KIT 3.3

Develop and implement management options to minimise the cost of effectively and sustainably managing diseases

Impact	**Growers are able to sustainably reduce the impact of the most important diseases on farming systems and grain production.**
Summary	• Growers have access to options to effectively minimise the impact of diseases on farming systems and profitability. • Growers implement integrated management strategies to maintain the effectiveness of disease control options.

OVERVIEW

Disease remains an important constraint to grain crop production in all GRDC regions with wheat diseases alone estimated to cause an average annual loss of more than $913 million to the Australian wheat industry. While adoption of stubble retention and reduced tillage practices have revolutionised grain production in Australian farming systems, the widespread adoption of these practices has led to increased prevalence of some diseases. Over some time, GRDC has invested in RD&E focused on disease management at both regional and national levels. Losses would be far higher without the additional control strategies developed from these investments, which include the use of resistant varieties, new rotation options, paddock management strategies and tactical use of fungicides. While progress has been made for many of the major diseases, including rusts, Ascochyta, and blackleg; others, such as Rhizoctonia, crown rot and in some legumes, root lesion nematodes, remain problematic and may require greater attention or a different approach.

The key areas of RD&E that will further advance profitable disease management should include active disease surveillance and diagnostics, epidemiology, pathogen biology, genetic solutions and development of integrated disease management packages. Additionally, with accelerating advances in agricultural technology there will be a much wider range of technology available to develop and support on-farm disease management. These advances may come from remote sensing and/or new identification technology with the ability to identify disease (endemic and exotic) outbreaks before symptoms appear, thus enabling more targeted and timely fungicide applications. By combining these early detection technologies with disease models informed by more accurate weather forecasts, growers will have the tools and knowledge for optimised strategic fungicide application. Growers having access to optimised strategic fungicide application methodologies will reduce disease control costs while also decreasing risk and uncertainty associated with disease management decisions.

Key Investment Target (KIT) 3.3 aims to develop knowledge, novel tools and technologies to reduce the impact of priority diseases (Table 1) on farming systems and grain production with the following scopes:

1. Understanding of the distribution and impact of diseases
2. Understanding of the biology and ecology of diseases
3. Tools and technologies to manage disease
4. Integration of disease control decision-making in farming systems.

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SCOPE – Understanding the distribution and impact of diseases

The current and potential future distributions and impacts of diseases are quantified.

Surveillance and diagnostic capacity are fundamental elements to the development of cost-effective disease management strategies. The key objectives of effective surveillance and diagnostics are:

- Delivery of actionable intelligence that can enhance profitable and sustainable disease management,
- Deliver a basis for prioritisation of RD&E that focuses effort on reducing costs of the most economically important diseases,
- Delivery of a mechanism for monitoring of disease across the landscape to identify emerging threats,
- Characterisation of the changing nature of the pathogen population (e.g. fungicide resistance and emergence of new pathotypes) to inform short and long-term disease management and breeding programs,
- Deliver optimal management of biosecurity risks and demonstration of disease area freedom (DAF) to support market access.

There is an opportunity to enhance the value of surveillance data that is collected through better data management and coordination of activities. Improved surveillance will facilitate industry's ability to demonstrate DAF; analyse inter-seasonal and national trends; monitor the impact of RD&E efforts; and predict future disease epidemics. GRDC will continue to invest in the improvement of disease surveillance and diagnostics as well as the establishment of differential crop and pathogen sets. In combination, this will provide the grains industry with knowledge of the nature, occurrence and frequency of pathogen pathotypes across Australia.

Investment Outcome 3.3.1 – Growers have access to and use tools and technologies to identify, quantify and map the distribution of diseases in farming systems.

Growers require short and long-term information at paddock and regional scales to optimally plan for and manage diseases. Surveillance activities should be designed and coordinated across regions to optimise the management of data. Improved data management will enhance the ability to analyse data across regions and over time, improve the ability to forecast outbreaks, and assist in planning and informing profitable decision making. Where possible, surveillance activities will be designed to match the sampling intensity to the desired level of confidence required for data analysis. This will require new tools and technologies, such as remote sensing and in-field diagnostics. Additionally, there is a requirement for the development and implementation of robust strategies that facilitate rapid adoption of novel and practical disease identification tools.

Investment Outcome 3.3.2 – Growers and researchers understand the current and future potential impacts of different diseases.

Understanding the relationship between incidence and severity data and the ultimate yield and economic impacts of different diseases is critical. Robust and cost-effective methodologies are vital to determine this relationship across different crops and diseases. Pathogen fitness and impact may be affected by climate change, changing farming practices and changing landscape management. Therefore, ongoing pathogen sampling and characterisation (e.g. monitoring virulence evolution and fungicide resistance) is required to ensure that information on shifts in populations and pathotypes is generated. This, in combination with differential sets, is also required to inform breeding programs to ensure they are breeding resistance to the current and most prevalent races. To manage the biosecurity risks of high priority exotic and endemic diseases, GRDC will align with national strategies taking a collaborative and coordinated approach with other stakeholders across government and the plant industries.

Investment Outcome 3.3.3 – Research efforts focus on diseases prioritised on the basis of current or future potential impacts.

Future RD&E effort will be focussed on the diseases with the greatest potential impact on the enduring profitability of Australian grain growers. Emerging diseases will be prioritised based on their potential impact to industry. Estimates of yield and economic losses caused by diseases are required to achieve this ongoing crop disease prioritisation. Analysis of current and historical disease surveillance and impact data will assist in predicting future trends. Biosecurity preparedness research efforts will be prioritised based on relative risk.

SCOPE – Understanding the biology and ecology of priority diseases

Knowledge of disease life cycles under current and future growing conditions is improved to support the development of optimal management options.

Development of sound disease management practices requires understanding of epidemiology and pathogen biology within Australian farming systems. Agronomic practices, such as crop rotation, stubble management, and tillage practices, can alter disease epidemiology and pathogen dynamics, leading to changes in disease incidence and severity. These farming systems influence the time taken for inoculum to break down, affecting 'safe' crop rotation intervals. They also impact on the microclimate in the crop canopy, which can affect the development of foliar diseases and microflora in the soil. Previous epidemiology and disease management research was largely conducted in earlier farming systems involving multiple tillage events per season. Consequently, epidemiology and disease management research need to be revisited to ensure the availability of robust foundational knowledge of disease epidemiology under modern and future farming systems including the effect of climatic variability. Outcomes from this research will underpin the development of best disease management practices.

Pathogens not only evolve in response to changes in farming practices and climate, but in response to changes in their host when novel varieties with new resistance combinations are deployed. Recently, several pathogens of major crop diseases have been reported to overcome genetic resistance due to a shift in the virulence spectrum. Further, other pathogens have developed resistance to commonly used fungicides, reducing the spectrum of fungicides available for control. Sustainable disease management practices require a thorough understanding of agricultural management in the landscape (e.g. crop spatial arrangement and extent, and rotational sequences) and how farming practices might influence host–pathogen interactions. Currently, limited information on pathogen temporal and spatial evolutionary dynamics is available for the major diseases impacting grain crops in Australian farming systems. Future research will focus on better understanding, through novel and innovative approaches, the complexity of interactions between grain crops and pathogens.

GRDC will continue to invest in furthering industry's knowledge of disease epidemiology and pathogen biology under current and future growing conditions and farming systems. This will inform the development of new disease management tactics and strategies. To drive optimum innovation and to ensure delivery of benefits to Australian grain growers, future RD&E investment will require collaboration. International will be important as will collaboration with parties from outside the grain industry, across disease/crop types. The investment focus will be on ensuring greater understanding of pathogen biology and host-pathogen interaction, including effector discovery and demonstration of translational applications.

Investment Outcome 3.3.4 – Growers and researchers understand the life cycle, dispersal, survival and distribution characteristics of diseases.

The successful development of effective on-farm disease management practices depends largely on the understanding of pathogen dynamics under current and future crop growing conditions. Future RD&E investments will aim to deliver new knowledge on the drivers of pathogen evolution and adaptation. GRDC will invest in generating new knowledge and understanding of the spatial patterns, including dispersal of pathogens to assist in the design of improved disease management strategies. Research on the underlying mechanisms of host-pathogen interactions both at the molecular and cellular levels will underpin the development of novel disease management technologies. This should include, but not be limited to, mechanisms of disease resistance, including quantitative disease resistance and effector discovery. Research is also required to better understand pathogen biology, including their saprophytic and pathogenic fitness under current and future climatic conditions.

Investment Outcome 3.3.5 – Growers have the knowledge and tools to effectively monitor changes in the impacts, crop interactions and fungicide resistance status of diseases.

Early detection of fungicide resistance or insensitivity in pathogen populations is important. Early detection allows time for changes in management practices to be adopted, thereby mitigating potential yield losses due to fungicide failure in addition to preventing resistant pathogen populations from becoming dominant. Interactive tools that show the distribution, frequency and incidence of fungicide resistance across regions will be invaluable in this area. In-field monitoring tools are key to fighting fungicide resistance and are therefore a focus of future RD&E investment.

SCOPE – Tools and technologies to manage disease

Tools and technologies are developed to assist growers to optimise management of priority diseases in farming systems.

Australian grain growers have widely adopted conservation agricultural farming principles, partly in response to altered rainfall patterns and the need to conserve moisture. In doing so, retention of crop residues has increased dramatically with fewer interventions (e.g. burning and ploughing) to remove or enhance the breakdown of residues. Consequently, inoculum loads of pathogens that are carried on the residue of diseased crops have increased. Previous GRDC investments have facilitated the development and extension of cultural practices to manage diseases caused by necrotrophic pathogens. These disease management practices reduce inoculum by decreasing residue carryover. However, disease management is becoming increasingly difficult to achieve in modern stubble-retained systems with tighter cropping rotations and limited viable crop options. The benefits of retained crop residues on the long-term profitability of Australian growers is clear. However, novel approaches to stubble management in farming systems are required to minimise disease inoculum carry-over.

In recent years, the incidence and severity of some stubble-borne diseases have increased. In response, growers have become more reliant on chemical control, with multiple fungicide applications occurring within a season to manage the increasing disease load. Fungicides are often applied prophylactically as an 'insurance policy'. Beside the input cost, this practice has the potential to exacerbate the development of fungicide resistance. Currently, growers have limited access to information on timely and actionable seasonal risk management options that optimise input costs and reduce the incidence of diseases. Additionally, there are few effective disease monitoring tools available to growers. Industry would benefit from decision support tools and systematic disease surveillance and monitoring to warn of endemic/emerging and exotic disease issues before significant crop losses occur.

Previously GRDC has invested in multi-faceted R&D to develop best crop disease management practices, including genetic, chemical and cultural approaches. For some crops and diseases, growers have been effective in using resistant varieties to control disease. However, the emergence of new and more virulent races/strains has led to the erosion and break down of available genetic resistance in adapted varieties. This necessitates the search for new and durable sources of genetic resistance. While significant advances have been made for some of the major diseases such as rusts, other diseases remain problematic, including Ascochyta in chickpea, blackleg in canola, Rhizoctonia and root lesion nematodes in some legumes. For some of the diseases where genetic resistance has been identified, translation into varieties has been hampered by inadequate genetic characterisation, ineffective and inefficient phenotyping and delays in the development of enabling selection tools. As such, breeders do not know whether they are using the same or different sources of resistance. The lack of knowledge of the number of resistance genes in potential parents makes effective gene deployment more difficult to achieve and often means a pool of fewer resistance genes are utilised. This limits the potential to improve the rate of genetic gain and ultimately the release of varieties with durable genetic resistance. Protection of Australian growers from the 'boom and bust' of more virulent pathogen strains requires development of varieties with durable resistance.

Moreover, the recent emergence of fungicide resistance in some pathogens causing cereal diseases poses serious threats to the grain industry. There is a dearth of knowledge on the best management strategies for fungicide resistance in Australian farming systems. Improving understanding of how management strategies using existing fungicides and modes of action impact on the level of efficacy and development of pathogen resistance will minimise the risk of crop losses. Additionally, there is the need to develop new chemistries and non-chemical alternatives, including biopesticides (e.g. RNAi technology) and microbial suppression products. Although some biological/biopesticide products are being deployed overseas to manage crop diseases, their use has not been widely evaluated or adopted in Australian farming systems.

GRDC will continue to invest in the development of knowledge and tools that assist grain growers manage important diseases of cereal and pulse crops. Future RD&E in this area will target the following:

Investment Outcome 3.3.6 – Growers have access to tools to accurately and rapidly detect endemic and exotic diseases in the field.

Maintenance and enhancement of diagnostic capacity for endemic and exotic diseases, utilising appropriate laboratory and in-field techniques, is important to appropriately service high priority needs. Rapid detection and management of endemic diseases will occur through the provision and adoption of diagnostic tools by grain growers and their advisers. Dynamic on-farm models which relate disease, environmental conditions and crop genetics to yield, will allow for cost-effective disease management and whole farm profitability. This will include the development of automated tools for

early detection and quantification of diseases on-farm to allow for economic and timely fungicide application. Previous GRDC investments, over the last decade, have developed and validated diagnostic and decision support tools to allow growers to better manage crop diseases. However, growers' uptake of some of the disease management tools (e.g PREDICTA®B) has been limited. Future RD&E investments will provide growers with practical tools and technologies to identify and quantify diseases on-farm.

Investment Outcome 3.3.7 – Growers have access to diverse genetic, chemical, biological and cultural options for the control of diseases.

A key to effective long-term sustainable crop disease control strategies is access to a diverse set of control options and tools. This will require accelerated discovery, characterisation and deployment of new, and durable sources of genetic resistance as well as the development of novel disease control chemistries and other non-chemical disease control measures. This will be achieved through:

- Mining genetic resources to identify, characterise, validate, and deploy new genetic diversity for major and quantitative durable resistances, benchmarked against existing appropriately designated resistance genes;
- Understanding the genetic basis of disease resistance with more emphasis on adult plant resistance that is effective against a wide range of pathotypes in different environments;
- New and accurate high throughput phenotyping of disease resistance targeted at management practices, breeding and pre-breeding applications;
- Improved host and pathogen differential sets are required and need to be accessible for a broader range of crop/disease combinations to allow consistent evaluation of disease responses with new varieties across all regions;
- Development of novel fungicide chemistries and non-fungicidal disease management approaches, which may include engineering and biological solutions. Some of these approaches may require fostering collaboration with non-traditional investment partners, including partnering with international entities where appropriate.

Investment Outcome 3.3.8 – Growers minimise the development of fungicide resistance through the use of diverse and practical disease management strategies.

GRDC and other Australian R&D investors will partner with companies that have proven research, freedom-to-operate and path to market expertise to facilitate the discovery and delivery of new chemistries, both traditional and novel. Minimising the risk of fungicide resistance will require appropriate deployment of existing chemistries in an integrated disease management strategy that is practical and easily adopted by growers.

SCOPE – Integration of disease control decision-making in farming systems

The management of diseases is optimised in a whole-of-farm business and farming system context.

Successful in-season management of disease relies on growers and industry understanding:

- The level of inoculum in the landscape,
- The likelihood of environmental conditions occurring that favour disease expression,
- How their crop or variety will be impacted by disease and
- What economic, effective and practical options are available to manage disease.

These tactical decisions are further influenced by knowledge of how inoculum persists between seasons and across the rotation based on crop sequencing. Implementation of integrated disease management (IDM) offers the best option for managing grain crop diseases. Optimum IDM calls for minimal use of pesticides, and only if deemed necessary, giving preference to other control methods, such as host-plant resistance, cultural practices and biological control in a holistic way rather than using a single component strategy. Effective IDM requires development of sustainable and diverse disease management strategies. It needs to take into consideration other farm inputs and activities, and to focus on long-term crop disease management while maintaining flexibility to capture opportunities. While the benefits of using IDM to manage crop disease have been investigated at both regional and national levels through previous GRDC investments, the practicalities of implementing this approach in Australian grain production systems are somewhat limited. Previous GRDC investments have provided strategies for effective disease management but it is challenging to integrate this knowledge into wider farming system decision making.

Currently, disease management involves essentially a two-tactic approach – genetic and chemical with limited cultural options available. Cultural practices such as cultivation techniques, plant density, sowing date, crop rotation, soil amendments and fertiliser management have been used singly and in combination as tools for disease management. However, there is limited information about the relative efficacy and economics of different combinations of these tactics. Additionally, utilisation of cultural disease strategies, such as lengthening rotations with diverse crop species, are often in conflict with those that are most profitable. For example, a wheat/lentil/wheat/lentil crop sequence compared with incorporating canola, barley and chickpea. This is further exacerbated in some agroecological zones where there is limited availability of locally adapted break crops (e.g. lower rainfall zones of WA, western NSW and QLD).

Currently, some disease surveillance systems exist to inform industry of pathogen incidence across the landscape, but these are somewhat limited. In addition, there is inadequate accuracy in weather forecasting (see KIT 5.1) and integration of knowledge of pathogen incidence to predict when disease might be expressed. There is low grower confidence in utilising economic thresholds to make chemical application decisions, such as timing and rates. Hence, fungicide applications are often made to crops multiple times in a season, even when not actually required, as an 'insurance policy'. This has led to fungicide resistance in some pathogens of diseases, including barley powdery mildew and Septoria tritici blotch.

Furthermore, growers are concerned that messages about best practice fungicide resistance management have not been consistent. The strategies to delay the development of fungicide resistance can be different to the strategies to delay herbicide resistance and this creates uncertainty for industry. Preservation of existing chemistries requires robust IDM that is practical, effective and economical. More importantly, the communication that extends this research needs to be clear and consistent.

GRDC will continue to invest in the integration of technologies and knowledge so growers can make informed decisions to manage on-going pathogen and fungicide evolution in Australian farming systems. Future RD&E in this area will target the following:

Investment Outcome 3.3.9 – Growers understand the risk and economic implications of disease management options within farming systems.

Diverse, practical and cost-effective disease management strategies to minimise genetic host resistance breakdown and pathogen fungicide resistance will be developed. This will include better understanding of how improved varieties respond in the presence of disease across different environments, ensuring that growers have the confidence to adopt new varieties based on yield, grain quality and disease performance data.

Investment Outcome 3.3.10 – Growers and their advisers have knowledge of seasonal disease risks at paddock, farm and regional levels.

An RD&E priority will be the development of dynamic disease risk/decision support tools incorporating surveillance data, epidemiology and seasonal forecasting to predict when disease might be expressed. This may require partnering with non-traditional research organisations with proven expertise, such as the Bureau of Meteorology.

Investment Outcome 3.3.11 – Growers have knowledge of the short-term and long-term relevance of varietal responses, rotations, disease thresholds and farming system changes in making informed decisions on disease management.

The management of diseases is optimised in a whole-of-farm business and farming system context to ensure enduring profitability to Australian grain growers. This will require robust integrated disease management packages, which incorporate novel disease quantification and management technologies and approaches, that are also practical and cost effective.

Table 1: Research focus for the priority diseases based on economic impacts and cropping areas

Priority	Crop	Disease	Pathogen knowledge			Control measures			
			Surveillance and diagnostics	Pathogen biology	Epidemiology	Cultural approach	Chemical/ biological/ physical approach	Genetic approach	Integrated disease management package
Primary	Wheat	Crown rot	X	X			X	X	X
		Rhizoctonia	X	X		X	X	X	X
		Root lesion nematodes	X	X		X	X	X	X
		Septoria tritici blotch	X	X			X	X	X
		Rusts	X					X	X
		Yellow leaf spot	X	X			X	X	X
	Barley	Net blotches	X	X			X	X	X
		Powdery Mildew	X						X
		Root lesion nematodes	X	X	X	X	X		X
		Rusts	X					X	X
	Canola	Blackleg	X	X			X		X
		Sclerotinia	X				X		X
		Viruses	X	X	X	X	X	X	X
	Chickpea, Faba bean, Field pea, Lentil	Ascochyta	X	X	X		X	X	X
		Viruses	X	X	X	X	X	X	X
Secondary	Oat	Septoria leaf spot	X	X	X		X	X	X
	Sorghum	Charcoal rot	X	X	X	X	X		X
	Chickpea, Faba bean, lentil, Lupin	Botrytis spp	X	X	X		X		X
		Sclerotinia	X	X	X		X		X

Note: The table above identifies target diseases based on their economic importance and cropped areas. It does not indicate where our current investments are or when they will conclude as this information is dynamic.

There are other diseases not covered above that may warrant investment, which should be identified and prioritised separately. They fall generally into the following categories:
1) Minor diseases in major crops (e.g. downy mildew in canola), 2) Major diseases in minor crops (e.g. halo blight in mung bean), 3) Emerging diseases with potential for significant impact (e.g. Ramularia in barley), 4) Managing biosecurity risks (e.g. wheat blast).