobin) works but efficacy decreases under high pathogen loads – always check label to see if registration current
- Harvest as quickly as possible after skin set.
- Fumigation does not always work especially if it is followed by planting with infected seed.
- Cultivars vary in susceptibility and expression of the disease

Further Reading

http://www.sardi.sa.gov.au/__data/assets/pdf_file/0009/46593/black_dot.pdf

2013 Potato PreDicta Pt manual - Ed M Rettke SARDI

Final reports on the HAL website
http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

2005 PT01001 Control of black in potatoes
2009 PT06014 Reducing the impact of black dot on fresh market potatoes -
2010 PT08048 Pilot project – diagnostic tests for soilborne pathogens, international collaboration
2011 PT08046 Development of a soil borne pathogen testing service for the fresh market industry
2014 PT09039 Diagnostic tests for soil pathogens

4.2.2 POWDERY SCAB

Note: The following can be be used in conjunction with the Decision Trees produced as part of PT09039

This disease should be avoided at all costs if one has clean ground.

The Pathogen and the Disease

- Caused by the protozoan *Spongospora subterranea*
- Root infection by the pathogen is invisible to the naked eye and this is generally accompanied by root galling and tuber lesions
- Tuber lesions are the well-known symptoms and are often confused with common scab
- Root galls are small white growths of callous tissue on the plant roots
- Plants may develop tuber powdery scab but not root galls and vice versa
- The pathogen survives for long periods in the soil >10years
- Transmitted by infected seed tubers and infested soil into new ground
- Seed tuber-borne inoculum may be less important when soil is already heavily infested
- Paddock history (previous potato crop infection) can provide a guide as to probability of infection depending upon susceptibility of the variety
- Favoured under cool and wet soils (<15^{0}C)
- Can contaminate grading lines
- Avoid compacted soil areas
- Removing infected tubers from seed lines does little to diminish risk from remaining tubers as resting spores will be in soil on remaining tubers
- Most of the evidence around susceptibility is based upon tuber symptoms.
- Root infection could result in significant yield losses. It is believed that all strains in Australia are similar

Management Options

- Make sure you have correctly identified which type of scab is present
- Have paddock tested using PreDicta Pt – where it's been trialed in southern Australia it has proven to work well for powdery scab prediction
- No pesticides are currently registered in Australia for control
- If ground is clean avoid having this pathogen at all costs, Plant in warmer conditions which results in quicker growth therefore less time for infection
- Varieties vary in their susceptibility(See Powdery Scab Decision Tree)
- Avoid excess soil moisture (ie keep soil moisture below field capacity during tuber initiation)*
- Maintain good farm hygiene policy (see http://www.farmbiosecurity.com.au/)
- Do not feed infected tubers to stock, they will spread the pathogen elsewhere
- Increase rotations (10 years is suggested as a minimum between potato crops to achieve substantial reductions in soil inoculum *(see sheet on rotations)*

******This is sometimes seen as conflicting with management for diseases such as common scab where a wetter soil is recommended. This is not necessarily the case. Soils should be kept moist (between FC and above wilting point but without excess moisture, if water drains from soil or can be squeezed out of soil it is above field capacity.*

- Avoid soils that are compacted (>2000kPa with a penetrometer) consider introducing controlled traffic
- Avoid volunteer potatoes between cropping cycles
- Nightshade weeds such as black and hairy nightshade are hosts and a number of other plants are also suspected

- At very high levels of soil infestation and with only susceptible varieties available not-planting potatoes maybe the best option.
- Planting tubers shallower in the hills may help reduce risk as do other practices that encourage rapid emergence
- Employ good shed and seed hygiene

Potential Management options
These are limited and it generally requires a longer term management approach.
The following options have been tried in some locations and met with varying degrees of success. Where you may have an intractable powdery scab problem and wish to continue growing potatoes they may be worth trialling.

- Biofumigation using mustards such as Caliente have been shown to produce positive results when combined with less susceptible cultivars
- *Nutrient manipulation using high levels of urea, elemental sulphur applications and keeping Zn at the upper end of its range have produced some positive results in the Ballarat region in the Central Victorian uplands.

**NOTE: Caution is required however as applications of high levels of these nutrients may cause nutrient imbalances and in the case of sulphur significant changes to soil pH.*

Further Reading
http://www.uiweb.uidaho.edu/ag/plantdisease/scabnote.htm

http://www.tia.tas.edu.au/__data/assets/pdf_file/0003/354567/Potato-pathogens.pdf

http://www.appsnet.org/publications/Darwin_Presentations/Wednesday%20Presentations%20_WF2/Richard%20Falloon.pdf

2013 Potato PreDicta Pt manual – ed M Rettke SARDI

A number of final reports can be found on the HAL website
http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

1996 PT303	Epidemiology and control of powdery scab in potatoes
2003 PT96032	Influence of rotation and biofumigation on soil-borne diseases of potatoes
2004 PT98018	Cleaning and disinfestation strategies on farms
2008 PT04001	Understanding the implications of pastures on the management of soil-borne diseases of seed potatoes
2010 PT04016	Potato Processor R&D Program (APRP1)
2012 PT08032	Population genetics and phylogeny of the plant pathogenic protozoan *Spongospora subterranea* f. sp. Subterranea

2014 PT09039 which includes the following APRP2 programs:

PT09026	Soil health disease mitigation program
Pt09026A(i)	Soil amendments and nutrients
Pt09026(ii)	Impact of rotations
Pt09019	Comparison between DNA testing and visual methods for assessing seed tuber health

4.2.3 RHIZOCTONIA SOLANI

Note The following can be be used in conjunction with the Decision Trees produced as part of PT09039

The Pathogen and Disease(s)

- Commonly known as black scurf or stem canker there are three principal strains (AG 2.1, AG 2.2, AG 3)all of which cause lesions on roots, stolons, tubers and stems.
- AG 3 is the one most commonly associated with the familiar black scurf on tubers and is by far the most common.
- Ag 2.2 seems to occur in hot spells of weather and maybe a niche pathogen on potatoes
- AG2.1has also been found associated with potatoes in South Australia
- Visual symptoms include misshapen tubers, aerial tubers, skin defects and black scurf on tubers
- Rhizoctonia infection does not always show as black scurf, can cause death of new shoots from tubers
- Incidence and severity can vary widely depending upon region, season and inoculum levels in soil - outbreaks in southern regions can be associated with cooler seasonal conditions.
- Across Australia the strain and isolates may vary
- Once plant has a green top it appears to be less susceptible to infection
- Causes both yield and packout decreases
- Spread by both soil and tuber borne inoculum
- Varietal susceptibility varies but no very tolerant or resistant varieties
- Response to fungicides can vary between isolates and strains
- AG 2.1 shown to infect onions, brassicas and legumes as well
- A number of host plants but this is not well understood

Management

- A number of fungicides are registered (2014) for control including: Tolclofos-methyl, Pencycuron, Flutolanil, Fludioxonil + Metalxyl - M and Azoxystrobin
- Remove all potato trash from field after harvest
- Undecomposed plant material provides a disease reservoir
- Knock down pastures early to avoid undecomposed plant material
- Know which Rhizoctonia you have as this may help determine fungicidal treatment
- Fungicide efficacy varies between soil and seed treatment and are also more effective against the AG3 strain
- No evidence at this stage that altering nutrition has an impact upon Rhizoctonia
- Plant when soil temperature >12^{o}C and avoid planting too deep in cooler soil to encourage more rapid emergence
- Promote factors that encourage rapid emergence, pre-sprouted seed,
- Promote organic matter and practices that avoid compaction
- Build up a long term relationship with seed supplier who supplies ‘clean’ seed
- Practice good seed and shed hygiene
- At this stage, the soil DNA test is not a reliable indicator if a low reading is provided however a high inoculum reading should serve as a warning of a potential problem

Further Reading

http://digital.library.adelaide.edu.au/dspace/bitstream/2440/62522/1/02whole.pdf http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes/seed__and__soil_borne_diseases/biological_and_chemical_control_of_rhizoctonia/understanding_rhizoctonia/?SQ_DESIGN_NAME=printer_friendly

HAL Final reports
http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

1996 PT105	Control of black leg black scurf and other post-harvest storage rots of seed potatoes
1997 PT315	Rhizoctonia control in fresh market potatoes
2000 PT98036	Biological and chemical control of Rhizoctonia
2003 PT96032	Influence of rotation and biofumigation on soil-borne diseases of potatoes
2004 PT 98018	Understanding the implications of pastures on the management of soil borne diseases of seed potatoes
2010 PT04016	Potato Processor R&D Program (APRP1)
2014 PT09039	Which includes:
	PT09026 Soil health disease mitigation program
	PT09026(ii) Impact of rotations

4.2.4 COMMON SCAB

Note: The following can be be used in conjunction with the Decision Trees produced as part of PT09039

The Pathogen and Disease

- Caused by the filamentous bacterium *Streptomyces scabies* and some other *Streptomyces* spp. That exist as both free living organisms and also as pathogens
- Possibly once introduced into soil is there almost forever
- Incidence and severity can vary significantly depending upon season, variety and region
- Tuber symptoms are sometimes confused with powdery scab
- Produces the toxin Thaxtomin which is what causes the familiar scabs on tubers.
- No direct impact upon yield but reduces packout
- Expression more severe at pH >5.2 – 5.5
- Spread by both tuber and soil inoculum
- Can build up rapidly in a season
- Cultivars vary in susceptibility
- Does not need host plants including potatoes as it can survive on plant material in soil,
- Can infect other root crops, eg carrot
- Paddock history is probably the most reliable indicator
- Favoured by warm dry conditions
- Tuber transmission important in new ground whilst soil more important in infected soil

Management

- Be sure you have disease correctly identified
- Keep pH below ~5.2 -5.5 and avoid liming in season prior to planting, Ph management is not a guarantee but helps in many instances
- Visual inspection of ungraded seed is a good indicator of likely infection risk in daughter tubers(ie presence of scabby tubers)
- A DNA test is not available for soil or peel but if you have soil that is suspected to be free of the diseases then a test maybe warranted
- Always use seed treatments. They work although efficacy declines with increasing soil inoculum and tuber infection levels
- Mancozeb or Fludioxonil based products and Fludioxonil + Metalxyl - M both control common scab on seed, above ground sprays do not work l(check Label prior to use)
- Grading out infected tubers from seed does not diminish risk in fact may disguise the problem therefore obtain visual rating before grading
- Later planting has met with success in Tasmania – although yield maybe depressed
- Use less susceptible varieties (if possible)
- Treat most root crops (eg carrots, swedes, beets, radish and parsnip) the same as potatoes when planning rotations ie they also host disease.
- Avoid bringing contaminated seed onto new ground
- Avoid cloddy seed beds and undecomposed turf both of which produce pockets of air and favour common scab. In the Netherlands potatoes are seldom planted directly after pasture for this reason
- Maintain farm good Farm Hygiene
- Do not allow soil to become too dry particularly during 2-3 weeks around tuber initiation*. Crop uniformity also helps in this strategy.
- A rapid and even emergence is an important means of reducing impact in some areas (eg Tasmania)

- At this stage, the soil DNA test is not a reliable indicator if a low reading is provided however a high inoculum reading should serve as a warning of a potential problem

*****_This is sometimes seen as conflicting with management for diseases such as powdery scab where a drier soil is recommended. This is not necessarily the case. Soils should be kept moist (between FC and above wilting point but without excess moisture, if water drains from soil or can be squeezed out of soil it is above field capacity Conversely if it can not be formed into a ball it maybe too dry._

The Sygenta Smart Test for Reglone application is a good indicator for soil dryness. See:

http://www.syngenta.com/country/au/SiteCollectionDocuments/Product.Plus/All%20technotes/TN09-141%20%20%20REGLONE%20-%20Getting%20the%20best%20result%20in%20potatoes%20PRINT.pdf

Potential Management Options
The following options have been tried in some locations and met with varying degrees of success;

Manipulating soil K:Mg ratios so that both elements are in the mid-range. In Canada a ratio of 0.6K to 1 Mg was found to produce positive results

Avoiding excess Nitrogen

Use of biofumigants has also proved effective in a number of locations

Further Reading

http://www.depi.vic.gov.au/agriculture-and-food/pests-diseases-and-weeds/plant-diseases/vegetable/potato-diseases/common-scab-of-potatoes

Reports from the HAL website
http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

1996 PT303	Epidemiology and control of powdery scab in potatoes
2000 PT447	Integrated management with biofumigation to control soil pest and diseases
2000 PT 96010	Investigation of common scab disease and control methods
2003 PT96032	Influence of rotation and biofumigation on soil-borne diseases of potatoes
2003 PT 98015	New chemical treatments for fungal diseases of seed potatoes
2005 PT02017	Effects of potato seed characteristics on seed-piece breakdown and poor emergence
2006 PT02016	Common scab threshold on tuber seeds for processing potato crops
2008 PT04001	Understanding the implications of pastures on the management of soil-borne diseases of seed potatoes
2010 PT08048	Diagnostic tests for soil-borne pathogens, International collaboration
2010 PT04016	Potato Processor R&D Program (APRP1)
2014 PT09039 which includes:	

PT09026	Soil health disease mitigation program
PT09026A(i)	Soil amendments and nutrients – Weichel,
PT09026(ii)	Impact of rotations - Sparrow
PT09019	Comparison between DNA testing and visual methods for assessing seed tuber health – Tegg & Wilson
PT09023	Diagnostic tests for soil pathogens

4.2.5 VERTICILLIUM WILT

The Pathogen and the Disease

- Caused by a fungus with three species infecting potatoes in Australia *V. tricorpus, V.dahliae* and *V. albo-atrum*
- All are pathogenic, *V. da*hliae is the most important in Australia
- Considerable variation in virulence of various isolates of *V. dahliae* found
- Most virulent appear to be in Tasmania
- A major pathogen implicated in Potato Early Dying (PED) syndrome
- Often no distinctive visible symptoms other than general poor health, eg yellowing of foliage, wilting and occasionally necrosis etc may occur.
- A strong interaction with root lesion nematodes (*Pratylenchus* spp.) in that when Verticillium and root lesion nematode occur together PED is more pronounced
- Appears to be a threshold level of inoculum in soil before infection occurs
- *V. dahliae* may persist in soil as sclerotia for many years
- *V. albo-atrum* usually only survives on plant residue and is less persistent than *V.dahliae*
- Cultivars vary in susceptibility
- Depending upon species can be spread in both contaminated soil and infected seed
- Can cause vascular browning in infected tubers, although this is not always the case

Management

- Control options are limited, There is no registered chemical control in Australia
- Avoid leaving plant residue in paddocks
- Practice rotations
- Avoid planting potatoes especially susceptible cultivars in soils with high inoculum levels
- If soil is clean avoid planting with infected tubers
- Past history is a guide for crop performance
- If it is suspected - obtain a proper diagnosis
- Control volunteer potatoes and possible host species such as pigweed, nightshades, bindweed, and thornapple

Potential Management Options

In some situations there has been a response from applying sulphur to the soil

Further Reading

http://www.google.com.au/url?url=http://www.cottoncrc.org.au/files/2f23da10-e6ba-4603-bfdd-995a0163440b/IDMGL02h.pdf&rct=j&frm=1&q=&esrc=s&sa=U&ei=uA66U9KkCMi7kQWLooCoCw&ved=0CB0QFjAB&usg=AFQjCNEKfBnhRl8qKUcKms03mIofCoswTw

http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes/potato_early_dying_in_australia
http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes/seed__and__soil_borne_diseases/diseases_in_seed_potatoes

http://www.appsnet.org/publications/Potato_Diseases_Workshop/6.%20Nair_Seed%20tuber%20Verticillium.pdf

Reports on the HAL website of interest
http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

1998 PT412	Potato early dying in Australia
2000 PT447	Integrated management with biofumigation to control soil pest and diseases
2003 PT96032	Influence of rotation and biofumigation on soil-borne diseases of potatoes

2008 PT04001	Understanding the implications of pastures on the management of soil-borne diseases of seed potatoes
2014 PT09039	this will include PT09029 “Enhancing the understanding of *Verticillium* spp. in Australian potato production”

4.2.6 PINK ROT

The Pathogen and Disease

- Caused by the fungus *Phytopthora erythroseptica* and sometimes by *P. cryptogea.*
- Isolates vary in virulence
- Infects all below ground parts of plant
- Can be spread by symptomless tubers and also in water
- In early infection stage resembles blackleg
- The cut surface of tubers turns a characteristic pink colour within 15mins of cutting and then turns black over a couple of hours
- Can spread rapidly in the right conditions – warm (20-30^{o}C) wet soils (eg compacted areas)
- Cultivars vary in susceptibility
- A large number of host species (see Table on weed sheet)
- Can survive for long periods in the soil

Management Options

- Metalaxyl-M is effective but care needs to be exercised to ensure that this chemical is not being overused in the cropping cycle*
- Some isolates have been found to develop metalaxyl resistance in the US
- Some cultivars less susceptible than others but all will get the disease to some extent
- Practice good rotation
- Avoid practices that lead water logging such as compaction
- Avoid soils that are compacted (>2000kPa with a penetrometer) consider introducing controlled traffic
- Remove all volunteers and potential hosts from paddocks
- Avoid mixing tubers from contaminated areas with other tubers during storage or better still avoid harvest of contaminated tubers.
- Avoid excessive moisture**

Potential Management Options

Biofumigants such as mustards have also been shown to be effective but caution required as at high levels they are phytotoxic
**Note Metalxyl is a chemical which has been shown in certain soils to develop enhanced biodegradation. In other words the soil microorganisms use it as food source and thus it is rapidly degraded before it can be effective. This is more likely to occur with repeated usage on many crops*

***Note 2 * This is sometimes seen as conflicting with management for diseases such as common scab where a wetter soil is recommended. This is not necessarily the case. Soils should be kept moist (between FC and above wilting point but without excess moisture, if water drains from soil or can be squeezed out of soil it is above field capacity.*

Further Reading:

http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes/pink_rot_of_potatoes
http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes/pink_rot_of_potatoes/studies_on_pink_rot

http://www.syngenta.com/country/au/SiteCollectionDocuments/Product.Plus/All%20technotes/TN09-142%20%20%20RIDOMIL%20-%20Pink%20Rot%20Control%20in%20Potatoes%20PRINT.pdf

Reports on the HAL website of interest
http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

2000 PT97026	Developing soil and water management systems for potato production on sandy soils in Australia (a useful guide to ripping)

2001 PT97004	Potato pink rot control in field and storage
2002 PT1042	Control of pink rot in potatoes
2013 MT09040	Development and demonstration of controlled traffic farming techniques for production of potatoes and other vegetables

4.2.7 BACTERIAL WILT

The Pathogen and Disease

- One of the most destructive diseases of potatoes
- A soil borne organism
- Caused by the bacterium Ralstonia solanacearum
- Based on the plants it attacks the species is divided into a number of Biovars
- The most predominant Biovar in Australia is Race 3 strain 2.
- Occurs up East Coast of Australia (except Tas)
- Other strains are also found in tropics
- Will attack a large number of species
- In potatoes it shows up as wilting, yellowing and the in-rolling of leaves which eventually die from base of stem upwards
- Tuber symptoms have brown-grey areas on outside and when cut show a pale grey pus in the vascular tissue and this may also exude from 'eyes' as the disease advances
- Spread in water, tubers and is maintained in infested areas by a number of other plant hosts
- Favoured by warm wet conditions in soil (eg typical Australian summer conditions)

Management Options

- A minimum of two to five years without potatoes or other hosts is required to stop infection in an infected paddock
- Control host weeds such as nightshade and thornapple (see weed table)
- Crops such as peanut, tomatoes, eggplant, capsicum, tobacco, beans and even banana are all hosts
- Do not allow irrigation water to run off infested paddocks
- Maintain good Farm Hygiene
- Avoid deep ploughing infested paddocks as it can survive deep in soil
- Keep machinery clean and treat infested land as a 'Quarantine Zone' to minimise spread to clean areas
- Whilst varieties may differ in susceptibility there is no true resistance and variations in susceptibility are minor.
- There is no recognised chemical treatment

Further Reading

http://www.depi.vic.gov.au/agriculture-and-food/pests-diseases-and-weeds/plant-diseases/vegetable/potato-diseases/potatoes-bacterial-wilt

http://archive.agric.wa.gov.au/objtwr/imported_assets/content/pw/ph/dis/veg/fs00701.pdf

Potato Diseases 2005 AE Mulder and L J Turksteen – Nivap Holland and Aardappel Wereld

HAL Reports available on the HAL Website
http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

2004 PT 01031	Enhanced detection of potato cyst nematode and bacterial wilt to improve market access
2014 PT09039	Project PT09026 Monitoring for bacterial wilt

4.2.8 ERWINIA Spp. (Bacterial Soft rots)

The Pathogen and Disease

- There are several species that infect potatoes
- *E. carotovora* subsp. *carotovora*
- *E. carotovora* subsp. a*troseptica*
- *E. chrysanthemi*
- The first two also cause blackleg symptoms
- Although common in soil the first two can also be carried internally in tubers
- Usually enter plant through lenticels and injury sites
- Can enter plant through lenticels in wash water especially if water is considerably colder than potatoes
- Favoured by warmer temperatures (>10^{0}C), optimal temperature is 25-30^{o}C
- Although common in soil it is also spread through contaminated seed tubers which can make problem worse
- Varieties vary in susceptibility
- Most infection occurs in field

Management Options

- Cool tubers rapidly after washing
- Avoid tubers being warm and moist (ie uncooled in plastic bags)
- Sanitizers in wash water are needed at very high concentrations to be effective
- Avoid using seed lines where black leg has had to be rogued heavily
- If a consistent problem use less susceptible varieties
- Reducing time to emergence from planting can reduce infection (ie plant when soil warmer or plant a bit less deeper if soils cooler)

Further Reading

http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes
http://www.sardi.sa.gov.au/__data/assets/pdf_file/0016/71251/erwinia1.pdf
http://www.sardi.sa.gov.au/__data/assets/pdf_file/0017/71252/erwinia2.pdf
http://www.sardi.sa.gov.au/__data/assets/pdf_file/0019/71254/erwinia3.pdf
http://www.sardi.sa.gov.au/__data/assets/pdf_file/0020/71255/erwinia4.pdf
http://www.sardi.sa.gov.au/__data/assets/pdf_file/0003/71256/erwinia5.pdf
http://www.sardi.sa.gov.au/__data/assets/pdf_file/0004/71257/erwinia6.pdf

HAL Reports on HAL Website:
http://www.horticulture.com.au/reports/search_final_reports.asp?src=side
1996 PT105 Control of black leg black scurf and other post harvest storage rots of seed potatoes
2003 PT 98007 Managing bacterial breakdown in washed potatoes

2005 Potato Diseases, AE Mulder and L J Turksteen – Nivap Holland and Aardappel Wereld

4.2.9 SOIL PESTS

There have been several reports produced which have looked at soil pests in potato production, in particular white fringed weevil and African black beetle
These are covered under the following HAL Projects;

http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

1996 PT021	Soil insect pests of potatoes
1997 PT406	Development of a biological control for wireworm
2000 PT447	Integrated management with biofumigation to control soil pests and diseases
2005 PT01008	Monitoring and developing management strategies for soil insect pests of potatoes
2014 PT09027	Improving management of white fringed weevils in potatoes

There are also a number of books available on management of soil pests including:

1998 Insects & Diseases of Australian Potato Crops by P Horne and R deBoer, Melb. Univ. Press.

There have also been a number of projects performed as part of the HAL vegetable research program which would be of relevance for soil borne pests however this is outside the scope of this report and it is suggested that a small project be performed to integrate this work into a similar package as in this report. Project PT01008 would serve as a good base upon which to build this package.

A reference for white fringed weevil control is;

http://www.utas.edu.au/__data/assets/pdf_file/0006/354579/white-fringed-weevil-in-potatoes-fact-sheet.pdf

4.2.10 SOIL NUTRITION

FAQ

Q When I look at the research results for nutrition I start to get very confused due to the plethora of recommendations, what is real?

A Plant nutrition and soil nutrients is an extremely complex topic due to the vast number of interactions which can occur (see Fig 1), however there are some basics which should form the basis of management and/or should be asked of your consultant/analytical lab.

Nutrient levels – These need to be considered as a whole due to their interaction within the plant. It also needs to be noted that an individual nutrient maybe high or low depending upon concentration of other nutrients, ie if all nutrients in a test are at their optimum level except for one which is at the bottom or just below its range (eg Ca) then Ca would be low. However if all elements are at the same level then they may still in balance, albeit the plant maybe starving!

Thus when looking at soil tests and their interpretations nutrient levels need to be interpreted with respect to the calibrations for each test. As a minimum, a proper calibration should define the range of values over which a response may be expected and a point at which no further positive response will occur. Whilst many laboratories also make recommendations based upon ratios of one element to another using the concept of nutrient balance, in many cases the evidence to support these recommendations is debatable.

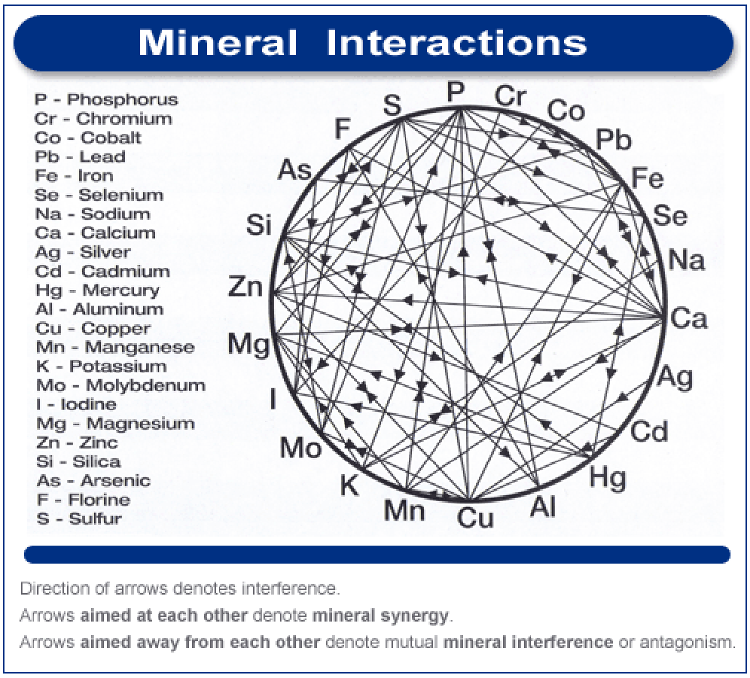

Fig 1, Diagram of the interactions that occur in soil between various elements. (From Mulder's chart in "Osman K T 2013 Soils Principles, Properties and Management 271pp Springer"

Soil testing is a valuable tool but it is not the only answer as it merely shows what is potentially in the soil for crop growth and there are a plethora of factors which will have an impact upon whether or not the elements actually are used by the crop.

A further point is that not all analytical tests for soil nutrients measure the same thing or will give equivalent results, therefore caution is required when comparing test results. The few brief notes below may be useful.

pH – water or calcium chloride tests will give different results so it is important to compare like with like.

Lime – This is very misunderstood compound. Whilst liming usually increases pH it takes several months. It is the carbonates in lime that raises pH and lime does very little in increasing Ca in plant as only a very small fraction is soluble. Lime is a very inefficient method to improve calcium levels for plant growth. It does however improve soil structure and microbial activity.

Calcium - $CaNO_3$ provides Ca to the plant and does not affect pH. Ca is only taken up by roots immediately adjacent to the tuber. Ca is relatively immobile in the soil and is taken into the plant with water uptake during transpiration. Consequently application must be where roots are feeding the tuber. Water stress can also lead to Ca deficiency due to inadequate uptake even if soil is well supplied with Ca. Any application to the aerial parts of the plant is a waste of money!

Further Reading on Ca and potatoes

http://AUSVEG.com.au/events/convention-2014/speakerpresentations/BarryBull_speakersession.pdf

Nitrogen – Many use Urea as its cheap. Whilst its use as a soil fumigant has been demonstrated in some instances (see powdery scab sheet), its efficacy as fertilizer is debatable depending upon the soil type, up to 60% of the N that is applied in Urea can go to the atmosphere. Typically losses are around 30% on average. Losses can be reduced by irrigation or rainfallso that urea is washed at least 5mm into soil. High N may exacerbate common scab and after cooking darkening (ACD)and it also reduces storage and soluble solids

Potassium – low levels also implicated with ACD and poor solids

Phosphorous – In Tasmania no difference was found on P-fixing Ferrosls between P applied as a starter or as band in soil

Sulphur – High sulphur levels or applications have been implicated in helping reduce some soil borne diseases eg powdery scab. However applying elemental sulphur will decrease soil pH.

Silicon – There is some evidence that silicon applied to plants can assist in disease management suppression (see VG06009; Management of vegetable diseases with silicon). See also;

https://hal.archives-ouvertes.fr/hal-00930510/document

Micro nutrients - Zn and B levels are important and there is some evidence that Zn may help with powdery scab control. Caution with all micronutrients is required as there is fine line between beneficial and phytotoxic effects.

Further Reading

There is a vast amount of literature on nutrition, more than any other single aspect of horticulture. The following website maybe useful;
http://www.yara.us/agriculture/crops/potato/crop-nutrition/

http://era.deedi.qld.gov.au/1658/

Other projects within HIA are also covering this topic eg
Soil wealth Fact sheets are being produced from VG13076 see:
Interpreting Soil Tests

As noted earlier also see Potato council;
http://www.potato.org.uk/knowledge-hub

Appendix 2

Plant Factors

5 Plant Factors

This is a bit of a catch all category and includes post-harvest areas as well. Again the emphasis in this work has been on pathogens with viruses featuring.

5.1 PRE-EXISTING MATERIAL

Over the past 20years there have been a number of useful fact sheets that have been produced on the following topics:

Bacterial soft rots
http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes

Soil Pests
https://www.agric.wa.gov.au/potatoes/mid-west-potatoes-seed-production-and-pest-and-disease-management?page=0%2C2

General Pests
http://www.vegetableswa.com.au/documents/goodpractice/PestandDisease-v5.pdf

http://www.daff.qld.gov.au/plants/fruit-and-vegetables/vegetables/potatoes/pests-and-diseases-potatoes

These sheets are still available on line and as they were produced from the levy should be available to be reformatted and reused. The information is still topical

5.2 VIRUSES

5.2.1 GENERAL COMMENTS

- Plant viruses can severely debilitate crops and there are many that can attack potatoes
- Susceptibility to viruses may vary throughout the lifespan of the plant
- Transmission to daughter tubers can vary depending upon virus, time of infection and also potato cultivar,
- Depending upon virus, transmission can be via aphids, thrips or mechanical means
- Volunteer potatoes and other Solanaceous weeds can be important reservoirs of virus
- PVA found not to be spread by cutting
- Viruses cannot always be detected visually

Further Reading

http://researchrepository.murdoch.edu.au/3001/2/02Whole.pdf

http://www.crawfordfund.org/wp-content/uploads/2014/03/Salazar-Potato-Viruses.pdf

http://www.pir.sa.gov.au/__data/assets/pdf_file/0003/46605/virus_abstract.pdf

5.2.2 PVY

- Rapidly transmitted by aphids (seconds)
- Insecticides do not stop PVY
- Oils can be effective in early part of season for some virus control
- Can persist for several hours on clothing and equipment including tyres.
- Transmission by feeding aphids is almost instantaneous

Further Reading

https://www.agric.wa.gov.au/potatoes/potato-virus-y-potato-crops

http://archive.agric.wa.gov.au/objtwr/imported_assets/content/pw/ph/dis/fs00203.pdf

http://AUSVEG.com.au/potatoes/pvyposterV12lr.pdf

http://AUSVEG.com.au/potatoes/multimedia.htm - an informative oral presentation

http://www.vicspa.org.au/f.ashx/Potato-facts-PVY-2.pdf

5.2.3 PVX

- Transmitted solely by mechanical means
- Tubers are the main means of spread

5.2.4 PVS

- PVS can reduce yield by up to 20% and no demonstration of spread by cutting
- Spread almost solely by infected tubers
- Tubers need to be grown out and indexed to detect within season infection of PVS.

5.2.5 PLRV

- Unlike PVY PLRV requires several hours feeding by aphids and there is lag phase between a plant being infected and its ability to transmit infection (~ 1day).
- Tuber is major means of spread

Further Reading

https://www.agric.wa.gov.au/potatoes/potato-leafroll-virus-potato-crops

5.2.6 TSWV

- TSWV appears to be self-eliminating
- Spread by thrips
- Major source of infection are alternate hosts of which there are a large number from a wide range of different plant families.
- Seed is important as a source for only a few varieties eg Atlantic.

- Grow out test may not work with TSWV as it has been found that early shoots may be –ve for virus with later shoots +ve.

http://archive.agric.wa.gov.au/objtwr/imported_assets/content/pw/ins/pp/hort/fn069_2004.pdf

Q How do I know if my seed tubers are clean of virus?

A Tuber testing works for most viruses especially those using PCR however without a grow out test you cannot be completely certain (except for TSWV). Field inspections as part of certification provide some assurance but not all viruses are visually detectable in all cultivars. Indexing tubers can also help however viruses such as Y really to be tested in shoots not tubers.

Crop Health Services and some other labs offer grow out test for PVY and also some other viruses – this has advantage as it shows what is in actual seed not what was in parent crop.

A number of commercial virus test kits are available. Sensitivity of these test varies but they can give an indication of virus in a crop. See :

< http://www.pocketdiagnostickits.com.au/pocket-diagnostic-kits-potatoes.html>

There are considerable resources available on the Internet

5.2.7 RECOMMENDATIONS FOR THE TASMANIAN SEED POTATO INDUSTRY FOR THE CONTROL OF POTATO VIRUSES

The following is an extract from a report (PT03069) by Dr R Jones for the Tasmanian seed potato industry. It is placed here in its entirety as it is relevant to all growers and especially seed growers.

Recommendations to seed growers (R Jones. WA)

• Leave three row spaces between generations

• Leave three row spaces between lines within generations

• Control weed rigorously, especially nightshade and volunteers

• Avoid strips of G1 (or G2). Plant as rectangular blocks to minimise edges

adjacent to other generations

• Place G1 and G2 at the edge of the paddock if possible. If there is a high

risk of grazing by wildlife (eg wallaby, grasshoppers etc) it may be

necessary to reconsider and plant within the paddock

• When planning machinery movements (eg sprayers, spreaders, irrigators

etc) always work from the earliest to the latest generations.

• Always clean and sterilise machinery between paddocks

• Do not allow uncertified seed on to seed farms. Minimise the introduction of anything but minitubers on to the farm or use only virus tested G2 from specialised seed growers

• Consider the supply of certified seed (eg Nicola) to Dutch Cream / backyard growers

• Restrict access to early generation plots (no unauthorised personnel)

• Clean down boots and leggings frequently using disinfectant / detergent

Recommendations to seed cutters

• Clean and disinfect seed cutters frequently – where possible between lines using pressure wash and a suitable disinfectant (eg Virkon or farmclense)

• Trial Virkon on cut tuber surfaces to determine the impact on germination and growth

• Spray the cutting knives after each line

• Clean the cutter down using a pressure wash at the end of each day

• Sequence the cutting operation so as the earliest generations are cut first and later generations last

• If the seed line is known to contain virus ensure the cutter is cleaned down immediately after the line is cut

• Early generations should all be hand cut on farm. Several knives should be used to allow a longer period of disinfection (eg 10 minutes) between use.

• Remove discard piles/bins promptly. Regularly monitor for aphids on sprouting tubers

• Minimise surface damage during grading (skinning)

Recommendations to the potato industry

• Seed potato movements should be restricted to within designated seed areas. Only virus tested seed should be moved between seed growers.

• Wherever possible multiply minitubers and G2 on specialised farms in low aphid population areas. This seed can then be passed on to other seed growers for further multiplication.

• Alternatively, isolate clean material from current lines to provide a flush out of any infected material. Separate clean seed pipeline as far as practical from infected lines (never in the same paddock)

• Contract machinery – Ensure rigid hygiene protocols before transfer between farms.

• Promote the awareness of the importance of virus free seed stocks to commercial growers

• Set high standards of cleanliness when personnel visit growers' properties

Recommendations to DPIWE

• Virus test G3 seed crops. Sample at second inspection. Test for X and S, and in high risk areas Y, PLRV, TSWV.

• No other potato material to be brought near any minituber facility

• Ensure strict hygiene protocols for officers entering growers properties, promote high standards and set an example

• Use virus test kits to raise awareness in the industry of the virus issue and to give instant Ids

• The certification tolerances should be graduated so that stringency decreases with generation

• Enforce planting distances by introducing a 3 row spacing between generations and lines and increasing the distance between certified seed and ware and no uncertified seed to be sown on a seed farm.

• Improve the minimum requirements in the National Standards / or adopt higher standards in Tasmania as has been done in WA

• Benchmark National Standards against other national schemes.

• Institute a computerised seed tracking service

• Set a temporary special tolerance for PVS

Recommended Research

• Test the spread of PVS and PVX through the seed cutters

• Determine the strains of PVS and PVX

• Survey backyards, volunteer potatoes, nightshade and fat hen for virus

reservoirs

• Trial disinfectant efficacy and toxicity on cut tuber surfaces

• Test the survival of PVX and PVS on different surfaces - current

information is inadequate

• Examine the transmission of PVS and PVX by grasshoppers, sandblasting

and grazing

• Test the breeding lines from Toolangi for PVY on DPIWE farm and

elsewhere in Tasmania

From HAL Report PT03069 (2007) Management strategy for elimination of viruses from certified seed potato stocks in Tasmania

5.3 NUTRITION

This has been covered under section 3.5.10

Appendix 3

Seed and Tuber Factors

6 Post-harvest and Storage

Factors determining quality

- Whilst a suberized layer is important on cut seed no relationship has been found between thickness of this layer and seed piece breakdown
- Strong positive correlation between seed firmness and breakdown
- The presence of *Fusarium* on seed is the major threat to quality (breakdown)
- Levels of N & P in tubers especially N affect yield of daughter tubers
- Grading of seed does not diminish disease risk (in other words because you cannot see it it doesn't mean its not there)
- No reliable objective measure of P-age
- Seed performance unable to be predicted by management and storage
- The earlier a crop senesces the lower is the number of stems on daughter tubers
- Performance of seed at one location does not predict performance of same seed somewhere else.
- Correlation between stem and tuber is varietal dependent and is not always strong
- Emergence is slower in drier soils
- Haulm killing rather than die off usually produces a better seed performance
- Cement can be phytotoxic and should not be mixed with tato dust
- Efficacy of some fungicides can vary with soil type and also extent of disease pressure
- Virus transmission through cutting is worse when blades cut shoots

Some Management Options

- *Fusarium* can be detected with a cut test (place cut seed in plastic bag for 3 weeks and then assess for presence of *Fusarium* on cut surface.
- Carryover of seed borne inoculum becomes increasingly important with decreasing level of disease in soils.
- Tuber size is affected by emergence – slow emergence gives larger tubers
- Quick emergence gives a higher yield
- P-age an important but nebulous concept – factors such as planting date, senescence date, digging date, coolstorage temperature, seed cutting and soil structure are more important in determining stem number and emergence.
- Best determinant of P-age performance is planting date and buying from the same producer as his/her practices will be relatively constant
- Management not P-age were found to be most overall factor driving yield across the industry.
- In Tasmania the recommendation for seed production was plant late and kill early

- Ensure that you know incidence of disease on tubers prior to grading
- Visual assessment correlates well with DNA test for common scab, powdery scab and black scurf
- Never plant tubers in clean ground without first assessing their disease status
- Good Certification practices are essential for management of seed-borne pathogens, especially viruses

Some useful HAL reports from their website are listed below

http://www.horticulture.com.au/reports/search_final_reports.asp?src=side

2000 PT96010	Investigation of common scab disease and control methods
2001 PT0003	A comparative evaluation of different materials used for cut potato seed treatments
2002 PT98008	Improving seed potato production
2003 PT98015	New chemical treatments for fungal diseases of seed potatoes
2004 PT99052	Potato tuber management in realtion to environmental and nutritional stress
2004 PT99022	An agronomic and economic blueprint for using whole round seed for processing potatoes
2005 PT01030	Seed potato handling and storage – best practice
2005 PT 02017	Effects of potato seed characteristics on seed piece breakdown and poor emergence
2006 PT 02012	Optimising production and storage conditions for seed potato physiologiocal quality
2006 PT 02016	Common scab threshold on tuber seeds for processing potato crops

7 Appendix 4: Definition of Terms used in this Report

Immunity
A pathogen is completely prevented from infecting a host

Inoculum
Living pathogens such as spores, bacteria etc which can infect other living organisms

Isolate
A genetically distinct variation of a fungal species that may differ from other isolates by virulence or the plant species which it infects

Organic Matter
Usually dark brown or black material that is unable to be separated from the soil and whose origin is no longer recognisable. Made from the decomposition of plant and animal debris, including microorganisms, through the action of microorganisms such as; insects, fungi and bacteria.

Phytotoxic
Something (usually a chemical) that kills or severely debilitates a plant

Resistance
Where a pathogen is impaired in its ability to infect and/or replicate within an organism, resistance can vary from immunity (see above) through to symptoms of varying severity.

Saprophyte
An organism that lives on dead or dying plant material. May or not also cause disease.

Sclerotia
The tiny sometimes microscopic balls that are the means by which many fungi can survive for long periods without a host plant. They are somewhat analogous to a plant's seeds.

Soil Carbon
Whilst this is often used with interchangeably with soil organic matter it is **not** the same thing. Soil carbon has a number of forms and can be measured a number of ways. The four forms of soil carbon crop are:
1. residues (plant pieces > 2mm in size)
2. Particulate organic carbon very small pieces of plants (2mm – 0.053mm)
3. Humus which is decomposed organic material stuck onto and inseparable from mineral soil particles
4. Recalcitrant carbon such as charcoal that is essentially stable.

Tolerance
A pathogen can infect and replicate within the plant but disease symptoms are suppressed to varying degree.

Virulence
A term used to describe how severely a pathogen affects the host

Appendix 5

Registration Self-Assessment Tool

The following is a verbatim copy from the APVMA website of the results from assessing the use of S applications as a disease suppressant.

Registration Self-assessment Tool (Agriculture)

This self-assessment tool is based on relevant provisions of the Agvet Code and associated legislative instruments. This interactive questionnaire is designed to help you determine whether your product requires registration as an agricultural chemical product under the Agvet Code.

This self-assessment tool is only relevant to agricultural products, as defined by the Agvet Code. If your product is identified as not requiring registration as an agricultural chemical product by this self-assessment tool, it may still require registration by the APVMA if it meets the definition of a veterinary chemical product. If your product does not require registration by the APVMA it may still be subject to other Commonwealth and/or State and Territory legislation.

This self-assessment tool does not assess the name of your product. A product name should meet the requirement outlined in the AgLabelling Code .and any claims made (or implicit) in a product name are considered to be product claims, regardless of the nature of the product.

The results of the self-assessment tool should be treated as preliminary guidance only and should not be relied upon as a substitute for obtaining expert advice or submitting a APVMA Item 25 assessment

Every effort has been made to ensure the results of the self-assessment tool are accurate. However, the APVMA cannot and does not guarantee the accuracy of the output as this is determined by your own responses to the questions. Before proceeding, please read the general disclaimer at http://www.apvma.gov.au/disclaimer.php.

Q.1 Product Name: **Sulphur**

Q.2 Is the product a substance which is represented, imported, manufactured, supplied or used as a means of directly or indirectly...

(a) Destroying, stupefying, repelling, inhibiting the feeding of, or preventing the infestation by or attacks of, any pest in relation to a plant, a place or a thing
Yes

(b) Destroying a plant
No

(c) Modifying the physiology of a plant or pest so as to alter its natural development, productivity, quality or reproductive capacity
No

(d) Modifying an effect of another agricultural chemical product
No

(e) Attracting a pest for the purpose of destroying it
No

Q.4 Is the product a mould inhibitor used in the manufacture of paper, paper pulp, glue, plywood, carpets, plastic, glass, fabrics, domestic items, bedding material or leather goods or surface coatings that is not released into the environment from the manufactured product and is not claimed to have any effect as a pesticide? **No**

Q.5 Is the product a mould inhibitor used in the manufacture of surface coatings (including paint but excluding anti fouling paint) that is not released into the environment from the manufactured product and is not claimed to have any effect as a pesticide? **No**

Q.6 Is the product ...

(a) a fungicide, bactericide or deodorant for use in foot wear and clothing? (b) a cut flower preservative?
(c) an industrial biocide used in paper pulp manufacture?
(d) a hot water or steam treatment, based solely on water with no other constituents?
(e) a head lice or body lice treatment for humans?
(f) none of above?

Q.7 Is the product ...

(a) a vertebrate pest management lure?
(b) an invertebrate pest management lure based on food and containing no active constituents?
(c) a predatory insect, predatory mite or macroscopic parasite?
(d) the nematode *Deladenus siricidicola* for the control of *Sirex* species wood wasps in pine plantations?
(e) A hay, silage or legume inoculant based on bacteria, enzymes or both
(f) None of above

Q.8 Is the product used as a physical barrier to a pest? **No**

Q.9 Does the product contain naturally occurring *Trichoderma* species? **No**

Q.10 Is the product ...

(a) a substance to adjust pH of swimming pool or spa water?
(b) ozone generated on site for the treatment of swimming pool or spa water?
(c) a disinfectant, mould inhibitor, air freshener or sanitiser sold for domestic use, but not a sanitiser for use in swimming pool or spa water?
(d) cyanuric acid for use in swimming pools as a chlorine stabiliser?
(e) none of above?

Q.11 Is the product for domestic use by householders in controlling a plant disease or pest? **No**

Q.12 Is the product a soil ameliorant, conditioner or fertiliser? **Yes**

The product...
(a) Does NOT claim to have any effect as a regulator of plant growth?
No

Registration required

Thank you for using the APVMA's Registration Self-assessment Tool (Agriculture)

Based on your responses it is believed that **Sulphur** probably does require registration under the *Agricultural and Veterinary Chemicals Code Act 1994*. Please keep a copy of this PDF file, which details your responses, for your records.

Unless a formal exemption or a permit is granted by the APVMA, it is an offence under the Agvet Code (a schedule to the above Act) to supply a chemical product that is not a registered chemical product, where it is required by law to be registered. Monetary penalties apply to breaches of the Agvet Code.

You could consider applying for a technical assessment by the APVMA of the label, claims, formulation and proposed/intended uses of **Sulphur**. The APVMA will compare these with the legislative tests to determine categorically if your product requires registration.

There are fees associated with applying for an assessment, and making an application does not authorise you to supply or continue supplying an unregistered chemical product. Full details about the registration process (including the fees and timeframes for applications) are available from our website www.apvma.gov.au.

Your obligations under other regulatory schemes or systems have not been determined through this process.

Author Comment

The determination as shown hinges upon the answer provided to Q 2 (a). If this is answered as no then the result gives No registration required.

8 Acknowledgements and References

These are provided at the end of Part B

Appendix 2 – Gap Analysis Report

Horticulture Innovation Australia

Extension Potential and Gap Analysis of Australian Potato Research

Part B
Gap Analysis

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PT13013

December 2014

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1 Executive Summary

A review of all production related R&D funded through the HAL mechanism over the past two decades has revealed that whilst research has generally been of a high calibre it has often suffered from poor outcomes with limited or no adoption/uptake by industry.

This Gap Analysis is primarily focussed on the APRP2 Program but has also considered the broader research portfolio which covers production/agronomy etc.

As part of this analysis some systemic issues in the general R&D formulation process were identified and a mechanism is proposed to address these issues.

This mechanism is envisaged as being of broader application across the HAL R&D portfolio.

Several sub-sets of recommendations are provided;

- General Recommendations that cover activities that need to be enacted across the Potato R&D portfolio and many may also apply to other areas within HAL
- Areas for continued Research and Investment and suggested timelines
- Areas where if further investment is proposed far greater rigour needs to be exercised
- Areas where no investment is warranted at this stage

Whilst many recommendations are made from a technical perspective it is acknowledged that the ultimate determination of investment rests with the Group charged with that responsibility. This report is to help inform that process.

1.1 Summary of Research Design and Conduct Findings

- That a new research protocol and structure as outlined in Section 7 be adopted
- A Potato Industry Advisory Group and Technical Advisory Group be formed to guide investment in R & D
- The Technical Advisory Group be mandated to ensure projects are meeting scientific and technical aims and will be able to deliver meaningful outcomes.
- A formal Induction Program for personnel involved in Project assessment and formulation be developed
- HAL (HIA) acquaint all R & D staff of obligations under the Defence Control Act 2012
- A strategic research portfolio be developed to cover soil-borne disease and soil health
- Further investment in soil-borne disease however be subject to a national stocktake of R&D in this area including linkages to other RDCs
- Any proposed work on soil/plant amendments checked against APVMA guidelines prior to commencement
- Stop/go areas be built into projects based upon KPIs and that ADOPT (CSIRO) and Program Logic be used to develop performance criteria
- Large multi-disciplinary projects have personnel from appropriate disciplines as part of the research team and are not overly complex
- Co-contribution projects be subject to same rigour as all levy projects
- A mechanism for managing R&D legacy be developed by HIA and legacy should be a key consideration in all project evaluation
- New product R&D and technology should have both a demonstrated market failure and a clear path to commercialization

1.2 Summary of Funding Recommendations

The following table briefly summarizes the recommendations listed in Section 2 and in the general body of the report. These should be consulted for more detailed information.

1.2.1 Immediate Funding

- Commence an extension/Tech transfer program based upon the findings in Part A of Pt13013 and with PreDicta Pt as a major platform
- Commence a baseline survey of current awareness (see 2.2.1,1)
- Continue investment in PreDicta Pt to become a cornerstone of Soil-borne disease extension/information. To do this it needs to;
  - extend to other regions in Australia
  - extend to other nematodes especially PCN (if possible)
  - develop peel tests for common, powdery scab, Rhizoctonia, Verticillium, Black dot,
  - integrate decision trees into the manual
  - improve varietal susceptibility ratings
  - include a pink rot test
- Develop a Biosecurity R&D sub-program and where relevant incorporate findings of Pt 13006
- Desktop study to determine factors limiting yield in Australian potato production regions

1.2.2 Funding Subject to Caveats

- A stocktake of Australian Soil Disease Research
- Strategic Investment in;
  - Soil microbiology and characterisation of disease suppressive soils
  - Endophytes as a means of disease control
  - Work on biofumigants to determine modes of action
  - Determine role of other soil/tuber diseases in crop loss including Rhizoctonia strains and also organisms such as Erwinia.
  - Develop a better understanding of non-vector borne viruses
  - Review if there is any appetite within industry (including Chemical companies) for a chemical treatment to assist in Powdery Scab control

1.2.3 No Further Funding

- Research on fertilizer amendments as a means of soil-borne disease control be discontinued
- General levy expenditure on Bacterial wilt detection
- Use of foliar treatments for common scab without some commercial involvement and a path to registration (unless this is part of a research program to understand mechanisms
- On plant nutrition unless there is a compelling case and principles with broad application cane be established

2 Recommendations

2.1 General Recommendations

General Recommendations are provided and their implementation is seen as a precursor to the specific ones which follow. Thus they require immediate attention. It is the author's view that unless substantial changes are made to the R&D process then little change can be expected from the current situation. These recommendations are to inform this process.

2.1.1 Research Formulation

In formulating research it is recommended that;

- a new research structure and protocol be developed in accordance with the principles and recommendations in Chapter 7.
- a Technical Advisory Group and a Potato Industry Advisory Group (Investment Group) be formed as soon as possible. The function of the Technical Group is to provide advice on projects, the technical merits, rigour and likelihood of success etc. Members may fluctuate although a chair and one or two others should be ongoing. The Investment Group makes the decision on investment based upon the industry strategic plan
- models such as ADOPT (CSIRO) as well as the Cost Benefit Tool and Program Logic produced in VG12048 be employed as part of research formulation and KPI generation process
- stop/go areas be built into projects (particularly strategic) that reflect performance, likelihood of success etc.
- a formal induction and training program is devised and provided to personnel involved in assessing projects and formulating research programs

2.1.2 Research Conduct

During a research program it is recommended that;

- in research on new products and technologies there is a clear path to commercialization and that there is a current market failure,
- multi-disciplinary projects have personnel from the relevant disciplines as part of the research team
- care is exercised to avoid complex projects such as were encountered in APRP2
- milestone payment(s) be linked to definite outcomes and outputs as defined by the KPI process
- HAL and Potato Industry develop a process for maintaining legacy and corporate knowledge

- the Technical Advisory Group is mandated to ensure that all projects are meeting scientific and technical aims and on track to deliver meaningful outcomes

- HAL acquaints itself and researchers with its obligations under the Defence Trade Controls Act 2012 to ensure that any pathogen related work does not come under this act. (see; http://www.defence.gov.au/deco/)

- HAL ensures that potential registration issues be addressed through APVMA prior to any research on a product or technology to be applied to soil or plants (including fertilizers or fertilizer practice)

- Any co-contribution R&D be subject to the same level of rigour and control as General Levy projects.

2.1.3 Strategic Research

That;

- HAL develops a strategic (across or multi-industry) research portfolio within the R&D program to cover soil-borne diseases

- HAL develop a process for developing linkages with other RDCs for strategic research commonalities for soil-borne disease R&D

- further investment in strategic soil-borne disease R&D be conditional upon conducting a national stocktake of research being performed by an independent reviewer

2.2 Ongoing Research and Extension Investment

2.2.1 Immediate – (next 12mths)

The following activities are seen as high priority and actionable over a the next 12mths.

1. A key recommendation is to repeat the survey conducted by Leigh Sparrow In APRP1 as part of project PT04016, sub-program 4 (see 5.1.8), in order to determine changes since the survey was performed and provide a baseline for measuring uptake from planned communication activities, including PreDicta Pt.

2. A communication and extension program (as identified in the Potato Industry Strategic Plans) be built around the outputs generated from APRP2 and other related research activities as described in the Appendices of PT13013, Part A

3. An oversight Group be formed and tasked with reviewing and implementing a comprehensive communication and extension program for the findings from Part A and future R&D. The Group to consist of a member each from; DEPI, SARDI, Technical Advisory Group, Industry and the communication team.

4. The PreDicta Pt manual be extended and tested in other regions

5. That the PreDicta Pt manual form the cornerstone of ongoing extension activity on soil-borne diseases

6. That the ‘Decision Trees’ from PT09026 be incorporated into the PreDicta Pt manual

7. Develop peel test options for common scab, Rhizoctonia strains, powdery scab and *Verticillium*.

8. Update and proof varietal susceptibility ratings to powdery scab through in-vitro testing utilising method of Falloon (see PT09026) and verified through field observations

9. Conduct research on suitability of PreDicta Pt test for nematodes for PCN verification

10. Update and reprint the Seed Handling Manual (project PT01030) and other previously produced information sheets (identified in Part A) and incorporate in the communication program where appropriate

11. Update and produce in booklet form project PT98018 “Cleaning and Disinfestation Practices for Potato Farms”

12. That HAL develop and maintain a document control system to ensure that all extension material is up to date and to maintain legacy – including the PreDicta Pt Manual

13. Note Abraham and O’Brien’s (2014) recommendations on biosecurity and allocate a portion of the annual budget to fund biosecurity related activity to increase supply chain awareness as part of a Biosecurity sub-program

Research (Other)

1. Adoption of recommendations from scoping study on virus Y (PT13006) and develop a cohesive strategy on general virus research.
2. Perform a desktop study on limitations to yield in Australian potato production along the lines performed recently in NZ to assist in informing future research directions.
3. HAL in conjunction with the Technical Advisory Group and Potato Industry Advisory Group develop a mechanism and framework to ensure that;

   a. Findings from PT13010 and other studies on diseases of relevance to seed certification have a mechanism for implementation.

   b. There is a systematic approach of validating and applying current science to seed certification thresholds for disease on a nationally consistent and coherent basis

4. Develop a sub-program on biosecurity to fund both communication and extension activities in this area in accordance with the industry’s Biosecurity Plan and obligations under the Plant Health Deed

5. Within the Biosecurity sub-program maintain an ongoing levy funded program of monitoring for tomato potato psyllid and Liberibacter in Australian potato crops.

2.2.2 Short-Medium Term (1-3yrs)

Some of the projects listed below may well fall under a strategic research portfolio, (eg 10)

1. Develop soil threshold levels for economic impact of *Verticillium* (both *dahliae* and *albo-atrum*) and black dot and incorporate into PreDicta Pt.
2. Develop a pink rot test and threshold in soil for incorporation into PreDicta Pt
3. Extending and validating the DNA test for nematodes to other species especially PCN and possibly other root lesion species of Pratylenchus.
4. Determine the extent of crop loss due to *Erwinia* spp. In Australia
5. General Levy funded projects to determine mode of action of organic amendments on pathogen (ie suppression, disinfestation etc.). results to also inform the 'Decision Trees' and PreDicta Pt manual
6. Review to determine if there is any appetite within the potato industry for a chemical treatment to assist in control of powdery scab
7. As part of Biosecurity program conduct a review of ICON (import condition) protocols for disease detection and produce appropriate recommendations
8. Develop agreed protocols for rating varietal susceptibility in Australia to the common soil-borne diseases.
9. Commence a study on the role of Rhizoctonia strains and their relationship to disease expression in Australia.
10. In conjunction with the above determine if thresholds exist for either soil or tuber borne Rhizoctonia and tuber malformation
11. Clarify the role of seed and soil-borne inoculum on expression of the soil-borne diseases that were the focus of APRP2
12. The impact of crop rotations be continued to be measured albeit on a smaller scale and also to consider role of other crops and weeds in the cropping cycle and their impact on disease.
13. Develop a better understanding as to the persistence and transmissibility of non-vectored viruses of concern to potato production

2.2.3 Longer Term Strategic (4+ years)

Under a strategic portfolio as outlined above there is the opportunity to develop and /or continue;

- an endophyte research program for both disease suppression and also improved nutrient uptake etc.. This is a potentially high gain but also high risk program and also unlikely to have commercial application within five years.

- research on disease suppressive soils but as a wider industry program (specifically horticulture but if appropriate other areas as well). The ultimate composition to be informed by the survey/stocktake recommended on page 7.

- Work toward an integrated understanding of soil microorganisms and their role in soil ecology and disease epidemiology particularly of diseases such as common scab. Again a long-term project 5-10 years.

- Any potential registration issues need to be addressed early in any project that will involve product applications

2.3 Further Investment Only with Improved Rigour

2.3.1 Plant/Soil Nutrition (including soil amendment R & D)

- Soil and plant nutrition research should no longer be supported solely from levy funds unless a convincing case can be made that some principles will be obtained which can be applied beyond the trial sites. As part of making a case all of the following issues need to be addressed:

  1. any implications for post-harvest,
  2. relationship to other plant and soil nutrition knowledge,
  3. relevance to regions/soil types different to research plots
  4. highlight potential conflicts with existing knowledge,
  5. methodology and extraction processes need to be in-line with commercial practice (unless it is proposed that a new method is the outcome).
  6. provide a comprehensive review of past work in the area and how this will improve that knowledge.

- Funding for nutrition information packages should not be provided unless there is a clear pathway for updating/maintenance, commercialisation and thus a legacy. In evaluating any potential project a cost/benefit analysis incorporating tools such as ADOPT and program Logic must be performed.

- Where research is designed to investigate changing soil/plant nutrient profiles as a means of disease control that in addition to the points above, HAL ensures that potential registration issues be addressed prior to any research on a product or technology to be applied to soil or plants.

2.3.2 Product Comparisons

- Product/equipment evaluation projects should be discontinued unless there is a commercial partner involved (see template for Research Formulation) and a clear path for adoption.

- Product/equipment evaluation should not be funded through levy funds. Co-investment funding is required here
- Research investigating efficacy of chemistry for which labels are already in place needs to be carefully constructed so that results are both useful and not easily challenged. There needs to be a clear path for adoption and generally this requires affected parties should be involved in this research. A Co-investment contribution should be mandatory
- Research on new chemistry needs to have a co-investment component and a clear path to commercialization.

2.4 No further Activity at this stage

- Research on fertilizer amendments as a means of Rhizoctonia and common scab control be discontinued
- No further general levy funding on fertilizer amendments for other diseases without a compelling case and technical review
- No further General levy expenditure on Bacterial wilt detection
- No further work on the application of foliar treatments for common scab without some commercial involvement and a path to registration (unless this is part of a research program to understand mechanisms

3 Scope

Agronomy or production related research (includes soil health and soil-borne diseases) has formed a major component of research investment by the potato industry and HAL over the past 20yrs.. Furthermore the APRP1 and APRP2 programs which fall under this topic were amongst some of HAL's biggest investments. This report which is in two parts examines HAL's investment in production related research with particular emphasis on the APRP programs.

Part A examined and extracted the information that can be used by industry to form the basis of an Extension and Communication program.

Part B is a consequence of Part A and is to identify, and examine the gaps in this research effort and suggest possible areas of further R&D which can be submitted to the Industry Research Advisory process. It will also propose some mechanisms for the future conduct of research to avoid some of the pitfalls that have occurred in research formulation and extension in the past. In the latter context it is an extension of an earlier report by Abraham and O'Brien (2014).

Investment in R&D is the same as that for any other investment. It is for the purpose of generating a return. In other words it must result in an action or activity that alters or reaffirms the current direction of a business related activity (ie an outcome). It is for this reason that growers and taxpayers are asked to forgo income. It is against this principle that this report has been framed.

At the time of writing (October, 2014), the Horticulture Australia website listed 242 potato specific research reports which have been published over more than 20yrs. This research is from both the fresh and processed potato sector and includes the APRP1 program. The scope of these reports ranges from the very specific (eg study tours) to the very broad and comprehensive (eg soil disease and crop rotations). For the purposes of this study a total of 104 reports were identified of possible relevance including APRP1 (treated as a single report) and the individual reports produced under the APRP2 umbrella.

Whilst most of these projects were funded through the levy process some were also through the VC mechanism, however both types have been considered.

4 Gap Analysis

4.1 Introduction

The Review of APRP2 by Abraham and O'Brien (2014) included a stocktake of the science in APRP2. It is not the aim of this report to repeat that analysis but rather to examine the past research in order to suggest future direction(s). Nonetheless this report is an adjunct to the Review and wherever possible will link to Abraham and O'Brien's findings.

As noted earlier, at the time of writing (October 2014) there are 242 potato R& D related reports on the HAL website. The research themes spanned by HAL research is diverse but this analysis will be restricted to the 104 reports identified as applying to agronomy and particularly soil pathology for the past 15-20years (Appendix 1),

This report will first examine the outputs from the APRP programs and then consider other R&D under broadly themed categories such as nutrition, seed and tubers etc. It is acknowledged that some reports fit into more than one category and that allocations are open to debate however for the purpose of this report this is not seen as of prime importance. Not all reports could be accessed in full. The reasons for this were not always clear although some were done through the VC mechanism, whilst others were maybe never put in digital format.

In evaluating future R&D this has been done based upon both the success and outputs from the research to date as well as the likelihood of further success in the future. This is considered from both a scientific and also adoption viewpoint (ie where investment may give a return over short, medium and long term time frames). It is emphasised that this report is intended to cover both the fresh and processing sectors.

It is noted that the R&D that has been performed to date comprises both strategic and also applied research and the recommendations are framed in this context. It is accepted that the division between what is strategic and what is applied can be blurred and open to debate. Thus for the purpose of this report applied research is defined as that which is unlikely to yield a practical outcome that can be delivered or implemented on farm within two years. Strategic research perforce is thus anything over a longer time frame.

It is also acknowledged that it is up to the industry and HIA to decide in conjunction with the strategic plan whether or not all or any of these recommendations are utilised. Given that the industry has many other areas of concern, soil pathogen research may no longer have the same priority as it once had.

In completing this analysis some systemic issues were identified that it is believed have been one of the reasons for often poor outcomes from R&D. This is discussed in Chapter 7 and a template for research formulation is suggested which it is believed will address this area whereby work is completed and then forgotten or unused.

4.1.1 General Comments

With the exception of the work on soil health and some of that related to seed and tubers there has been a general lack of focus in much of the research. Projects are disparate and seldom related to each other. This is to a large extent historical and is no doubt a consequence of how projects used to be designed. (i.e. people having ideas and sending these to industry for approval). Whilst this procedure is to a large extent now no longer operating the end of the APRP2 program will mean that formulating research will once again be brought into focus. Furthermore the changes to the system due to the transition of HAL into HIA provide an opportunity to re-examine the procurement and utilisation of R&D.

There is considerable heterogeneity in the quality of the research reviewed, both in terms of science and also presentation. Whilst some is world class and has added considerably to our knowledge there is also some that is either unusable or will never be used. The unusable work is particularly prevalent in a number of the nutrition studies where 7 of the 11 reports identified were classified as unusable for the purpose of developing extension programs. There were even extension specific projects, identified that were unsuitable for extension! This will be explored in more detail later. Conversely in a number of instances the research has formed the basis for production of extension materials which have already been produced. This includes work for example on black dot, pink rot, tomato potato psyllid, virus Y and a number of other topics. Some of this material is now no longer available although it may still be current.

It also needs to be acknowledged that many reports were precursors to subsequent work and thus have contributed to a step-wise increase in knowledge, particularly around the more intractable soil diseases such as powdery scab.

Unfortunately there are also reports which have just languished and that, apart from by the people who wrote them, appear to have been forgotten. This includes work on seed certification and common scab, late blight, seed age, post-harvest tuber quality and seed storage to name the more obvious ones. This is regrettable from several perspectives, it is wasteful of resources, it is knowledge which would or may have added value to the industry and it is disappointing to those who did the work. In many of these instances they have been followed up with those concerned and it would appear that there is no single reason for the lack of implementation. Contributing factors include changes in personnel performing the R&D, lack of effective implementation strategies by organisations and personnel concerned, poor project definition, changed priorities by industry or agencies and in some cases inadequate consideration as to what the results may mean to industry. It also needs to be considered that over this time period there have been some major changes in jurisdictional involvement in R&D, major changes in how HAL (formerly HRDC and now HIA) operated and also significant changes in the peak industry body. At the same time the potato industry has undergone significant consolidation and change.

By way of example, as a result of this Gap Analysis an excellent report which should have already been in the Potato Biosecurity Plan (PBP) was identified. This work by Edwards (PT04010) produced a protocol and management plan to cover the contingency of type 2 late blight arriving in Australia. This has now been passed onto Plant Health Australia (PHA) for incorporation in the PBP. This situation arose because no-one from PHA knew about it.

There were also a number of projects that compared efficacy of commercial products for disease control. In some cases they compared products which had a label whilst in others there were also non-label products compared. These reports were generally not used in compiling extension recommendations due to their contentious nature or because they may leave open legal challenge.

5 APRP2 Projects

5.1 Applied Disease Management

5.1.1 Control of Potato Psyllid within an IPM Strategy [PT09004]

This project is a result of the appearance of the tomato potato psyllid appearing in NZ and the desire to investigate potential methods of control using an IPM strategy. As such it is outside the rest of the APRP2 program which was based around soil-borne diseases and their control.

Nonetheless a basis for an IPM program was developed. This program has been further refined outside of APRP2 and is being employed in parts of NZ.

As noted by Abraham and O'Brien in their APRP2 review the psyllid project opens up the question as to why IPM is not more extensively utilised? This topic will be covered later on in this report.

No specific recommendations arise from this project.

5.1.2 Disease Prediction [PT09023]

The final report for this area of R&D provides an honest and succinct evaluation of the work to date and also suggestions for future work (see Technical Summary and Recommendations sections respectively in PT09023). These appraisals provide an excellent example for future report writing.

The release in July 2013 of the PreDicta Pt test for powdery scab, black dot and root knot nematodes is a significant advance in the management of these diseases. It provides a much greater degree of confidence for growers to assess the potential impact of these soil borne pests and diseases on crop performance. This is a major advance for the potato industry and in fact a world leading technology.

The ability of the test to predict the impact of other soil borne diseases is less clear although the data is reasonably conclusive that where there is a high reading for common scab, Rhizoctonia (AG 2.1 and AG 3) and also *Verticillium* (both spp. but particularly *albo-atrum*) then it is highly likely that one could have problems in any potato crop sown in the particular ground. Notwithstanding SARDI's recommendation to revise/update the existing manual there are a number of areas which to a varying extent would benefit from further research and or refinement. These are listed by disease below. The listing is purely alphabetical and does not reflect any degree of priority.

Black dot (*Colletotrichum coccodes*)

This is a disease which to a large extent has historically only been of concern to the fresh market due to its effect upon skin finish. However there is some concern that it may also be of importance to the process sector due to its potential to reduce yields. The potential role of black dot and yield merits further investigation. If an impact is discovered then further R&D is required to determine if a threshold value applies.

Separate work (University of Melbourne) outside of APRP2 has also revealed some variation in isolates and it remains to be seen whether this is also a factor in pathogenicity and also impact.

Recommendation

- Determine impact of black dot on yield loss
- Should yield loss be demonstrated then determine if a threshold level exists

Common scab (*Streptomyces scabies* TXTA gene)

As with Rhizoctonia (see below) the ability to develop a reliable prediction based upon soil DNA has so far eluded this research. At this stage perhaps the best that can be noted insofar as DNA testing is concerned is that a negative does not imply lack of risk whilst a high level of DNA gives grounds for concern as to the crops potential to develop the disease under favourable conditions.

This disease requires more attention from a DNA testing perspective. It maybe that seed inoculum is also involved however this aspect has not had sufficient attention. Similarly the impact of pathogenic and non-pathogenic Streptomyces strains needs to be investigated as well as the extent to which the expression of Thaxotomin is modulated and having an impact upon tuber symptoms.

It has also been suggested that testing be designed around indicator species as described in PT09026. However this is a long term project.

It appears from the work to date that this organism will require a more integrated approach when it comes to disease risk prediction. At this stage an important management option is variety and there is a need for greater clarity around varietal susceptibility ratings.

What is also clear is that there is still some confusion as to the importance of seed and soil-borne inoculum. There is no simple answer to common scab management and a holistic approach is required and this is behind the decision tree approach of outlined in PT09026. From the perspective of the PreDicta Pt Manual the following recommendations are advanced.

Recommendations

- Field Experiments to determine contributions of seed and soil–borne inoculum
- Integrate the decision tree (PT09026) into PreDicta Pt manual to produce a more integrated interpretation guide for assessing risk
- Develop an agreed criteria for varietal susceptibility ratings of common scab that are applicable to both field and lab conditions

Powdery Scab (*Spongospora subterranea*)

As noted above the thinking on this disease has changed over the course of APRP2 and there is now an increased focus on other aspects of the disease apart from tuber lesions. There is a need to look at the DNA test and how it relates to galling and no doubt as we learn more about root infection this aspect as well. There is also an urgent need to revisit the varietal susceptibility list which once again needs to be considered against the information that has come to light during the course of APRP2.

Thus assessments of the disease and its impacts based purely upon tuber symptoms may be quite misleading. This then makes interpretation of some experimental data rather problematic. It also raises some doubt about the varietal susceptibility ratings which have attracted some controversy. A QPCR test (PT09026 AI) developed by Fallon shows promise to provide a quick inexpensive screening method to provide some initial ratings that would go some way to updating the anomalies within the existing rating system. It is recommended that this be undertaken as part of the PreDicta Pt Manual update.

There is still some uncertainty surrounding the role of powdery scab and yield. With the exception of Tasmania, many trials in Australia have failed to establish a relationship between powdery scab infection and yield (deBoer pers. comm.). Whether this is because up until now powdery scab has been assessed primarily through the expression of tuber lesions and thus ignoring other symptoms or there is actually no effect upon yield is not clear. This needs clarifying.

Unfortunately at this stage there is no registered treatment for powdery scab control in Australia and options for growers are somewhat limited should they identify a problem. Essentially there are only two alternatives for paddocks which are heavily infested with powdery scab, either stop growing or find a resistant variety. A possible third is the use of biofumigant crops. Whilst in APRP1 there was optimism over the potential for registration of Shirlan (Fluazinam) for use in potatoes this was never pursued. There is still a need for a suitable chemical control for this disease.

Most of the work and therefore the Manual has been focussed on SE Australia, reflecting the major process potato growing areas. The interpretation guide needs further refinement for other areas to gain a more universal acceptance in Australia.

SARDI's report also suggested a more structured approach to the role of biofumigant crops and their impact upon this disease. It is acknowledged that it is still uncertain whether these crops are acting as fumigants or suppressants or even just increasing the biodiversity of microbial communities through increasing soil organic matter.

Recommendations

- Refine Interpretation guide for varietal susceptibility integrating existing ratings with field observations and results from a QPCR testing regimen
- Quantify the effects of root galling and infection on yield
- Develop and incorporate within PreDicta Pt an economic threshold level should a relationship to yield be found.
- Clarify the role/mechanism of biofumigants in disease control
- Conduct a review through the SARP process of whether or not there is any desire for a soil or tuber chemical control option of this disease
- Expand PreDicta Pt Manual to and associated training to cover other production areas and refine if required

Nematodes (*Meloidogyne fallax, M.hapla*)

Of these two species *M. fallax* is currently seen as the major problem for the industry. The impact of *M.fallax* shows some regional variation even although it is widely distributed in Australia. The pre-plant test has been found to provide reasonable predictive capacity and soil inoculum is seen as the major source of infection. SARDI have recommended that a peel test be developed as an alternative to pre-plant tuber inspection. There is merit in doing this even if it only verifies that the existing visual method of assessment is satisfactory (eg. as shown in PT09019 for powdery scab). This would also be concordant with recommendations elsewhere in this report around seed certification and disease thresholds.

As noted for powdery scab the role of bio-fumigants also warrants clarification, however this work is likely to be strongly influenced by climate and soil type so a regional approach may also be required. This would be best managed with co-investment.

There is potential here for the PreDicta Pt test to extend to PCN and if this can be utilised this has the potential to save the industry considerable cost by offering a much cheaper and integrated testing service rather than having to use the present costly PCN test. A project for validation testing is developed and is a priority.

Recommendations

- Investigate the suitability of a peel test for *M.fallax*.
- Investigate if a peel and soil test can be used for PCN monitoring and seed certfication
- Clarify the role/mechanisms of biofumigants in nematode control.

Rhizoctonia (*Rhizoctonia solani* AG3 & AG2.1)

Like common scab, Rhizoctonia has proved problematic and the usefulness of the soil test and developing thresholds for crop impacts has proved elusive. So far it has not been possible to establish reliable pathogen DNA threshold levels for soil based inoculum. Perhaps the best that can be said is, the same as to what has been noted for common scab, ie low or undetectable does not imply low risk, but a high level should give grounds for concern.

It is known from work elsewhere (in other R&D projects and also UK) that the seed tubers carry inoculum (especially AG3) and it would seem appropriate that further work in this area look at developing and validating a peel test and integrating this into the PreDicta Pt guide. As with common scab a more holistic approach may be required for this disease. A greater understanding of the relative role of AG3 and AG2 is required from an epidemiological perspective, so that chemical control can me more efficacious. As noted in Part A not all products are equally as effective against AG3 and AG2.1

Currently the test provides some indication of risk but the role of seed and soil-borne inoculum requires further clarification. This requires further work for both the AG 2.1 and AG 3 strains. Uncertainty surrounds the extent to which Rhizoctonia is affecting plants through the killing or pruning of shoots prior to emergence. This uncertainty may also be a contributing factor toward the difficulty of establishing thresholds. For fresh market in particular it would be desirable to gain a more quantitative understanding between Rhizoctonia infection, DNA levels and malformed tubers.

The effect of Rhizoctonia upon crop yield and performance may also be influenced by inadequate diagnosis in the field and thus the impact of the disease may be underestimated.

Research elsewhere has also suggested that the different strains may have differential responses to various registered chemical treatments (Todd, 2009).

Recommendations

- Investigate a peel test as an adjunct to soil testing
- Gain a better understanding of the epidemiology of AG2.1 and AG3 in potato production across Australia
- Produce an integrated guide for incorporation into PreDicta Pt manual. The ‘Decision Trees’ produced in PT09026 are seen as a valuable resource here.
- Determine the impact of shoot death (longer term, funding priority)
- For the fresh market investigate tuber malformation and seed/soil inoculum (longer term)

***Verticillium* (*Verticillium dahliae*)**

The research on this disease from the University of Melbourne has greatly added to our knowledge on this disease. Many isolates have been identified and these vary both in virulence and also geographically.

The DNA assay has shown a strong relationship between pre-plant levels of *Verticillium* and that found in the tubers. A test for the associated *Pratylenchus crenatus* (PT09029) has also been developed. It is strongly suspected that these pre-plant tests provide a good indication of risk but this has yet to be quantified and as yet no pathogen DNA threshold is available. Discussion amongst those involved suggests that this threshold may be quite low for a yield impact upon a crop and that it would not require a great deal of extra investment to generate this data.

Although an in-vitro interaction between *P crenatus* and *Verticillium* has been shown the quantitative impact of this under field conditions has not yet been established.

Recommendation

- Develop threshold values for disease risk (Short term)
- Continue to tease out the relationship between *Verticillium* and *Pratylenchus* spp. so that appropriate thresholds can be developed for where both species are present.

Other Diseases

Two other diseases which have been raised as candidates for inclusion under a DNA test are pink rot (*Phytophthora erythroseptica*) and *Fusarium oxysporu*m.

Whilst it could be argued that pink rot is often a manifestation of poor soil management (ie compaction, water logging etc.) it is nonetheless a significant problem in a number of areas. A pink rot test would provide both a management tool for assessing risk but also could help producers monitor changes in soil management practices.

Potato early dying (PED) is also another disease which may warrant further investigation. Unfortunately the term PED and *Verticillium* are often used interchangeably and whilst the research to date suggests that PED may be caused by *Verticillium* it is also true that not all PED is due to *Verticillium*. Other candidates include *Erwinia* and *Fusarium* spp.

Fusarium species are problematic and some evidence, both anecdotal and clinical indicates that particularly during summer a number of internal problems in fresh potatoes in Australia may be a result of *Fusarium* infection. This needs clarifying.

To this list could also be added *Erwinia* spp. However DNA tests for bacteria do involve some other complications and thus may require extensive investment. A peel test for this organism would probably be of use however a soil test may take considerable investment for a less certain outcome.

Recommendations

- An assay test be developed for pink rot for field evaluation
- Determine the extent of *Fusarium oxysporum* as a contributor to potato losses in Australia as a possible precursor to developing a DNA test
- The need for a test for *Erwinia* spp. be investigated through a survey of crops and the extent of *Erwinia* infection in crops

Peel Testing

In the discussion above the need for a peel test for these organisms has been highlighted. To date there has not been a strong focus on peel testing of potatoes. It is highly probable that the expression of many of these diseases on potatoes is a result of an interaction between both soil and seed-borne inoculum and that this interaction may vary between the different pathogens.

Furthermore one of the important themes to come from the APRP2 research and indeed from other R&D elsewhere is that there is no substitute for having clean soil and where this exists then its status should be zealously guarded. The main way many soil-borne diseases enter clean ground is through contaminated equipment and seed. A peel test would assist in keeping clean ground disease free, o assist in research comparing impacts of seed and soil borne inoculum and may help contribute towards providing a greater degree of predictability for some of the more difficult diseases such as common scab and Rhizoctonia.

It would also be of significant importance in seed certification.

Recommendation

- Peel testing for soil-borne diseases be developed alongside those developed for soil,

General Comments on PreDicta Pt

SARDI have also made some recommendations on some strategies which they feel may enhance uptake of the service. These have been listed in the Recommendations section of their report and are as follows;

- Facilitate grower group program for on-farm demonstration of the use, decision making and evaluation of benefits from utilising PreDicta Pt and implementing those decisions

- Continue to develop linkage between PreDicta Pt results and practical disease management options from other field work and experience

- Capture examples and data of where commercial use of the PreDicta Pt test has improved outcomes for promotion to the wider industry to inform both evaluation and also further extension activities

- Resource a specific program to review and evaluate the PreDicta Pt testing service during the establishment phase of it becoming a commercial service, including the importance of using correct soil sampling procedures by test users.

In essence these points essentially describe an extension/communication and evaluation program. This is strongly endorsed but with the caveat that the organisation performing the evaluation role be independent of SARDI. However the communication and extension program will require a strong input from SARDI. Prior to beginning this program effective KPIs need to be developed using the ADOPT and Program Logic models as a method for informing and measuring the process. It is also suggested that a survey similar to that performed by Sparrow in APRP1 (see Section 5.1.8) be performed immediately in order to establish a benchmark. (It is perhaps an indication of the long-term nature of effecting change in that when the PreDicta Pt program was put through the IAC meetings in June 2014 it was found that to get 90% uptake within the industry a timeframe of over 10 years was forecast. Any evaluation program should thus consider this time-frame.)

Should the uptake and evaluation process show significant commitment to this area then as a major platform and outcome from the APRP1 & 2 programs the industry needs to ensure that for this investment to have ongoing return there needs to be a commitment to maintaining the PreDicta Pt Manual and keeping it up to date (see later discussion on legacy).

Whilst SARDI at this stage are committed to the ongoing development of the PreDicta Pt, for the potato industry this is conditional upon an industry commitment, hence the need to perform the above program.

Recommendation

- Benchmark current usage of PreDicta Pt

- An extension/communication and evaluation program be instigated for PreDicta Pt and for this to cover all potato producing regions in Australia

- Establish a legacy framework for the PreDicta Pt Manual

General Recommendations

To prioritise the order in which further investment should be made is difficult as the relative importance of various soil borne pathogens varies from region to region. Nonetheless several options stand out which would be of benefit to the entire industry irrespective of the local environment and could be done for relatively little cost;

- Establish a legacy framework for the PreDicta Pt Manual should the Evaluation program and usage demonstrate that it is warranted

- Updating the PT Manual with particular reference to varietal susceptibility and integrating the 'Decision Trees' from PT09026 into the guide.

- Validating a DNA test for PCN

- Further refinement of the test and its suitability for common scab and Rhizoctonia strains

- Develop an economic impact and if needed a threshold for black dot

- Developing an economic impact threshold for *Verticillium dahliae* and also *V. albo-atrum*.

- Develop and improve peel test options (very important for those without disease)

- Develop and validate a Pink Rot PreDicta Pt assay

- Develop a legacy plan

5.1.3 Comparison between DNA testing and visual methods for assessing Seed tuber health [PT09019]

This project is one of very few that has attempted to provide some empirical evidence behind seed certification standards. Research that can be used to validate seed protocols and provide a scientific basis for current practice or practice change has been relatively uncommon in Australia.

The results from this work suggest that unless one is concerned about introducing soil pathogens into clean ground the current visual seed testing regime on ungraded seed, provides a good indicator of seed pathogen load. The research provides support for the conclusions of Pung (PT02016) which showed that for common scab, grading did not result in improved outcomes from daughter tubers and in fact may have been counter-productive by providing a false feeling of security around the quality of seed. The consequence being that high pathogen loads could be introduced into ground that may not have a particularly high pre-existing level of scab.

Pung also noted that common scab thresholds in seed could probably be eased to 10% without any substantial effect upon the resultant crop. Unfortunately the ability of people to differentiate between common and powdery scab mean that it was unlikely that such a change can be effected. Whilst the research by Pung was insightful it demonstrates the importance of ensuing that research is also guided by what can be practically implemented.

Project PT09019 raises the more general issue of seed certification and science based standards. It was noted by Pung (PT02016) and also by De Boer (PT02016) that there has been very little research performed in Australia (or elsewhere) to validate current seed certification protocols. Although this project showed that there is no need for any change to existing practice this research is just as valuable in that it validates an existing standard. It does however raise the question as to what would happen if it had been found that the current visual assessment was unsatisfactory. There is no properly constituted framework for the science to be incorporated into the seed certification system.

As will be elaborated later (Section 6.2.3) any well-constructed R&D which can inform seed certification is valuable. There is a strong case for further R&D in this area. The development of more sophisticated tools for disease detection does permit a re-examination of the relevance of current thresholds of disease in seed potatoes and the resultant impact in the daughter crop. Seed certification should have a science base. However, an important caveat of this work is that seed standards need to address several key criteria:

They should be based upon science and;

- achievable in the grading shed (ie with powdery and common scab there is no point in having different visual thresholds as the diseases are often confused by even skilled operators
- They should be achievable by producers
- They should be acceptable to customers
- They should be harmonised across Australia
- There needs to be a mechanism for implementation

Recommendation

- Seed potato certification disease thresholds need to be examined on a pathogen by pathogen basis to determine the appropriateness of current standards in the light of new molecular tools now available.
- Compare visual and molecular disease assessment techniques for their accuracy in identifying pathogens to assist controlling disease spread by seed potatoes

5.1.4 Soil Nutritional Amendments [PT09026 (Ai)]

Summary

As noted by O'Brien and Abraham in their report this program has been somewhat problematic. To some extent it has been a bit of a catch-all for a series of projects that didn't fit in to other research spheres. Nonetheless the resultant report provides a very good synthesis of the work and this has culminated in the development of decision support trees which for the first time provide an integrated approach to the management of three important soil-borne diseases; powdery scab, common scab and Rhizoctonia. Whilst serving as a management tool they also serve to highlight the current gaps or weaknesses in our knowledge of these intractable diseases. They also are seen as tools to be continually refined and updated based upon field experience and research.

In reviewing PT09026 it will be split under the two broad definitions of Applied and Strategic Research, with the later considered elsewhere. The criteria for these two definitions are that the results are either ready for implementation or are still some time away from a commercial application.

APPLIED RESEARCH

The Research Program

PT09026(AI) was to a considerable extent built upon earlier work in APRP1 (particularly Sub-Program 3) from which a number of the hypotheses for the APRP2 program were developed.

Research from APRP1 suggested that the impact of some soil diseases, particularly powdery scab and common scab may be reduced by manipulating some soil nutrients. Of particular interest were Zn, S and Fe as well as K:Mg ratios and Ammonium Sulphate. Various organic amendments were also compared. Pot trials also indicated a positive effect of raising B levels and reducing scab.

As part of the review process for this report (PT13013) APRP1 was consulted and the data re-examined in order to better understand the supporting principles for the APRP2 program. This has led to the conclusion that the impact of various organic and inorganic treatments upon the three diseases of powdery scab, common scab and Rhizoctonia was to some extent overstated in APRP1. This may help explain why the results from APRP2 have not provided as definitive answers as were perhaps anticipated.

The PT09026(Ai) component of the APRP2 program involved Australian, Canadian and New Zealand researchers. The Australian research concentrated on field applications of various elements with some supporting pot trials. The New Zealand work helped inform the field trials by investigating nutrient manipulation through pot experiments whilst the Canadian research comprised field trials with green manures as well as development of molecular tools for identifying key micro-organisms involved in soil disease suppression and expression. The work on soil micro-organisms will be considered under strategic research.

Powdery Scab

The NZ research showed that with pot trials the use of elemental sulphur and boron and possibly ammonium reduced powdery scab in-vitro. It also showed that silicon may alleviate the impact of root infection by powdery scab but not reduce infection. Only very high levels of potassium (almost phytotoxic) reduced powdery scab. No effect was found on powdery scab from elevated iron levels or from sulphate sulphur.

Field trials in Australia were mainly performed in the Ballarat area. Trials extended over five years and these consistently revealed that application of S (particularly elemental) reduced both incidence and severity of powdery scab. The effect however was greatly confounded by variety and in only a few trials did the reduction in incidence and severity of powdery scab result in an improvement in yield or packout. Treatments produced a much stronger effect in a susceptible variety such as Shepody.

When the data for all years was combined and subjected to Restricted Maximum Likelihood Analysis (REML) some positive impacts upon yield and packout were obtained from applications of S at 0.8t/ha and also soil applications of either Zn or Fe EDTA. The effect was also varietal dependant. A note of caution is also required as this level of S application is considerably higher than typical fertilizer rates and thus may have quite dramatic effects dependent upon soil type.

The reason for the reduction in powdery scab from Fe and Zn applications are unexplained and unfortunately do not parallel those from pot trials. It is thus difficult to determine whether the field results indicate a more universal effect or are idiosyncratic to the Ballarat area. Caution also needs to be exercised with Zn as it can easily become phytotoxic if concentrations become too high in soil. As noted above, the results were far more impressive for a susceptible than a less susceptible variety. Even the REML analysis failed to show an impact of any treatment on yield or packout of Russet Burbank.

Whilst the effects of S in reducing powdery scab are encouraging and parallel those found elsewhere (NZ & UK) it must be emphasised that these results will need truthing in other soils and regions. These results however should assist in conducting experiments elsewhere. The anti-biotic properties of sulphur are well proven in a wide range of plant health circumstances (Dubuis et al. 2005, and Kruse et al. 2007) so it could be anticipated that this effect may also work in other areas.

The soil amendment research has been complicated by other research in APRP2 that has revealed more about the nature of powdery scab. Much of the assessment of impact has been based upon the appearance of the tuber (ie the coverage and severity of lesions on the tuber). With the progression of R&D in APRP2 it has become apparent that tuber lesions are just one form of expression and that root galling may also be very important, even if tuber lesions are not produced. This has made interpretation of R&D on powdery scab less straightforward than hitherto. The relative impacts of galling and tuber lesions need to be further elucidated.

Common Scab and Rhizoctonia

For the other soil-borne diseases the results of the soil amendments have been patchy. This was also the case in APRP1. The impact of pH on common scab has been re-affirmed and it has been shown that Ca can be added to soils without necessarily compromising common scab incidence and severity. However caution is warranted as the data is not validated across a range of soil types. Until it has been shown otherwise it is prudent to maintain soil pH below 5.5, preferably closer to 5.

There is little evidence to suggest that either common scab or Rhizoctonia were affected by nutrient manipulation. Changing the K:Mg ratio failed to show any impact on severity or incidence of common scab although there was an impact on yield. This suggests a nutritional effect. Given that this research started in APRP1 and has continued over APRP2 the results are somewhat disappointing.

Addition of soil organic amendments has proved positive and this supports a considerable body of work produced over the years on the benefits of soil organic amendments upon pest and diseases (eg Alyokhin et al. 2005, Blaesing 2013) and numerous grower led experiments (eg. Darryl Long in

Tasmania with the mustard cv 'Caliente'). Whether this is just due to changes in microorganism ecology/populations, phytotoxic effects, disease suppression or a combination of all three is unclear.

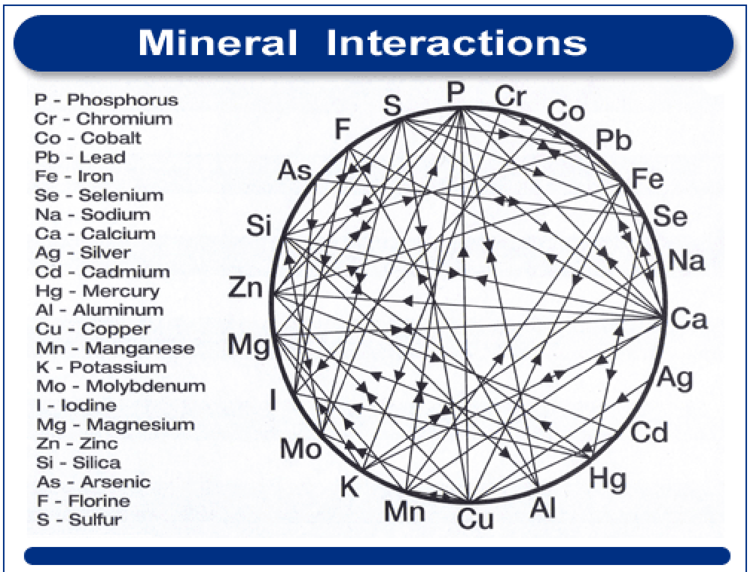
Interpretation Of Soil Nutrition Experiments

The major difficulty in performing and then interpreting research where soil chemistry is concerned is its complexity. Testament to the complexity of this research is the astronomical number of publications on soil/plant nutrition. Whilst it is not the purpose of this report to provide a review of soil/plant nutrition it is however necessary to briefly highlight the extent of these interactions and thus difficulties associated with R&D in this area.

The importance of nutrition and plant health is well known and documented with books having been written on the subject, (eg. Mineral Nutrition and Plant Disease by Datnoff et al 2007). In addition the antibiotic properties of elements such as sulphur, zinc and copper are also well known. Indeed these elements are found in many fungicides and bactericides. Huber et al (2012) noted that the impact of nutrition is relatively small at either ends of the resistance/susceptibility spectrum but can be substantial in the middle portions. It has also been found in many studies that applications of fertilizer to control one disease may exacerbate another (Huber et al. 2012).

The problem however is that, like soil health, defining 'optimum' nutrition for disease management is considerably more difficult and lacks universality due to the complex interaction between soils and nutrients as well as varietal effects. The area is complex, involving soil physical, chemical and biological attributes as well as the interaction between various cations and anions themselves (Blaesing 2013). Antagonistic relationships also exist between anions, and cations that usually make interpretation difficult and development of principles problematic. Adsorption to clay minerals varies according to the type of clay mineral and this in turn affects availability in the soil solution (Bear 1964). It is these types of interactions that appear to be the principle reasons as to why generalised recommendations have proved elusive.

As an example of the complexity inherent in nutrient work a diagram from Mulder (Osman 2013) is reproduced below.



Direction of arrows denotes interference.
Arrows **aimed at each other** denote **mineral synergy**.
Arrows **aimed away from each other** denote mutual **mineral interference** or antagonism.

For the elements considered as useful in this report it is known that Zn and P are mutually antagonistic (Boawn & Leggett, 1964; Blaesing 2004). Similarly there are also interactions between N and S (Kruse et al.2007, Muttucumaru et al. 2013). Therefore the applications of large volumes of both Zn and S, well in excess of normal fertilizer rates, needs to be approached with caution. It is a weakness of this research that the area of soil chemistry and nutrients has not been adequately addressed.

Furthermore as the brief discussion above notes, it will be necessary to truth this work in other areas with properly constructed trials and the results to date raise a number of important questions for ongoing management. It is also difficult to extract any principles for ongoing management for regions other than Ballarat. It is unclear from the APRP research how often these large inputs of S and Zn or Fe would be required. Is it required before every crop? What is the threshold level for application? Conversely is there a threshold level where S application may have a deleterious effect? How is this treatment likely to vary in its impact between soil types and regions? How can it be managed in integrated cropping programs where soil pH needs to be varied for different crops? Whilst the REML analysis showed that there was an impact when data over the length of the research program was pooled, this effect was not seen in every year. This then raises the question of how long should trials be performed in other areas in order to prove or disprove an effect?

A major finding from the research in APRP1 & 2 is that the main determinant in response to both disease and treatment for powdery and common scab is variety. Thus any research in this area needs to be qualified by this effect.

There is not a lot of evidence as to how nutrient manipulation operates on powdery scab. For example, are we seeing phytotoxic effects, an enhancement of the plants defences or changes in microbial ecology or all three and if so how or why? Does nutrient manipulation have an effect upon all stages of powdery scab and if so is it the same for each?

This very brief summary of the issues surrounding nutrient amendments is not meant to suggest that there should not be research into this area but to help frame future industry investment decisions. Potential R&D could be both strategic and or applied. Strategic work will likely be long term and costly and would involve developing a more mechanistic understanding of what/how and where exactly the various elements/compounds are acting to reduce disease. Understanding basic principles will then inform applied work which would constitute trials of these (S & Zn) in other areas over several years to determine their efficacy. The caveat to this however is that as both APRP1 and 2 have shown that variety is a major factor in the response to nutritional amendments there is a possibility that any trial work in this area could be redundant due to varietal effects. This varietal effect reinforces the need to establish some background principles and understanding of mechanisms.

Until more is known about the actual effect that an element or compound is having this type of work will always be accompanied by a great deal of uncertainty in both outcome and applicability. Any further research on S, Fe or Zn will need to be done on a regional basis on a co-contribution basis. It will also require appropriate rigour. Future work in this area also requires a soil chemist to be part of the research team so that impacts are discussed not only in terms of the elements or compounds in the treatments but also their likely interaction with others.

There would appear to be no further benefit to be gained in continuing fertilizer trials for either common scab or Rhizoctonia control.

Lastly it is important to note in the context of this type of research that the use of chemicals (including those used as fertilisers) for use as soil amendments may require APVMA approval. As noted in Part A of this report it would appear that the use of S, Fe and Zn when used for disease control may require formal clarification from the APVMA before explicit recommendations can be made.The APVMA website has a self-assessment tool which can serve as a guide when assessing the usage implications. This should always be utilised when embarking upon work of this nature. If a nutrient requires registration, this will have implications for both cost and implementation. It is emphasised though that this is a guide only and if in doubt clarification from the APVMA would be required. See;

https://portal.apvma.gov.au/rap/dmprr-a

When this test was applied to the S aspect of this research it suggested that registration maybe required. The crucial question (Q2) from the self-assessment test in determining this result was:

“Is the product a substance which is represented, imported, manufactured, supplied or used as a means of directly or indirectly…

(a) Destroying, stupefying, repelling, inhibiting the feeding of, or preventing the infestation by or attacks of, any pest in relation to a plant, a place or a thing

If the answer to this question is Yes then it means further clarification is required.

‘Decision Trees’

As noted earlier, a major output from PT09026 has been the production of three decision support systems. This marks the first attempt to synthesize our current state of knowledge into a tool that can be used to improve management approaches to these intractable diseases.

These ‘Trees’ build upon decades of previous R&D and it is timely that a more integrated approach to soil health and disease management was produced. To this end the data sheets, FAQs and ‘Decision Trees’ which are in the Appendices of Part A of this project are seen as the basis upon which a communications and information program can be based.

The Decision Trees need to be incorporated as a working document into the PreDicta Pt manual.

The ‘trees’ also inform gaps in current knowledge. For organisms such as common scab and Rhizoctonia there appears to be a sound case for developing a more holistic approach to disease risk and management through a better understanding of the interaction between these pathogens and population dynamics, particularly in conjunction with other microorganisms. As noted in the ‘Decision Trees’ the best that the PreDicta Pt test can offer in respect of these two diseases is a reasonable certainty that a high level of soil inoculum carries a higher degree of risk. Unfortunately the converse is not true. It has already been noted earlier that we also still do not have a clear understanding as to relative importance of the AG 3 and AG 2 strains of Rhizoctonia in potato production around Australia.

Among the most prominent Gaps highlighted by the ‘Decision Trees’ are;

- varietal susceptibility ratings,
- lack of a peel test for tuber borne disease and associated thresholds for diseases
- lack of any registered chemical for powdery scab control,

- lack of knowledge surrounding shoot death from Rhizoctonia infection
- lack of knowledge about partitioning of risk to a current crop from either seed tuber infection or the pre-existing pathogen levels in the soil,

Recommendations

- The 'Decision Trees' from PT-09026 (AI) be incorporated into the PreDicta Pt manual
- A small group be tasked with liaising with an industry communication program to ensure that the 'Decision Trees' reflects industry feedback. A review committee comprising a member from DEPI, an industry member, a rep from SARDI, a non-conflicted technical person and the leader of the communications program should review this regularly.
- Future R&D involving soil chemistry have a soil chemist as part of the research team
- Any future R&D involving soil nutrition be supported with a sound rationale for undertaking the R&D including a supporting literature review and to be subject to independent technical review before proceeding.
- Future work on organic amendments be properly constructed to determine the mode of action and also their relevance to various production regions in Australia. The former is considered a strategic R&D approach, the latter applied and funded through a co-investment mechanism
- There be no further research on fertilizer effects on common scab and Rhizoctonia without compelling evidence.
- The impact of S, Fe and Zn be tested in other areas and supported through co-investment mechanisms
- The varietal susceptibility ratings for the three diseases (powdery scab, common scab and Rhizoctonia) need to be reviewed and if required updated ,
- A DNA peel test for these three diseases be developed along with appropriate thresholds for disease risk
- A review through the SARP process of whether there is any appetite within the industry for a registered chemical for powdery scab control,
- Ensure that any work on soil amendments is checked against APVMA guidelines for whether or not a registration is required. This includes products that would normally be used as fertilizers.
- Review the need to continue research into common scab and Rhizoctonia and if it is considered desirous to continue this research develop a program of more strategic research that would involve;

    a. Determining the relative importance of AG3 and AG2 types of Rhizoctonia in potato crops and investigate the extent of shoot death from Rhizoctonia infection

b. Improving our knowledge about partitioning of risk to a current crop from either seed tuber infection or the pre-existing pathogen levels in the soil,

c. Developing a greater understanding of soil microorganisms population dynamics and their impacts upon the ecology of diseases such as Rhizoctonia and common scab

5.1.5 Novel Chemicals for Control Of Common Scab (PT09026)

Albeit a minor project this work identified that the use of the herbicide 2,4-D in very dilute concentrations could produce a dramatic reduction in both incidence and severity of common scab on tubers both as a foliar application and also when used as a dip on seed tubers. The project also showed that some other chemicals eg. 2,5-DBB could produce the same effect. A small project, it was designed merely as proof of concept. The results identified the mode of action also produced an assay by which any potential new chemical could be evaluated.

Whilst a registration was not the intended outcome of this work, the dilemma these results pose around registration highlights the problem of this type of R&D without a commercial partner who is prepared to see a commercial outcome/product.

There is little appetite for registration of 2,4-D or substitutes as the cost would be high and there would be little payoff for the company concerned as the potential sales volume would neither be large nor possibly be protected by patent. Although there are overseas registrations for the use of 2,4-D on potatoes (eg improved skin colour on red skinned varieties in the US) there are no registrations in place for its use as pesticide against common scab. The registration process for 2,4-D or a substitute will thus be extensive and expensive. Furthermore it would most likely need to be entirely at the industry's expense. It may also cause a degree of consumer concern given the often irrational debate around the use of chemicals, especially 2,4-D.

Alternative chemicals face similar hurdles.

However notwithstanding these issues it needs to be emphasised that these observations are not designed to prevent research in this sphere where the outcome is to gain insights into the pathogen and its biology.

Recommendations

- This work be discontinued unless a commercial partner can be found who may wish to investigate alternative compounds
- Future work of this nature should also not proceed unless there is strong interest from a commercial partner or at the very least a clear pathway to commercialisation.

5.1.6 Impact of Rotations [PT09026 (Aii)]

Over an eight year period the levels of inoculum of *Rhizoctonia solani*, common scab and powdery scab were monitored at a number of sites in order to determine the impact of crop rotations on these intractable diseases. This is a world first and showed that the typical five year rotation between crops had little impact upon the level of powdery scab in the soil. The impact upon soil DNA for the other two diseases was less striking and suggested, that at least for Rhizoctonia, a good rotation does indeed lead to lower levels of inoculum in the soil.

It was also found that a number of rotational crops can have an impact (positive and negative) on the levels of soil inoculum for all of these diseases and that this impact depends on the disease and also the crop.

This study has been illuminating in showing just how difficult it is to rid soils of these organisms once they're established.

It is difficult to know where to go with this work, as already noted there are potentially a number of interactions that will influence levels of inoculum. Research of this nature however is important for mixed cropping regions but its value lies from its long term monitoring. Thus for a study like this to continue it will require long term commitment. Due to the likely regional nature of any results it is probably best funded through a combination of general levy and co-investment. A reduced program at only a few selected sites and taking into account crop expression of the disease and also the impact of weed hosts could potentially yield further valuable information.

Recommendations

- The results from this study be incorporated into the PreDicta Pt manual
- The study be continued on a smaller number of sites and include crop impacts (potatoes only) and weed hosts through a mix of levy and co-investment funding
- Further research be performed on the role of other crops in the cropping cycle in the persistence of Rhizoctonia strains.

5.1.7 Bacterial Wilt [PT09026(C))]

The work under this title focussed on validating sampling protocols and testing the Bunyip River in Victoria for the presence of the bacterial wilt pathogen *Ralstonia solancearum*. It has long been known that bacterial wilt can be spread through contaminated water (Mulder & Turkensteen, 2005). Sporadic outbreaks of bacterial wilt were often linked to flooding episodes of the Bunyip River. The purpose of this project was to determine if the Bunyip River was the source of infection and if so to develop a catchment management plan to minimise the risk of disease spread. The project suffered in the first two years due to weather factors and only managed a single detection from the Bunyip River in 2012/13. The project was extended to a third year on the proviso that a VC contribution be secured.

The project validated the existing testing diagnostic methods (including the use of in-field lateral flow devices that can be purchased and used by growers)and discovered a potential host for bacterial wilt in the aquatic weed *Damasonium minus*, however this has yet to be proven.

Fact sheets have been produced.

It is unclear why this project came under the APRP2 umbrella. Recommendations from the project are for further work so as to develop high throughput testing for cost effective sampling. Unless it is intended that this is to be provided as free of charge to the industry then such a protocol would seem to fall within the sphere of normal commercial development. At best this should be funded through co-investment sources.

The research on bacterial wilt also raises another issue which although not relevant to this particular project is nonetheless of importance to any research agency working on plant pathogens. The Defence Trade Controls Act 2012 specifies a large number of plant pathogens under the Defence and Strategic Goods List (DSGL) for which approval maybe required for conducting research. The Act is wide ranging and powerful and covers supply of DSGL technology, publication and arranging other persons overseas to engage in DSGL technology. Bacterial wilt is one of the pathogens listed in the DSGL. More detailed information is to be found on the following website;

http://www.defence.gov.au/deco/>

Recommendation

- The results be incorporated into the communication program (Part A)
- No further general levy funds be expended in this area at this stage.
- Hal familiarise itself and researchers with its obligations under the Defence Trade Controls Act 2012.

5.1.8 Measuring Uptake

In APRP1 as part of project PT04016, sub-program 4, Sparrow performed an extensive benchmarking survey in 2005 amongst growers in Tasmania and Ballarat. This survey was designed to provide a baseline against which industry R&D impact could be compared. The survey was comprehensive and illuminating. To the best of this author's knowledge it has not been repeated. This is somewhat surprising given the survey's original intent.

As it is now nine years since the original survey it would seem appropriate to repeat the same survey within the same sample populations. It is not often that one has access to such baseline data. Completion of such a survey at this juncture would provide a valuable baseline against which to measure impact of work since the original survey and more importantly provide a measure against which a new communication/extension program as detailed in Part A and elaborated further in this Part. This is seen as a key recommendation.

Recommendation

- It is recommended that this survey be repeated as soon as possible in order to determine changes since the survey was performed and provide a baseline for measuring uptake from planned communication activities as this may help inform communication activities on potato research

5.2 Strategic Studies on Disease Epidemiology and Assessment

Under this title comes work on soil microbiology, soil "health", endophytes and understanding of infection processes. This research comprises several projects and a sub-project of PT09026.

Strategic research, as in fact with all investigations, needs to be carefully planned and with numerous decision points at which the direction and future of the R&D need to be decided.

5.2.1 General Comment

Through the APRP1 & 2 research programs our understanding and knowledge of a number of diseases has changed. This has meant that some of the original assumptions upon which the research program was predicated no longer hold true. The most striking example is powdery scab. Initially research focussed upon tuber expression (ie lesion incidence, coverage and severity). As the research progressed it became obvious that this was only one manifestation of the disease and that root galling and root infection maybe just as, or, even more significant.

Recommendation

- Further research on refining the role of root infection in powdery scab and quantifying its impact upon yield is warranted.
- Develop quantitative test(s) that can be employed as part of an overall assessment of a variety's susceptibility to powdery scab.

5.2.2 *Verticillium* and Root Lesion Nematodes [PT09029]

The purpose of this project was to understand the role of *Verticillium* in potato early dying syndrome and to develop some understanding as to the interaction between *Verticillium* and root lesion nematodes as there is evidence that these act in a synergistic manner increasing pathogenicity.

The work found that there are three species of relevance in Australia (*V. dahliae, V. tricorpus* and *V. albo-atrum*) and that all are pathogenic. *V. dahliae* is the most important of the three in Australia. The extent of these three pathogens across Australia is not documented as the work to date has focussed on Victoria and Tasmania.

A number of strains of *V. dahliae* were identified and within these it was found that were significant variations in virulence. Differing levels of susceptibility to *V. dahliae* infection were also found between potato varieties. Unfortunately only a few varieties have been screened so far.

Pot trials established an interaction between *V. dahliae* and root lesion nematode (*P. crenatus)* and indicated that there may exist threshold levels at which this disease becomes a problem. Further pot trials were performed to investigate the impact of soil amendments (blood and bone meal, sulphur and brown coal) upon microsclerotia viability and also on the ability of brown coal to suppress *Verticillium* wilt. The results produced a reduction in spore viability in lab assays however the effect under field conditions is yet to be proven. The same cautionary comments discussed earlier on fertilizer and soil amendments apply in this situation as well.

This work has reached an important stage and there are some clear short term goals which would enable some good practical outcomes

Recommendations

- Varietal screening work be expanded to include major commercial varieties for all sectors of the industry,

- Establish pathogen DNA threshold levels in soils for *Verticillium* & *Pratylenchus* spp. and also elucidate the role of seed and soil inoculum in disease transmission. This work could then be integrated into the PreDicta Pt manual.

- Longer term but also equally important is looking at economic impact threshold levels of both *V. dahliae* and also root lesion nematodes in causing disease. There is also a need to extend this work to *V. albo-atrum*.

- Soil amendment research should be discontinued (see 5.1.4), unless a compelling case can be made to the contrary.

5.2.3 Endophytes [PT09026 B(i)]

Based on the author's understanding of this area, endophytes have the potential to yield substantial dividends in the future (Strobel & Daisy 2003, Rodriguez et al. 2009) however it is difficult to see a usable outcome for the potato industry in the short term. The use of endophytes by plants has been shown to confer environmental and productivity advantages to plants in many environments (see above references).

The research in this area within Australia has so far provided the following:

- Expertise in actinobacteria

- Pioneered the isolation and application of endophytic actinobacteria for cereal cropping to control fungal root diseases (not part of APRP2 though)

- Field testing of inoculants and compatibility with agrichemicals

- Development of effective production and delivery protocols for selected inoculants on cereals

Within APRP2, research has so far identified that some endophytes show activity against powdery scab in potatoes although to date only weak effects have been identified.

For this technology to have an impact in the potato industry there are however a number of significant hurdles to be negotiated:

1. Once identified any potentially useful organisms would need to be culturable and able to be reproduced by some within method to enable large scale production.

2. Unlike cereals potatoes are not reproduced from true seed thus a system to have these endophytes in the roots and tubers needs to be perfected for any useful endophytes that are isolated.

3. There needs to be a delivery system to get endophytes into the potato plant and to where they are required for disease control. It has been suggested that this may be able to be done at the tissue culture stage, however this is yet to be demonstrated. Timing of introduction into the plant may also require experimental work

4. It is not known at this stage the effect of each endophyte species has upon individual pathogens or across a range of pathogens. It may well be that a suite will be required to produce multiple types of enhanced pathogen tolerance. This may then also involve synergistic or antagonistic effects.

5. There are also likely to be intellectual property issues associated with this work should successful endophyte treatments be found.

6. Lastly any product likely to result from this work will need to be commercialised therefore a clear path to commercialisation would need to be developed.

Although potentially a very useful area of research it is not short term and like all this type of work has considerable risk of non-delivery. This is a high risk but potentially high gain area.

There are a number of overseas laboratories working in this field (eg Adaptive Symbiotics in the US) and some thought should be given to possible international collaboration.

Recommendation

- Future investment needs to consider linkages with other research programs and planning needs to be careful with defined performance targets and stop/go areas based around the steps identified above, as well as organism identification, its ability to be cultured, and stable under large scale production,

- Commercialisation and IP should be addressed early in any R&D program of this nature

5.2.4 Soil Microbial Activity [PT09026 A(i)]

Although included as a sub-project under PT09026 this project is also in part complementary to the endophyte project covered above.

Understanding and then manipulating microbial species and communities to improve crop performance is potentially one of the big “game changers” for the future of food production. It would be reasonable to state that at present we are only at the threshold of understanding the complexity of microbial/microbial, microbial/plant and microbial/soil interactions.

Within the realm of potato R&D, research has focussed upon the rhizosphere and its role in fixing N as well as soil microorganisms that may play a role in both disease suppression and productivity gains. This research has focussed on trying to identify the microorganisms characteristic of disease suppressive soils and how this might be used to induce disease suppression in non-suppressive soils. If successful this could be an important management tool for soil borne diseases in the future with the ultimate aim to provide growers with a low cost, non-chemical disease management strategy for soil borne diseases. Similar R&D is being pursued by the grain industry amongst others.

Although considerable progress has been made since this work commenced over seven years ago there is still some way to go before there will be any outputs that can be utilised or incorporated in current production systems. This is testament to the complexity of this research. It therefore seems unlikely that any commercial output/outcome is likely in the short term (1-3yrs).

As with the work on bacterial endophytes this research is likely to take a number of years before there will be direct outputs available for growers. Many of the challenges listed under the previous project on endophytes apply to this work also. A successful outcome however could provide a considerably more holistic approach to crop and disease management particularly when dealing with diseases such as common scab where there exists considerable uncertainty around the interaction of the Streptomyces strains found in the soil and their role in scab expression.

The future challenge will be to determine methods of introducing or stimulating microbial communities to achieve disease suppression and growth promotion in the field. For this technique to have commercial application it will have to be shown that it is functional across a wide variety of environments and repeatable over time. Data from work in grains shows that about a 1 in 9 addition of suppressive soil will induce the same effect in the recipient soil. A similar ratio has been found in APPRP2 for soils for potatoes. Unfortunately the work in grains has shown that diseases suppression is not always permanent and that a soil with disease suppression in one year does not always carry that through to the following year. Conversely it is also known that some soils in Ballarat have maintained their disease suppression over common scab for a long time. Thus the question is whether these differences are due to different soil types or different population dynamics or a combination thereof. Some caution also needs to be exercised before transfers of soils from one area to another are considered so that other less desirable organisms are not transferred.

Consideration needs to be given to possible integration with other research in this area, especially at the broader mechanistic functional level. Are there some broad principles that can be applied across a range of crops? Do the characteristics of these soils change with management use? There could be a case for establishing a group to work in this area across a range of crops (not just in potatoes or horticulture) including other vegetables and even grains. Depending on where the research heads there could also be IP issues involved, especially if there are tailored commercial “brews” being produced? A stocktake of the current status of this work in Australia is perhaps warranted before any further investment is made in horticulture.

An Integrated Approach

Notwithstanding the recommendations and observations that have already been made it is timely to consider that within Australia there are numerous projects involving soil health, disease suppressive soils, and other topics that have been subject to R&D within the potato program. Programs have been identified in RIRDC, Grains, Sugar, Cotton as well as other HAL research areas such as vegetables. There is a danger that there will be a plethora of overlapping projects and programs occurring in Australia. There is also a danger that by focusing upon one particular crop a bigger picture is lost. The vegetable industry has also conducted comprehensive reviews of soil-borne disease management (McMichael 2012) and general disease management Blaesing 2013.) The latter desktop also included soil health/disease. These studies are also seen as resources for the potato industry in informing future disease work and are complementary to this current report.

Of particular note in this regard is the rapidly evolving area around soil biology. Projects on endophytes, rhizosphere interactions and disease suppression are a common theme in a number of research programs. As has been suggested in some reports (eg PT09026) it is likely that similar organisms are involved in these mechanisms over a range of soil types. As noted earlier this is a potentially highly rewarding area for future research but it needs a more strategic focus.

Opportunities for more strategic investment in this type of R&D should be explored. From the perspective of individual commodities or industries there is much to be gained from a more cohesive approach to soil-borne research. It is likely to be long-term, therefore costly and is likely to have a high degree of risk. However given that the crops noted above grow in soil and that many of the diseases involve common pathogen species it is likely that common principles can be established. Individual crops can then develop a more crop specific implementation program based upon the more strategic discoveries. Overarching principles can be explored through strategic investments and direct crop/industry application funded through individual industry funding mechanisms. It is noted that this interlinking of work was also suggested by SARDI (PT09023).

5.2.5 Organic Amendments

Coincident with this avenue of research there have also been studies on soil organic amendments as part of the cropping cycle. This has found that various combinations of green manure crops (eg millet) produced improvements in yield of potatoes and reduced levels of disease severity. This approach is also being tried commercially by some innovative producers in Australia and elsewhere. The improvement in quality in potatoes with increasing organic matter levels in soils has been shown in other studies (Rigby 2008).

One area which merits comment on both the APRP1 & 2 projects is the lack of precision in defining what is meant by organic matter. It appears that plant residues and sometimes soil carbon are often used interchangeably. This lack of precision makes interpretation by others difficult as it is not always clear what is meant by the term organic matter[1] when it is used by various authors.

[1] NB This lack of precision has been noted across many projects that have been read as part of the research for this report and is not just restricted to the APRP1 & 2 programs.

The accepted use of the term organic matter is normally taken to mean;

Organic Matter – Usually dark brown or black material that is unable to be separated from the soil and whose origin is no longer recognisable. Made from the decomposition of plant and animal debris, including microorganisms, through the action of microorganisms such as; insects, fungi and bacteria.

Within the HAL projects the impact of organic matter (*sic*) across the various soil borne diseases has not always been measured simultaneously Thus it is not always clear whether a particular crop being produced to manage one disease has the same effect upon all diseases. Nonetheless the work reinforces the beneficial improvements to production that can be obtained by improving soil organic matter levels and serves to highlight the importance of organic matter in maintaining ‘healthy’ soils. There is no shortage of evidence about the benefits of improved soil organic matter on crop health. Whilst there may be a case for demonstration work on a district or area level to determine the appropriate species mix and timing this would be best done via co-investment with local interested groups. This would mean that those participating have an active interest in the outcome.

However the mechanisms operating when organic matter and also Biofumigants are incorporated into the cropping cycle are not well understood. There has also not yet been evidence as to the mode of action of many crops used for disease management. For example it is still unclear at this stage whether the use of a biofumigant, such as ‘Caliente’ mustard, is acting as a suppressant, sterilant or both. Organic matter as an agent for modifying soil microbial communities is also poorly understood.

In contemplating ‘soil health’ as a concept, perhaps the one thing that is surprising is that although we all believe we can recognize a healthy soil when we see it there is still no universally accepted method for objectively measuring soil health! Caution needs to be exercised when using this term.

Recommendations

- Work in the space of organic amendments and soil biology manipulation be split into two categories; strategic and applied.
- Strategic work to include gaining further understanding on the ecology of soil borne microorganisms and their role in both disease antagonism and also crop enhancement.
- That a stocktake be performed of current research across all RDCs in the area of soil health improvement and disease suppressive soils rior to any further investment
- Subject to such a stocktake a clearly articulated research and commercialisation pathway needs to defined
- Avenues for collaboration with other industry RDC’s be explored to enable a greater fundamental understanding of this whole area.
- Stop/go areas be built into projects of this nature based upon criteria such as performance, ability to be cultured, stability, scale-up potential and delivery systems etc.
- R&D to be undertaken in the first instance to determine mode(s) of action of biofumigants
- General levy funding should not be used to fund local or regional trials on the use of organic amendments and even in this situation the work should be performed to appropriate levels of scientific rigour and subject to technical review.

6 NON APRP Research

6.1 APRP Related Soil-Borne Disease Research

By far the bulk of research considered in this report is covered by soil-borne diseases and their mitigation. Excluding the projects captured under the APRP1 and APRP2 programs, there are a further 33 reports that fall under this mantle. Many of these projects have built upon earlier work and reflect the long period of time some researchers have been working in this field. Noteworthy are deBoer in Victoria and Hall in South Australia. This has meant that research in the field of soil borne diseases and rotations has resulted in an incremental increase in knowledge over time and a valuable long term 'research memory'. This work has been 'mined' to produce the Management Fact Sheets in Part A Appendix 1. Furthermore a considerable amount of this research has also been utilised in the APRP programs. Noteworthy in this respect is the earlier work on black dot.

Most institutions have produced their own fact sheets based upon HAL funded work and these are referenced in the Fact Sheets cited above. An URL to a typical example is below;

http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes

In addition to the work performed under APRP1 and 2 there has been research on pink rot, *Erwinia*, black dot, rotations, soil pests, farm hygiene and various management protocols.

A recurring theme of some of these projects is a lack of legacy where documents have been produced and are either no longer available or not current. In addition several reports described how they would produce management manuals, identification guides etc. but the author has been unable to find any evidence that this has occurred. It would seem desirable that the body charged with overseeing funding and research (HAL) should develop a mechanism whereby these materials once produced can be sourced at a later date and also that milestone payments are tied to outputs to ensure that final payments are not made until all promised outputs are delivered.

In terms of future research the major gaps in this work have been highlighted in previous sections and perhaps the most relevant question is to what extent has there been practice change from this work?

Recommendation

- HAL develop a mechanism for storing and providing access to industry of materials
- HAL to work with industry to develop a legacy system for R&D
- All projects to have legacy as a part of the outputs
- Payment milestones be tied to incremental deliverables which are identified within a R&D methodology

Projects consulted in reviewing this work are listed on the following page:

Year	Project Code	Project Title
1997	PT315	Rhizoctonia control in fresh market potatoes
1998	PT412	Potato early dying in Australia
1999	PT97010	Sustainable potato production in highland areas of NSW - Stage iii
2000	PT98036	Biological and chemical control of Rhizoctonia
2000	PT447	Integrated management with biofumigation to control soil pests and diseases
2000	PT97026	Developing Soil and water management systems for potato production on sandy soils in Australia
2001	PT97004	Potato Pink rot control in field and storage
2002	PT94028	Information packages and decision support software for improved nutrition management of potato crops
2002	PT1042	Control of Pink rot in potatoes
2003	Pt96032	Influence of rotation and biofumigation on soil-borne diseases of potatoes
2003	PT98007	Managing bacterial breakdown in washed potatoes
2004	PT98018	Cleaning and Disinfestation strategies for potato farms
2004	PT01031	Enhanced detection of potato cyst nematode and bacterial wilt to improve market access for the Australia and NZ potato industries
2005	PT01008	Monitoring and developing management strategies for soil insect pests of potatoes
2005	PT01001	Control of black dot in potatoes
2007	PT01041	Crop management tools for the french fry industry in the SE of South Australia
2008	PT04001	Understanding the implications of pastures on the management of soil borne diseases of seed potatoes
2008	PT05027	A potato crop management service to promote new technology in Tasmania
2009	PT06014	Reducing the impact of black dot on fresh market potatoes
2010	PT06014	Reducing Impact of black dot on Potatoes
2010	PT04016	Potato Processor R&D Program (APRP1)
2010	PT08048	Pilot Project - Diagnostic tests for soilborne pathogens, International Collaboration
2011	PT07038	Identifying microbial communities in disease suppressive soils as a means of improving root health of potatoes
2011	PT08046	Development of a soil borne pathogen testing service for the fresh market industry
2012	PT08032	Population genetics and phylogeny of the plant pathogenic protozoan Spongospora subterranea f. sp. Subterranea
2013	PT09040	Development and demonstration of controlled traffic farming techniques for production of potatoes and other vegetables
2014	PT09026 C	Monitoring for Bacterial Wilt
2014	PT09026 A(i)	Soil amendments and nutrients
2014	PT09026 B(i)	Actinobacterial endophytes and their potential for disease suppression in potato

Year	Project Code	Project Title
2014	PT09026 A(i)	Soil amendments and nutrients
2014	PT09023	Diagnostic tests for soil pathogens
2014	PT09026 (ii)	Impact of rotations
2014	PT090029	Enhancing the understanding of *Verticillium* spp in Australian potato production
2014	PT09026 A(i)	Soil amendments and nutrients
2014	PT09026 (ii)	Optimisation of 2,4-D and novel chemical foliar elements for control of common scab
2015	PT09027	Improving management of white-fringed weevils in potatoes
2015	PT13000	Understanding spatial variability in potato cropping to improve yield and production efficiency

6.2 Plant Nutrition

This is the area of R&D that has raised some of the author's greatest concerns.

As noted earlier in this report there have arguably been more papers published on plant nutrition than in any other area of horticultural/agricultural research. In many cases the R&D is of only limited use/application outside the research plots from where it was performed. The vast amount of data that has been produced, its often conflicting messages and continued repetition is testament to the complexities of research in this area.

Eleven HAL projects were found under this topic and they are listed below. In almost all cases these projects appear to have served very little purpose. There are a variety of reasons for this. In some cases they have not really added anything new to current knowledge, in others the authors display a lack of knowledge about the role of soil chemistry and its interactions, whilst in most the data is of strictly local use. There is often little attempt to integrate the work into a more holistic approach to soils and nutrition. As noted earlier soil nutrients need to be approached from an interactive viewpoint as it is seldom that changing one factor does not result in changes in others. These confounding processes have often been ignored in the subsequent report. The role of lime and soil Ca is an area of frequent misunderstanding.

A lack of congruence between research and commercial practice has also been identified as a serious issue in this work. Unless research aligns with standard commercial tests then it is also not very useful. Does the extractive method being used in R&D relate to what is being used commercially? If not have potential differences been identified and cross-referenced? For a number of soil nutrients, results can vary dramatically depending upon extraction technique. In some reports the extraction or analytical method was not even mentioned. This is inexcusable if it was intended that this R&D is to be applied. Unless the extraction method is supplied or referenced it is almost impossible to interpret data. This is a problem in both research and practice and it is acknowledged that some commercial labs also do not specify methods but merely supply recommendations. These factors can make it almost impossible to reconcile research findings with what an individual obtains from their soil tests.

In some other instances comprehensive packages have been developed of which the most outstanding example is the "Potato Crop Nutrient Evaluation System" produced by Maier and Shepherd (PT94028). This particular project (which was relatively expensive) produced a Windows 95 software package which could be used by growers. It was perhaps somewhat ahead of its time. Unfortunately it was never further developed. There was no provision for updates or legacy. A subsequent research project to investigate its uptake (PT03055) also appears to have never been acted upon. There was also a failure to acknowledge the broader advisory community as a key partner in this sphere. PT94028 thus languished and in fact disappeared. This sort of fate is not unique to HAL and potato research and there can be found on the internet and elsewhere many examples funded by various RDCs which have suffered a similar fate.

Information packages are seldom successful if they are not supported and continually upgraded and updated. Thus again unless there is procedure or system for ongoing support (usually involving a commercial partner with a vested interest in ensuing it continues) it is difficult to see how these sort of systems can be maintained.

In response to changes in MRLs, there was also significant work on Cadmium produced some time ago which resulted in a well-produced information card (see PT423). Although fertilizer technology and cultivars have since moved on it may be appropriate for the industry to check current levels in the newer cultivars.

Recommendation

- Soil and plant nutrition research should no longer be supported solely from levy funds unless a convincing case can be made that some principles will be obtained which can be applied beyond the trial sites. As part of making a case the following issues need to be addressed:

1. any implications for post-harvest,
2. relationship to other plant and soil nutrition knowledge,
3. relevance to regions/soil types different to research plots
4. highlight potential conflicts with existing knowledge,
5. methodology and extraction processes need to be in-line with commercial practice (unless it is proposed that a new method is the outcome).
6. provide a comprehensive review of past work in the area and how this will improve that knowledge.

- Funding for information packages should not be provided unless there is a clear pathway for updating/maintenance, commercialisation and thus a legacy. In evaluating any potential project a cost/benefit analysis incorporating tools such as ADOPT should be performed.

Projects consulted in reviewing this work are listed on the following page.

Year	Project Code	Project Title
1996	PT107	Development of crop management strategies for improved productivity and quality of potatoes grown on highly acid soils
1997	PT003	After cooking darkening of potatoes
1997	PT012	Soil Fertility Management in Potatoes on Atherton tablelands
1997	PT016	Yield and quality effects of post planting applications of nitrogen and potassium to potatoes
1997	PT213	Phosphate, nitrogen and irrigation management in potatoes
2000	PT423	National Strategy to reduce cadmium
2001	PT320	The trace element requirements of vegetables and poppies in Tasmania
2002	PT97003	More economically and environmentally responsible use of phosphorus fertiliser in potato cropping on krasnozem soils in Australia
2003	PT98011	Effect of Calcium Nutrition on decay of summer sown seed potatoes
2003	PT03055	Market research for potato nutrition software
2004	PT99057	Nitrogen dynamics in commercial seed potato crops and its effect on seed quality, storage and subsequent commercial performance
2007	PT96020	Mechanism of Cadmium accumulation by potato tubers

6.2.1 Comparing Products and Efficacy Data Generation

A number of reports in the HAL system were found that compared the efficacy of various commercial products including chemicals and also equipment. This can be a problematic area.

For projects comparing equipment or providing evaluations of technology they are often out of date very soon after publication of the report due to updates and modifications by manufacturers. Therefore unless the work is carefully crafted they (reports) have a very limited lifespan. It is also unclear the extent to which such reports are used by producers. I am unaware of any attempt being made to assess the efficacy or use of such data. Lastly there is always a concern that legal issues may arise.

Chemical efficacy research comprises two types of work. The first is the generation of data for registration of a new chemistry or extension of use and the second compares currently registered chemistries and their efficacy on their target disease.

With the first type of R&D unless there is a commercial partner or clear path to commercialisation and the research conforms to APVMA requirements such work should not progress. Whilst the gathering of data for efficacy and residue is a legitimate use of levy money it is difficult to support the case that R&D funding should go towards work that may/will never be implemented. The SARP process should also form a key role in informing this type of work.

The second type of research is very valuable as it is clear with our deeper understanding of diseases and also the various races of many pathogens that we may indeed need to be more highly discriminatory in our use of chemical controls. Some evidence to this effect was shown in the study by Todd (2009). However research of this nature needs to be carefully formulated as there is the ever-present threat of legal challenge in the case of adverse findings against a particular chemistry.

However it has also been found that research has been performed with chemicals which have a known efficacy but are not registered in Australia either for the crop in question or in some cases at all. There would seem to be little point in performing this type of work unless as noted above there is a clear intent for registration in which case a commercial partner or path to commercialisation is articulated. There is also the potential danger that investigations of this type could lead to inappropriate practices in the industry. It is thus a practice which should be discouraged.

Some research also uses experimental chemistry in order to determine modes of action. This is a legitimate practice and is seen as a more strategic approach to our understanding of diseases and pests (see 5.1.5).

Recommendation

- Product/equipment evaluation projects should be discontinued unless there is a commercial partner involved (see template for Research Formulation) and a clear path for adoption. This type of research should not be funded through levy funds.

- Research investigating efficacy of chemistry for which a label exists needs to be carefully composed so that results are both useful and not easily challenged.

- Data generation for registration and extension of use needs a; clear path for adoption, be subject to a SARP review and be consistent with APVMA guidelines. Co-investment to support such activities should be sought in the first instance.

- Experimental chemistry research needs care and should have critical stop/go points especially if it is intended that there be a commercial outcome.

6.2.2 Other (Biosecurity, General Plant Pests and Diseases and Production)

This section as will be seen from the list below covers a wide range of disparate topics and is largely a “catch-all”. It includes IPM, late blight, some virus work, Tomato Potato Psyllid (TPP), and crop monitoring.

The disparate nature of the work is both an artifact of the grouping method used and also a result of the fact that some projects arise due to a particularly pressing need that is either solved by R&D or else disappears over time. Projects which fell under this category are listed at the end of this section.

Perhaps the one surprising feature is the small number of projects on IPM and foliar diseases. This may be a reflection on the relative unimportance ascribed to these areas by the potato industry. The lack of IPM work and uptake by the industry also drew comment from Abraham and O’Brien in their report.

Research Gaps per se are not particularly relevant in the context of this grouping because as noted above the group has no common theme as it is a compilation of topics not covered elsewhere.

There is little that can be added by way of analysis of this work, although it appears that a number did not really result in any major outcomes and appear to have finished with publication of the final report. Again this only serves to highlight the necessity of having clearly defined outcomes as opposed to outputs

Field diagnostic tools need to be developed to assist in identifying pathogens such as Liberibacter viruses etc. Many of the protocols currently in use for disease detection on imported plants are old and need to be updated in the light of new developments in the field of diagnostics. There is a need to review the efficacy of these protocols.

There is an existing ongoing monitoring study for TPP, however this is VC project. The only and slim hope for eradicating this pest if it arrives in Australia is early detection. The industry needs to continue to monitor for this pest and test plants for Liberibacter infection. This is seen as an ongoing and essential project. It should not necessarily be solely East Coast focused.

The role of clothing implements and animals in transmitting contact viruses is also an area little understood. This needs to be examined in order to ensure we have good hygiene protocols on farm etc.

It is also noted that despite the risk to the Australian potato industry posed by pest and disease incursions, there is no cohesive program within the R&D portfolio to address biosecurity. The author’s experience through the vegetable industry is that many of the pests encountered in biosecurity are found in the Solanaceae and it would be prudent for a specific area of research funding to be devoted to this area. This was also recommended by Abraham & O’Brien in their report. Pest outbreaks close to Australia (eg. Tomato Potato Psyllid (TPP) in NZ 2006) have provided an increased focus on biosecurity in Australian potato production. It is likely that the pressure from exotic incursions will only increase as trade increases. Potatoes as a member of the Solanaceae will be subject to pressure from pests on other Solanaceous crops even if fresh imports of potatoes continue to be prohibited. The development of horticulture in Australia’s north is likely to provide an increased risk of exotic incursions due to the proximity to areas which have a number of pests not found in Australia. The Solanaceae is a particularly vulnerable family.

Furthermore there is an expectation across all jurisdictions in Australia that industries need to be actively involved in biosecurity and contributing into this sphere.

The industry has a Biosecurity Plan and it is strongly recommended that a specific program be developed within potato R&D to fund biosecurity activity.

As with other categories of R&D fact sheets produced from these reports should be re-examined and updated as part of a legacy and communication program. Individual fact sheets and associated reports are identified in Part A of this report.

Recommendation

- Develop a sub-program on biosecurity to fund research, communication and extension activities in this area
- Understand the drivers behind the attitudes toward the use of IPM
- Continue monitoring crops for TPP and Liberibacter and extend to other production areas in Australia
- Conduct a review of current ICON protocols for disease detection and produce appropriate recommendations; this will need to involve regulators.
- Develop a better understanding as to the persistence and transmission of non-vectored viruses and their role and impact in potato production
- ‘Spot’ or R&D arising from an acute need will always be required however it should always be subjected to the same scrutiny and rigour as any other program orientated work
- Update fact sheets listed in Part A that are still relevant and make available to the communications program

Reports consulted in reviewing this area are listed below.

Year	Project Code	Project Title
1993	PT009	Development of a test for potato leafroll virus & determination of PLRV strains in South Australia
1996	PT209	Determination of factors causing stem end browning in russet burbank potatoes
1998	PT656	National IPM program for potato pests
1998	PT341	Integrated management of early and late potato blights in Australia
1999	PT96047	Control of black nightshade (Solanum nigrum) and other weeds in potatoes
2000	PT432	Improved Production of Inland Potato Production
2002	PT01051	Factors affecting specific gravity loss in crisping potato crops in Koo Wee Rup, Vic
2005	PT02045	The monitoring of potato crops for insect movement on a district scale
2006	PT04010	Late Blight Management
2008	PT07035	Assessing water use in potato crops in the Mallee, SA
2009	PT06044	Improving management of potato virus S through a better understanding of mechanisms of virus transmission
2011	PT10018	Development of a contingency plan for zebra chip
2012	PT09004	Control of potato psyllid with an IPM strategy (part of APRP2)
2002	PT98009	Characterisation of Australian isolates of Phytopthera infestans and planning to manage new & more aggressive strains of the fungus

6.2.3 Seed and Tubers –including Viruses

Research in this area has been diverse and has covered topics such as Physiological age (P-age), tuber storage, virus transmission, seed treatments, disease mitigation, nutrition, common scab disease thresholds and as noted earlier a seed storage manual was produced in 2005.

Despite its continual attention seed P-age and a means of objective measurement appear to be still as elusive as ever. The main finding from projects on P-age was that other management factors had a far greater effect upon crop performance than apparent seed age (Brown, PT02012). However in the absence of an objective measure of seed age, this becomes a somewhat 'chicken and egg' discussion. Although it is undoubtedly an important area of research past history suggests that it would be unrealistic to expect short term results from any research into this area.

Controlling diseases in seed has been a recurring theme including research into the use of hot water treatments to control some diseases in/on seed pieces (de Boer, PT105). A lot of this work has also informed part of the APRP2 program.

A major gap in Australia and elsewhere in the world is the lack of science underpinning many of the standards used in seed certification. This was noted by de Boer (PT98015) and also Pung (PT02017). Threshold levels appear in most instances to be arbitrary and generally reflect what the seed industry thinks it can live with rather than any customer/crop performance outcome. This is to some extent reflected in the variation that exists between various systems around the world and in the case of Australia within the existing National Standard (Blaesing PT13010). Seed certification is a cornerstone of potato production and its importance cannot be overstated thus any research which can add value to this part of the supply chain is worth serious consideration.

It was noted earlier (Section 5.1.3) that the verification of seed certification standards is an area that warrants R&D in the future. For example questions have also been raised about the level of TSWV and transmissibility (Rodoni, PT08008) as well as transmission of viruses to daughter crops (see Lambert PT03069, PT06044 and Hay PT05011). This is not to suggest that viruses are not an issue but highlights the need for science and regulations to be in harmony.

New molecular technologies such as q-PCR offer for the first time an opportunity to develop a far more rigorous and objective approach to seed certification.

However in order for this to produce any meaningful outcome two issues require addressing. The first is a lack of an inclusive and effective system for integration of research results into the existing National Standards (Blaesing PT13010). This is exacerbated by the fact that within the existing National Standard there are state based variations. Although not strictly within the bounds of this report, this area is highlighted because until it is addressed any research in this area will be hamstrung by the lack of a formal process for effecting change in certification once research has identified an issue. This same process issue has been highlighted elsewhere when considering research involving biosecurity or any R&D where regulatory concerns arise.

The second concern is that the existing seed production system is relatively unsophisticated thus implementation of R&D requiring further technical input maybe problematic.

Nonetheless there have been some important tools produced from R&D on seed, including a seed handling manual (PT01030). Most of the information therein is still current and the Manual deserves to be updated (Not a big task) and reprinted.

There are also a number of fact sheets on post-harvest control of diseases such as *Erwinia* available on websites particularly SARDIs, see

http://www.sardi.sa.gov.au/pestsdiseases/horticulture/horticultural_crops/potatoes

These fact sheets which were produced through funding by HAL should be incorporated in the communication program.

Viruses especially PVY have reemerged over the past decade as an important disease of potatoes in many parts of Australia. This has been in part due to a somewhat cavalier attitude toward virus due to the past success of the seed certification program. Recycling of potatoes from ware programs as 'seed' has been a significant contributor to the problem. In addition varying symptomology between different strains has provided an added complication. As a consequence virus Y is now a significant problem in a number of growing regions. This would suggest that extension and communication of the dangers posed by viruses is still an important priority despite recent Industry extension/communication programs.

It would appear that there is also a significant gap in our understanding about the relative roles of vectors in virus in Australia (Rodoni pers. comm.) and this is an area that merits further clarification.

There is currently a project underway to look at the gaps in Virus Y knowledge/extension in Australia. This will serve as a useful corollary to this report. Consequently any recommendations around virus Y R&D will be left to this report. The only comment in this regard is that virus Y is a major problem in many parts of Australia and it deserves a degree of priority in R&D. Viruses were also mentioned in the earlier section on biosecurity and it would seem appropriate to perhaps have them included under a biosecurity portfolio.

Recommendations

- Reprinting and updating of the Seed Handling Manual and other previously produced information sheets.
- Continuation of a strong extension/communication program on the impact of viruses in potato production
- A systematic approach toward developing a National Seed Standard based upon the best available science through reviewing current knowledge and development of appropriate research themes.
- Research on issues affecting certification should not proceed without a clear path for utilisation
- Some consideration in the future may be warranted by the industry toward a systematic approach toward quantifying virus and seed infection.
- Under a biosecurity program develop a cohesive strategy into virus research particularly around virus Y and transmission pathways.
- Understand persistence and transmission of non-vector borne viruses (see also .6.2.2)

The list of projects that were consulted under this category is on the next page.:

Year	Project Code	Project Title
1993	PT006	Rapid identification of Streptomyces spp on potato, the key to integrated management of common scab
1996	PT105	Control of black leg, black scurf and other post harvest storage rots of seed potatoes
2000	PT98030	Reduced chemical usage in seed potatoes
2000	PT96010	Investigation of common scab disease and control methods
2001	PT0003	A comparative evaluation of different materials used for cut potato seed treatments
2002	PT98008	Improving Seed Potato production
2003	PT98015	New chemical treatments for fungal diseases of seed potatoes
2003	PT01048	Virus testing of early generation certified seed potato crops in WA
2004	PT99052	Potato tuber management in relation to environmental and nutritional stress
2004	PT02047	Minimising virus infection in early generation seed potato crops in WA
2004	PT02048	Developing a pests and disease crop monitoring program for WA seed potato crops
2004	PT01038	Evaluating a product for enhancing dormancy and storage qualities of potatoes
2004	PT99022	An agronomic and economic blueprint for using whole, round seed for processing potatoes
2005	PT01030	Seed Potato handling and storage - best practice
2005	PT03061	Improving virus control in seed schemes by combining aphid monitoring and virus testing
2005	PT02017	Effects of potato seed characteristics on seed-piece breakdown and poor emergence
2006	PT02012	Optimising production and storage conditions for seed potato physiological quality
2006	PT02022	A crop management service to promote new technology for potato seed production
2006	PT02016	Common scab threshold on tuber seeds for processing potato crops
2007	PT03069	Management strategy for elimination of viruses from certified seed potato stocks in tasmania
2007	PT05011	Managing viruses in Tasmania seed potato stocks
2012	PT10008	Economic evaluation of certified seed in the Australian potato industry
2012	PT08008	Improved virus diagnostics to support the Victorian Seed Potato Association
2013	PT12700	2012 Seed Potato Industry Conference
2014	PT13010	Seed Certification Review

6.2.4 Other (Non HAL) Research

During the course of this work the author became aware of a bench marking project that was performed in NZ. This study defined the likely maximum yield that could be obtained from potatoes and then measured the impact of various factors that prevented this yield from being obtained. This research utilised some complex modeling and whilst the numbers may be open to question the paper does at least provide some further information on the quantitative impacts upon the industry of diseases etc. Such information if produced for Australia cannot but help produce a better informed decision making process.

Recommendation

- It is suggested that a similar study should be undertaken in several key regions in Australia as a prelude and guide to further investment in production related R&D.

7 Research Formulation

7.1 Identifying the Problem

One of the factors which led to this analysis is that there has often been a failing at the delivery end of projects with outputs confused with outcomes. The consequence is that often good work has gone unutilised or been ignored. This is not necessarily a fault of the personnel involved but often due to the way projects have been formulated, conducted and lack of any or very little follow-up on recommendations beyond the life of the project.. This section will concentrate on expanding the pathway to adoption theme noted in the Abraham & O'Brien Report and will outline a template and protocol for future research formulation. In so doing it will have many similarities to an earlier report prepared for the vegetable industry which produced the program logic model (Blaesing 2013a).

Whilst this report is focused on the potato research program this section is seen as being of relevance to the broader HAL research portfolio and in research formulation generally.

Research by definition usually involves collection of new information. New information by itself serves little purpose and for it to be used changes will need to occur. Change involves people and therefore it is axiomatic that irrespective of any other factors adoption and implementation will ultimately depend upon people factors. People are thus a critical point for a successful outcome to research investment.

The following issues being lacking or poorly defined has been identified as generally the reason for projects (both VC and Levy) failing to deliver.

They are a lack of, or a poorly defined:

- legacy plan
- corporate memory
- ownership
- involvement of those upon which success will ultimately depend
- implementation body with an ongoing brief to ensure projects achieve their stated aims
- rigour and or objectiveness in the reporting and evaluation process (no independent peer review)
- project assessment
- unrealistic, non-existent or poor KPIs
- relationship between milestone reports, payments and outcomes

Legacy

Outputs from projects need to always consider legacy. For example what will happen when funding ends, who will maintain the database, reprint booklets etc. and ensure the data is still current? If Apps are to be produced who will maintain them?

The lack of legacy has been noted in many instances in this report. All projects and outputs will ultimately wither (some quickly) if this is not addressed. To address this issue requires industry, funding agency and also provider commitment. A current and very important project requiring a legacy plan is the PreDicta Pt manual. This will require ongoing commitment by all parties involved to ensure it stays current and relevant.

Legacy is also important when it comes to reviewing and planning new research activity, thus there needs to be set up within the HAL database a system whereby projects can be indexed and cross-referenced against certain key topic areas so that they can be accessed in future. To the author's knowledge this report represents the first time that any form of review and classification has occurred for potato R&D. It thus provides a basis for constructing such a system.

With the completion of this report and an earlier one for the vegetable industry there now exists a current status of disease R&D in the potato and vegetable sectors. The opportunity should not be lost to use these as a baseline for evaluating new proposals against what has happened before.

Corporate Memory

Research Investment is generally long term and it was noted by Abraham & O'Brien that the APRP2 project suffered from personnel changes. To this could be added more generally that all parties to research need to ensure that there is a commitment to R&D involving staff and resources. Whilst staff movements are inevitable; so too are changes in policies and priorities by both industry and government. The R&D system thus needs to be managed so that research memory and expertise is not lost. The knowledge developed through R&D needs to be as independent as possible from the personnel, ie loss of a staff member should not result in loss of a program or knowledge gained.

In order to facilitate this process the system proposed above, to create a database based upon topics and disciplines with adequate cross-referencing should form part of a training program for all personnel involved in R&D investment (see Reporting and Evaluation below).

Capacity also needs to be managed. Expertise is not something that can necessarily be obtained instantly. One of the strengths of the APRP2 program is that a number of the key personnel have been working in the area for a long time. This experience is invaluable. This situation has occurred due to continual investment in soil borne disease research. In reviewing R&D strategy both industry and government need to consider the longer term implications when significant changes are proposed to an investment portfolio. This should not be taken to mean that researchers have a guaranteed job in their chosen area of research but merely that the maintenance of capacity needs to be taken into account.

As a co-investor industry should also have a significant input into determining staffing of R&D projects.

Ownership

Unless the target group has an intrinsic desire or recognition of the need to change practice it is unlikely that anything will change no matter how brilliant the research. The case needs to be made that practice change is wanted and will occur. Merely providing information rarely changes anything. In some cases the desire for change may exist in others it is not recognized. In the former case change will be easier to effect however it will still need involvement and ownership by the target group. Where there is no recognition within the target group of a need for change then a carefully articulated plan needs to be developed and implemented in order to gain ownership.

Involvement

Usually implementing research will involve a wider group than merely the levy payers. Groups or individuals that will be critical to a successful outcome need to be identified at the proposal formulation stage. Failure to address this group and their needs will probably ensure that the research will go nowhere. Therefore everyone who has a 'What's in it for me?' question needs to be involved from the outset.

Research has at times identified issues related to regulation however there has not always been the involvement of relevant people to ensure that findings are implemented or reflected in regulations. As an example the project on Late Blight (PT04010), despite its excellence, languished because no-one who could incorporate its findings (PHA) knew about it. A similar situation exists with respect to issues around seed certification. In order for involvement to occur there needs to be a group tasked with implementation and this needs to comprise people who can affect potential outcomes.

Implementation Body

An implementation body is a corollary of the above and is needed to ensure that outputs are delivered and relevance is maintained. This may involve the organisation tasked with extension but it will also involve representatives of the target group and the researcher(s).

Proposal Formulation, Reporting and Evaluation

It is clear in reviewing potato research over the past two decades that some research has been based upon over ambitious projections of success and uptake; eg PT94028, an optimistic evaluation of previous work eg some of the outputs from APRP1, or a lack of understanding around the pathway to adoption eg (PT04010). It must be emphasized that this is not seen as a fault of the individuals concerned but as a fault of the R&D system under which these projects operated.

Abraham & O'Brien identified the dedication, passion and enthusiasm of researchers involved in APRP2. I concur with this view and these traits have been evident in technical meetings and have been a key feature of the research program. Whilst these are admirable and necessary attributes when performing research they are not necessarily desirable when it comes to evaluation and future research planning, particularly of one's own or a colleagues work. At the very least the personnel are in a conflict of interest position. It is also unrealistic to expect someone to be objective about their own work and its future when their livelihood may depend upon it. Researchers should not be placed in this position.

The previous IAC mechanism was seen as a way of ensuring that R &D projects aligned with industry priorities. However in many cases project/program appraisal may involve some quite detailed technical scientific discussion and knowledge. It is unrealistic to expect personnel involved in making decisions on research investment to have a level of technical understanding across all potential research disciplines and thus unfair to expect IAC members to be making decisions about research proposals about which their understanding of the science is limited. This system can lead to a level of disengagement by members as they do not really understand the science and an over confidence amongst researchers about success and outcomes etc. In such situations there is a tendency to 'trust the expert'!

Whilst researchers should help inform the formulation of research they are only one part of a complex group involving priorities of government, industry, communication/education and research.

Consequently it is proposed that future R&D planning follow a different model to that which has been utilised to date. Research formulation in the future should be informed by two groups; an independent Technical Advisory Group (TAG) with a chair and perhaps one or two other ongoing members but with the rest of membership somewhat fluid depending upon the type of advice being sought. Their advice is purely scientific/technical and looks at the technical merits and likelihood of success of any proposed work. The second group is an IAC equivalent. They make investment decisions based upon the strategic priorities of the industry but utilize the technical advice from the previous group when weighing up proposals/projects. Membership of this group is based upon technical and skills and also familiarity with research and implementing its outcomes. It is important to avoid personnel being involved who may have a conflict of interest.

The second group, Potato Industry Advisory Group (PIAG) would comprise approximately 5-6 personnel and an independent Chair and they would be charged with oversight of the R & D program. Again personnel will be skills based. Membership would comprise a representative from HIA, from the designated Industry body and levy payers and one Federal Government member. It is not intended that they have the necessary technical background as this advice will be sought from the TAG. The PIAG would be charged with aligning R&D investment with the strategic research plan, R&D governance, legacy and taking technical advice from TAG on both project proposals as well as performance.

Research which is to build upon previous work should only continue if the initial work has been subject to independent peer review. Normally this would be publication in a scientific paper however this may not always be possible and in this case HAL should seek an independent technical assessment. Such an assessment should review the rigour and conclusions of the previous work and also ascertain the probability of success and uptake within any proposed future work that may arise. This assessment would normally be provided by the technical group.

As noted above under 'Corporate Memory' a formal induction program for personnel involved in investment decisions needs to be developed. Such a program should be for everyone (ie researchers, technical experts and IAC members). It is my experience from serving on IAC committees that new personnel merely turn up and pick up the reigns with minimal briefing and no formal process. This is unacceptable. Personnel need to be inducted and provided with skills necessary to evaluate research proposals. Similarly there needs to be a greater effort by proposers of R&D to consider what has happened before and what were the outcomes. Outputs and outcomes are continually confused. For example it would be far more useful for proponents of a new proposal to describe what has happened as a result of their earlier research not what the research found. Previous and future outcomes should provide a justification for further investment not outputs.

R&D proposals can be developed by industry, by researchers or by government however in all cases it is seen that they should go through the same process and be subjected to the same degree of rigour. The use of formal models such as ADOPT and Program Logic be key part of the formulation process and also for evaluating likely outcomes from research. At the very least they will provide a basis for a crude cost/benefit analysis, something which does not happen currently for many projects.

The split of investment was covered by Abraham & O'Brien and it is not seen as part of this report's role to cover this area.

KPI Formulation

Most projects have poor or non-existent KPIs when it comes to extension and implementation. Very often extension is confused with reporting or information supply. Whilst nothing can happen without information this does not in itself produce behavioural change. It is necessary for projects to have KPIs that are tied to; milestones, stop/go decisions and a mechanism for review. A report is not a KPI it is merely a signal that an item of work has been completed. KPIs need to be linked to the expected outcomes from the project. How this is to be done is elaborated further below.

7.2 A Protocol of Research Engagement

This section draws together observations and findings in compiling this report and also upon those by Abraham & O'Brien and attempts to flesh out a detailed structure for future R&D delivery by HAL. Whilst it is not perfect and may require further refinement with time it is believed that adoption of the following principles and protocol will address the issues highlighted in this and previous reports.

As part of project/tender definition the following key questions need to be addressed

1. What practice or change do I wish to occur or happen as a result of this research?
2. What people and or organisations will need to be involved for the research to be implemented?
3. Is there any recognition or desire within this group that change is required?
4. What needs to be done if "3" is not present and can it be achieved?
5. Who or what will be responsible for overseeing R&D and ensuring that, the above 4 points are addressed and the outcome (Point 1, above) occurs?

Attention to these principles will serve several purposes;

- It will keep the research focused,
- It will provide KPIs as they will now have to be developed in order to achieve the outcome defined at the very beginning (point 1,)
- It will provide an ongoing mechanism by which progress can be monitored and if problems are encountered during the course of the program provide the flexibility for modification or alternatively halt the work if there is no chance of the findings being implemented. This also addresses the stop/go requirements noted by Abraham & O'Brien.
- It will ensure that there will be personnel involved who will be needed for implementation/ownership and that there is a greater chance of achieving any change(s) that may be required. This process is particularly important where regulatory or registration questions may arise)

- Following the Protocol of Engagement will also define the tech transfer and communication activity.

As a means of developing KPIs and assessing likely project success, it is suggested that the CSIRO ADOPT and Program Logic models form part of every project submission/evaluation. As an example when The PreDicta Pt test was put through the ADOPT model with the Fresh and Process IACs the result was surprising to all concerned. The model showed that it would take at least a decade before most of the industry would be utilizing this test! The participants had assumed a much more rapid uptake for what has been one of the 'flagships' of the APRP1 & 2 programs. It is not suggested though that this is a definitive answer but merely a means by which some guidance can be obtained to help inform investment decisions and impact.

A cost benefit tool has also been produced for evaluating soil research for the vegetable industry (Blaesing, 2013a VG12048) see; http://www.horticulture.com.au/reports/search_final_reports.asp

It is difficult to argue that there is anything unique about any aspect of potato R&D that would not benefit from utilizing these two models during the R&D formulation/evaluation process. They would provide a much better framework for formulating R&D and also the appropriate KPIs than exist at present

The oversight of R&D (point 5, above) is problematic to answer at this time due to the current HIA re-organisation process. Notwithstanding it is proposed that a partnership needs to occur between the new HIA and who or whatever is in charge of industry levies and ensuring that investment is in line with an industry's strategic R&D plan. This partnership needs to be tasked with ensuring that new and ongoing R &D is implemented and reviewed with the same attention to detail as other industry issues such as Minor Use, Biosecurity etc. It makes little sense for multi-million dollar investments to not have a strong oversight and commitment to ongoing review and implementation. It is suggested, based upon the former British Potato Council model that the Technology Transfer part of the R&D program should comprise 30-40% of the total budget. There are potentially a number of ways this could be effected.

Recommendations

- That a new research structure and process be developed in accordance with the principles and recommendations as outlined in this chapter

- That the template and protocol for research formulation listed under "A Protocol for Engagement" be adopted

- That both a Technical Advisory Group and a Potato Industry Advisory Group be formed as soon as possible with functions defined as described under "Proposal Formulation, Reporting and Evaluation"

- The Technical Group are purely to provide advice on the rigour, likelihood of success etc. of new projects, membership to comprise a chair and two others and the ability to co-opt others for advice if required

- The Potato Industry Advisory Group is responsible for providing the investment advice to HAL based upon the industries strategic plan and Technical feedback. An independent chair and 5-

6 others including a rep from HIA, the responsible grower body and 3-4 levy payers. There maybe merit in considering a Federal Government representative.

- That models such as ADOPT and Program Logic be employed as part of research formulation and KPI generation process.

- That milestone payment be linked to definite outcomes and outputs as defined by the KPI process.

A diagram summarizing this research formulation process follows and it is intended that this process would also be used as part of implementing the findings from this report.

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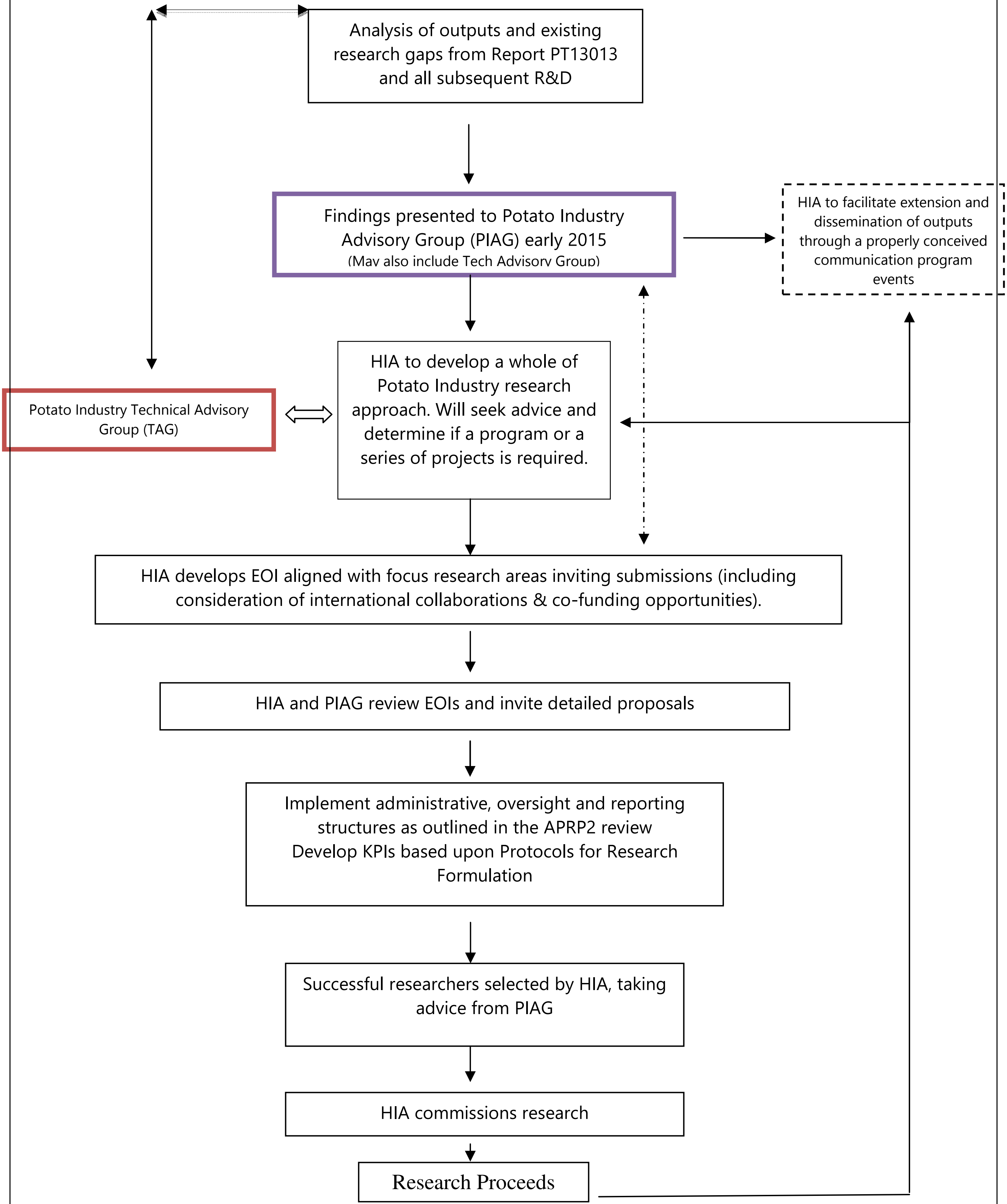
Analysis of outputs and existing research gaps from Report PT13013 and all subsequent R&D
Findings presented to Potato Industry Advisory Group (PIAG) early 2015
(May also include Tech Advisory Group)
HIA to facilitate extension and dissemination of outputs through a properly conceived communication program events
Potato Industry Technical Advisory Group (TAG)
HIA to develop a whole of Potato Industry research approach. Will seek advice and determine if a program or a series of projects is required.
HIA develops EOI aligned with focus research areas inviting submissions (including consideration of international collaborations & co-funding opportunities).
HIA and PIAG review EOIs and invite detailed proposals
Implement administrative, oversight and reporting structures as outlined in the APRP2 review
Develop KPIs based upon Protocols for Research Formulation
Successful researchers selected by HIA, taking advice from PIAG
HIA commissions research
Research Proceeds

8 Acknowledgements

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9 Additional References

For the review of projects these are listed at the end of each relevant section. Additional ones are as follows;

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< http://www.csiro.au/Organisation-Structure/Flagships/Sustainable-Agriculture-Flagship/ADOPT.aspx>

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10 Appendix 1

1993	PT009	Development of a test for potato leafroll virus & determination of PLRV strains in South Australia
1993	PT006	Rapid identification of Streptomyces spp. on potato, the key to integrated management of common scab
1996	PT107	Development of crop management strategies for improved productivity and quality of potatoes grown on highly acid soils
1996	PT209	Determination of factors causing stem end browning in russet burbank potatoes
1996	PT105	Control of black leg, black scurf and other post harvest storage rots of seed potatoes
1996	PT319	Development and extension of potato hygiene strategies
1996	PT221	Survey of incidence of black dot of potatoes
1996	PT021	Soil insect pests of potatoes
1997	PT015	Improved Productivity of the french fry industry in Victoria
1997	PT003	After cooking darkening of potatoes
1997	PT012	Soil Fertility Management in Potatoes on Atherton tablelands
1997	PT016	Yield and quality effects of post planting applications of nitrogen and potassium to potatoes
1997	PT213	Phosphate, nitrogen and irrigation management in potatoes
1997	PT303	The epidemiology and control of powdery scab of potatoes
1997	PT406	Development of a biological control for potato wireworm
1997	PT315	Rhizoctonia control on fresh market potatoes
1998	PT656	National IPM program for potato pests
1998	PT341	Integrated management of early and late potato blights in Australia
1998	PT412	Potato early dying in Australia
1999	PT96047	Control of black nightshade (Solanum nigrum) and other weeds in potatoes
1999	PT97010	Sustainable potato production in highland areas of NSW - Stage iii
2000	PT423	National Strategy to reduce cadmium
2000	PT432	Improved Production of Inland Potato Production
2000	PT98030	Reduced chemical usage in seed potatoes
2000	PT96010	Investigation of common scab disease and control methods
2000	PT98036	Biological and chemical control of Rhizoctonia
2000	PT447	Integrated management with biofumigation to control soil pests and diseases
2000	PT97026	Developing Soil and water management systems for potato production on sandy soils in Australia

2001	PT320	The trace element requirements of vegetables and poppies in Tasmania
2001	PT0003	A comparative evaluation of different materials used for cut potato seed treatments
2001	PT97004	Potato Pink rot control in field and storage
2002	PT97003	More economically and environmentally responsible use of phosphorus fertiliser in potato cropping on krasnozem soils in Australia
2002	PT01051	Factors affecting specific gravity loss in crisping potato crops in Koo Wee Rup, Vic
2002	PT98009	Characterisation of Australian isolates of Phytopthera infestans and planning to manage new & more aggressive strains of the fungus
2002	PT98008	Improving Seed Potato production
2002	PT94028	Information packages and decision support software for improved nutrition management of potato crops
2002	PT1042	Control of Pink rot in potatoes
2003	PT98011	Effect of Calcium Nutrition on decay of summer sown seed potatoes
2003	PT03055	Market research for potato nutrition software
2003	PT02033	Review of potato research and development program
2003	PT98015	New chemical treatments for fungal diseases of seed potatoes
2003	PT01048	Virus testing of early generation certified seed potato crops in WA
2003	Pt96032	Influence of rotation and biofumigation on soil-borne diseases of potatoes
2003	PT98007	Managing bacterial breakdown in washed potatoes
2004	PT99057	Nitrogen dynamics in commercial seed potato crops and its effect on seed quality, storage and subsequent commercial performance
2004	PT99052	Potato tuber management in relation to environmental and nutritional stress
2004	PT02047	Minimising virus infection in early generation seed potato crops in WA
2004	PT02048	Developing a pests and disease crop monitoring program for WA seed potato crops
2004	PT01038	Evaluating a product for enhancing dormancy and storage qualities of potatoes
2004	PT99022	An agronomic and economic blueprint for using whole, round seed for processing potatoes
2004	PT98018	Cleaning and Disinfestation strategies for potato farms
2004	PT01031	Enhanced detection of potato cyst nematode and bacterial wilt to improve market access for the Australia and New Zealand potato industries
2005	PT02045	The monitoring of potato crops for insect movement on a district scale
2005	PT01030	Seed Potato handling and storage - best practice
2005	PT03061	Improving virus control in seed schemes by combining aphid monitoring and virus testing
2005	PT02017	Effects of potato seed characteristics on seed-piece breakdown and poor emergence
2005	PT01008	Monitoring and developing management strategies for soil insect pests of potatoes

2005	PT01001	Control of black dot in potatoes
2006	PT00027	Making past industry information from R&D more accessible
2006	PT96009	Co-ordinating technology transfer in the Australian Potato Industry
2006	PT04010	Late Blight Management
2006	PT02012	Optimising production and storage conditions for seed potato physiological quality
2006	PT02022	A crop management service to promote new technology for potato seed production
2006	PT02016	Common scab threshold on tuber seeds for processing potato crops
2007	PT04002	Supplying information on demand via the Potato Internet Service
2007	PT96020	Mechanism of Cadmium accumulation by potato tubers
2007	PT03069	Management strategy for elimination of viruses from certified seed potato stocks in tasmania
2007	PT05011	Managing viruses in Tasmania seed potato stocks
2007	PT01041	Crop management tools for the french fry industry in the SE of South Australia
2008	PT07060	Enhancing environmental sustainability in the processing potato industry
2008	PT07035	Assessing water use in potato crops in the Mallee, SA
2008	PT04001	Understanding the implications of pastures on the management of soil borne diseases of seed potatoes
2008	PT05027	A potato crop management service to promote new technology in Tasmania
2009	PT08039	Potato Cyst Nematode information sessions - Putting the science in PCN
2009	PT06044	Improving management of potato virus S through a better understanding of mechanisms of virus transmission
2009	PT06014	Reducing the impact of black dot on fresh market potatoes
2010	MT09095	Tomato-potato psyllid a workshop series for the Tasmanian vegetable industry
2010	PT06014	Reducing Impact of black dot on Potatoes
2010	PT04016	Potato Processor R&D Program (APRP1)
2010	PT08048	Pilot Project - Diagnostic tests for soilborne pathogens, International Collaboration
2011	PT10018	Development of a contingency plan for zebra chip
2011	PT07038	Identifying microbial communities in disease suppressive soils as a means of improving root health of potatoes
2011	PT08046	Development of a soil borne pathogen testing service for the fresh market industry
2012	PT10026	Zebra Chip Awareness
2012	PT09004	Control of potato psyllid with an IPM strategy
2012	PT10008	Economic evaluation of certified seed in the Australian potato industry
2012	PT08008	Improved virus diagnostics to support the Victorian Seed Potato Association

2012	PT08032	Population genetics and phylogeny of the plant pathogenic protozoan Spongospora subterranea f. sp. Subterranea
2013	PT10009	Helping the WA potato industry capture winter production opportunities in the Mid-West
2013	PT12700	2012 Seed Potato Industry Conference
2013	PT09040	Development and demonstration of controlled traffic farming techniques for production of potatoes and other vegetables
2014	PT09019	Comparison between DNA testing and visual methods for assessing seed tuber health
2014	PT09026 C	Monitoring for Bacterial Wilt
2014	PT09026 A(i)	Soil amendments and nutrients
2014	PT09026 B(i)	Actinobacterial endophytes and their potential for disease suppression in potato
2014	PT09026 A(i)	Soil amendments and nutrients
2014	PT09023	Diagnostic tests for soil pathogens
2014	PT09026 (ii)	Impact of rotations
2014	PT090029	Enhancing the understanding of *Verticillium* spp in Australian potato production
2014	PT09026 A(i)	Soil amendments and nutrients
2014	PT09026 (ii)	Optimisation of 2,4-D and novel chemical foliar elements for control of common scab
2015	PT09027	Improving management of white-fringed weevils in potatoes
2015	PT13000	Understanding spatial variability in potato cropping to improve yield and production efficiency

Soil related

Plant related

not used in data sheets

not able to be used, data not suitable

seed

Extension

APRP2 projects

APRP1 projects