GRDC investments addressing "deep dive" issues – Medium Rainfall Zone Southern RCSN – January 2019

Issue No. 13 - Cereal leaf diseases - genetic solutions and integrated management strategies to manage Yellow Leaf Spot (YLS), Eyespot and Septoria tritici blotch (STB)

The risk of fungal pathogens developing pathotypes to with resistance to commonly used fungicides is increasing. An opportunity exists to mitigate this risk through development of genetic solutions and integrated management strategies for the major cereal foliar diseases.

GRDC investments addressing this issue

Improving grower surveillance, management, epidemiology knowledge and tools to manage crop disease in Victoria (DAV00129)	This project operates under three broad objectives, i) generation of knowledge, tools and technology which improve disease management and incorporation of research results from research trials and demonstrations into disease management packages, ii) systematic surveillance, monitoring and disease diagnostics, and iii) services to growers and agronomists through provision of extension information and disease identification and IDM training relevant to the local environment and farming systems. Research focuses on integrated disease management of yellow spot in wheat, scald and net form of net blotch in barley, viruses in cereals and pulse crops and fungal diseases of pulses in the Southern Region.
Improving grower surveillance, management, epidemiology knowledge and tools to manage crop disease in South Australia (DAS00139) – investment completed and a new investment is in place	The aim of this project is to identify disease threats, including emergency issues, and inform on management strategies for plant diseases that are impacting on the South Australian grains industry. Costs and losses to the grains industry will be reduced through improving grower management of crop diseases. Disease surveillance reports and management advice packages from active pathologist field surveillance will be developed and appropriately updated for cereals, pulses and oilseeds, and delivered annually. This includes emerging pathology issues such as virus management, ascochyta blight of pulses and white grain in cereals. A co-ordinated regional pathology strategy document will be updated and delivered annually to ensure that all stakeholders (growers, advisors,

	researchers, chemical companies and plant breeders) share this information as part of a nationally consistent extension effort. Seasonally appropriate, timely plant pathology capability and capacity in disease diagnostic support and appropriate rapid response to significant outbreaks of new and emerging diseases will be delivered as required. Pathotype changes, including virulences and fungicide resistances, will be monitored in coordination with centres of excellence, and information relayed to growers, advisors and breeding programs to enable improved crop type, variety, and fungicide selection to manage disease in the cropping season. An extension program will consist of timely electronic reports delivered in response to disease development dependent upon seasonal conditions. Annual technical support to deliver grower and advisor training in disease management will include publications and electronic media for best practice disease management in the context of cost-effective crop protection practice.
Regional Agronomy SA - Improving disease management through improved agronomic practices (DAS00167-BA)	Guided by a literature review, this project will identify at least three field crop diseases where improvements in management are possible and then instigate a range of field experiments and paddock surveys to produce a range of integrated disease management strategies aimed at improving the efficacy of current best management practice. Diseases of field crops in the Southern Region currently cause growers considerably in terms of loss of yields and grain quality as well as the expenses associated with controlling disease. Murray and Brennon (2012 a,b,c & d) estimated that diseases of wheat currently costs growers in the Southern region $62 .10/ha, disease in barley costs $53 .27 /ha, disease in oilseed crops costs $63/ha and disease in pulse crops costs $37/ha. Disease control can be provided through genetic resistance, cultural methods and through the application of fungicides. An understanding of agronomy and farming systems, can be used to improve the performance of disease management by incorporating genetic resistance, cultural controls and fungicides to provide sustainable, cost effective strategies to match the risk of disease to various agro-ecological environments.
Improving grower surveillance, management, epidemiology knowledge and tools to manage crop disease in New South Wales (DAN00177)	Objectives of this investment – 1. characterisation of the frequency of insensitivity in Septoria tritici blotch populations to azole fungicides, and develop and communicate information to sustain the effectiveness of fungicides against this pathogen; 2. survey of high risk regions; 3. annual monitoring of STB monitor for further evolution of mutations in response to changed fungicide use patterns and determine geographical distribution patterns of phenotype sensitivity groups against key fungicides; 4. phenotype isolates to define sensitivity baselines for STB across a range of fungicide dose rates against a minimum of two registered modes of action; 5. sequence genes known to be implicated with fungicide resistance in STB; 6. measure efficacy of currently registered fungicides and new actives for the treatment of Septoria tritici blotch against known mutations using glasshouse pot assays; 7. deliver up-to-date knowledge on fungicide resistance management strategies and molecular tools for each disease; 8. develop a rapid molecular assay for the known fungicide resistance mutations
Germplasm enhancement for yellow leaf spot resistance in wheat (DAW00206)	Yellow spot (YS) (syn. tan spot) Is an important foliar disease of wheat in Australia and can cause losses exceeding 50% when conditions are favourable for disease development. The primary objective of this research is to identify opportunities to enhance resistance to YS through the development of genetic knowledge genetic resources and selection methodologies that can be applied by commercial breeding entities. Although good progress has been made internationally to understand YS resistance, relatively few resistance genes have been Identified and mapped in Australian germplasm and only one (tsn1) is In general and known use in Australian breeding programs. There is a significant opportunity to enhance expression of YS resistance through identification of resistance factors other than tsn1 on chromosome 5BL. The project aims to provide improved genetic solutions to VS management by - 1. Demonstrating robust phenotyping in different environments and key plant growth stages, for use in genetics studies that can be adapted for selection in breeding and are validated with

	appropriate field testing. This component will be delivered by DEEDI in conjunction with DAFWA, ACNFP and DPI Vic and will address aspects of evaluation of resistance including screening methodologies that provide the most precise, cost effective and timely means of evaluating resistance. A rapid adult plant assay will be developed under controlled environment conditions. Further demonstration of robust phenotyping will be undertaken through a 'ring test' using targeted resistant material which will be evaluated at both seeding and adult stages in Queensland, Vitoria and Western Australia. In addition robustness of phenotyping will be evaluated through multi-site screening of genetic mapping populations among the collaborators. 2. Assaying the current pathogen population for variation in virulence/aggressiveness on a range of genetic wheat stocks difference in response to the pathogen, to determine the potential for pathotype co-evolution associated with resistance gene deployment. ACNFP will develop a current national collection of isolates of the pathogen which will be assayed for variation in virulence on a range of targeted wheat lines. The purpose of this work is to determine the existence of pathogen variation that may have a potential for pathotype co-evolution associated with resistance gene deployment. 3. Improving the understanding genetics of resistance in current and future donors, and the genetic relationship and interaction with the 5BL toxin insensitivity locus. that can improve breeding outcomes. A major effort will be made to elucidate the genetic relationship and interaction of novel resistance loci and will address aspects of resistance including: • What genes other than tsn1 (5BL) are contributing resistance in Australian resistance sources? • How do these putative genes relate to current knowledge of international germplasm and can this knowledge accelerate access to breeding tools and strategies? • Are genetic determinants of resistance response in seedlings different from determinants of response in adult plants? • To what extent does combining novel resistance loci with the 5BL toxin insensitivity locus improve resistance expression? • Can non-adapted bread wheat introductions and synthetic hexaploid (or derived) material provides additional diversity for resistance breeding? An Initial consideration of the genetic materials available or to be developed In this project include ten existing mapping populations and three new proposed populations. In addition, effort will be made to combine genetic variability within the Australian germplasm by developing large single seed descent F2·5 populations from complex crosses involving genotypes with different sources of yellow spot resistance. This will maximise genetic recombination, generate potential parental stocks enriched for resistance and create opportunities for fine mapping. 4. Providing phenotypic disease data through phenotyping of mapping populations for QTL development and validation in different genetic backgrounds, including potential for pyramid10g through multi-locus MAS and closer linkage of QTL markers. DAFWA DEEDI and DPI Vic will phenotype at least two populations every year both 1n the glasshouse and field. 5. Providing elite resistant lines (validated through field and glasshouse testing) from doubled haploid populations, derived research populations and genetic resources worldwide to enhance resistance expression and diversity when used in Australian wheat breeding programs. A national set of candidate resistance donors (including durums) will be sourced from overseas and developed for use by project collaborators. Resistant germplasm identified from the above sources and from existing research populations will be validated over multiple years and field environments Effort will be made to introgress resistance genes individually and in pairs, into elite Australian background, in order to develop fixed lines that breeders can use as parents.
Yield loss response curves for host resistance to leaf, crown and root diseases in wheat and barley' (DAW00245)	This project has been designed to develop more accurate yield loss information for the major diseases of wheat and barley, including crown rot, yellow spot, septoria nodorum blotch, septoria tritici blotch, net blotch, scald, barley leaf rust and powdery mildew and nematodes. The five-year project, from 2014/15 to 2018/19, will generate yield responses to regional priority pathogens and nematodes for a range of varietal resistances and disease pressures from negligible to severe. This

	is being be done by conducting field trials across a range of cropping regions where the diseases occur. The project is developing information to support crop agronomic decision-making, considering crop sequence, varietal selection, stubble management, seasonal climate, for disease risk considerations. By gaining improved understanding of the actual impacts of disease, more growers and advisers will make improved agri-chemical and plant variety decisions, which will result in improved profitability and sustainability. This project has been designed to develop, collate and deliver quantitative information on wheat and barley variety response to disease that is comprehensive, comparative and reliable in terms of yield and other system-relevant indicators of the impacts of resistance. It will achieve this by generating yield responses to a representative range of varietal resistances for regional priority pathogens and nematodes and under a range of disease pressures. The Australian grains industry can access a suite of crop management, agri-chemical and plant varietal options to deliver improved profitability and sustainable management of important disease threats. Crop agronomy is optimised within a range of crop sequence, stubble management, seasonal climate. sowing practice. soil type and disease risk situations. The industry has broadened its use of pesticides, particularly fungicides, as a means of seasonal disease risk management or as a tactical requirement. Resistant varieties continue to underpin the breadth of industry's approach to disease risk management including industry-wide regional benefits of epidemic mitigation and individual farm business benefits of profitability and sustainability. Optimising the mix of crop management, agri-chemical and plant variety options require a suite of information that can be integrated by individuals to make rational management decisions. To this end industry develop comprehensive, comparative and consistent qualitative information on varietal response to disease, supported directly by GRDC investment of around $1.5M p.a. in varietal disease response ratings for wheat and barley. This significant national effort effectively ranks varieties according to their likelihood of experiencing yield impacts (among varieties but within diseases) but does not quantify this risk in directly interpretable agronomic and economic terms that provide a more well-informed decision of how to optimise risk and profitability for a recognised suite of disease threats in a specific environment (both among varieties and between diseases). In providing growers with quantitative information about disease resistance, a significant national effort is required to develop comparative and consistent quantitatively based decision support rather than the broadly qualitative approaches currently available. In particular, the development of disease response curves indicating the potential yield losses associated with the selection of varieties with low levels (MS, S, VS) of varietal resistance has been identified by GRDC as a priority. This will assist in variety adoption strategies and also ensure growers are well prepared for situations requiring intervention with fungicide. The project will focus on regional disease priorities for the northern, southern and western regions including crown rot, root lesion nematodes, yellow spot of wheat and net blotch of barley, other foliar fungal diseases including rusts and mildew.
Centre for Crop and Disease Management (CUR00023)	CCDM Program 1 - Project A - Early detection and management strategies for fungal diseases CCDM Program 1 - Project B - Best management practices for fungal disease control CCDM Program 1 - Project C - Economics of disease management and capacity development. CCDM Program 2 - Extension and engagement CCDM Program 3 - Septoria nodorum blotch biology CCDM Program 4 - Tan (yellow) spot CCDM Program 5 - Net form of Net Blotch Functional Genomics CCDM Program 6 - Sclerotinia Stem Rot of Canola and lupins CCDM Program 6 - Ascochyta blight of pulses CCDM Program 8 - Durable Resistance to Powdery Mildew CCDM Program 9 – Fungicide resistance
National pathogen management modelling and delivery of decision-support (DAW00228)	Improving crop yield in Australian farming systems is hindered by a number of factors; crop disease is one of them. Recent reports commissioned by GRDC indicate that the annualised costs of diseases of cereals, and oilseeds and pulses is over $1.2 billion and $210 million, respectively. Managing diseases at the right time with the right control techniques can and will substantially reduce the costs of diseases and thereby increase farm income. However, such management

	needs to be economically viable. This project aims to provide the grains industry with tools and processed information in order to aid decisions on economically feasible crop disease management.
Understanding or evaluating the effectiveness of fungicides to manage Septoria Tritici Blotch (STB) and Leaf Rust (FAR00004A)	The research will combine field research on fungicide performance with laboratory testing of the fungal populations pre and post fungicide application in the regions where these diseases are most problematic. It will also give an early warning system across the prevalent regions for detection of resistant mutants following SDHI and strobilurin application.
Effective genetic control of Septoria tritici blotch (DAN00203)	Currently, control of the disease relies on growing resistant wheat varieties and or the use of fungicides in crop. Since 2010 the disease has increased rapidly in the high rainfall regions of Victoria, South Australia and Tasmania. Growers in these areas are reporting that 3-4 applications of fungicides are required to control the disease. Identification of resistance sources is the first step towards the development of improved varieties for growers in disease prone regions. Useful genetic variation for STB resistance exists within common wheat germplasm and has been successfully exploited from a wide range of donor sources of resistance such as landraces, wild progenitors of wheat, synthetic wheats and durums. However, only a few genotypes have been examined in detail to investigate modes of inheritance and to locate loci controlling STB resistance. Resistance to Z. tritici in wheat is complex, due to both qualitative and quantitative genes. Quantitative resistance seems to be effective against different pathogen populations. So far, 20 STB resistance genes/QTLs have been identified. Previous research has shown that different major genes vary in providing effective resistance over a period of time. Some of the STB resistant varieties have succumbed to changes in virulence of Z. tritici. Understanding the mode of inheritance of qualitative and quantitative genes bridges the gap between QTL analysis and practical breeding and is essential for breeding programs to develop selection strategies. Identifying new sources of resistance is now even more important with the development of fungicide resistance in the Australian Z. tritici population. NSWDPI (Dr. A Milgate) have sequenced the CYP51 gene, which is responsible for azole fungicide resistance, from a set of 100 Australian STB isolates collected across a time period spanning 1979 - 2013. The results have demonstrated that a number of mutations known to occur in the UK and Europe are present in the Australian population. Some of these mutations are silent and do not result in loss of fungicide sensitivity. However two of them called Y137F and the Y461S do result in loss of sensitivity. If the current practices of relying on fungicides to control STB are continued it may be expected we will see the selection of more serious levels of fungicide resistance. In addition to the shift in fungicide resistance of STB, results from pathotype screening show that isolates collected post 2010 STB have significant changes in virulence to known host resistance genes. This means that the options for control of the disease using fungicides and variety resistance have simultaneously come under threat. Seedling pathotype screening conducted at Wagga suggests a number of the major resistance genes utilised in the project CWQ00016 have now been overcome. These are; stb3,4,6,7,11,12. The seedling assays show that of the major sources of resistance only Bulgaria 88 (stb1) , Lorikeet (unknown) and Milan (unknown) display broad spectrum resistance. All the remaining sources of major genes show susceptible reactions to one or more isolates. This indicates that major resistance genes on their own are unlikely to be durable because in many cases the corresponding virulence genes are already present in the population. The effector based model has now been well established and its applicability to accelerate breeding programs proven. For example, the ToxA, Tox1 and Tox3 effector proteins are all being used by breeders to rapidly screen germplasm for susceptibility to Stagonospora nodorum blotch and Yellow leaf spot. Other programs are now underway around the country to exploit this model to accelerate disease management programs for other pathogens. Zymoseptoria tritici is closely related to other pathogens previously shown to use effectors to

	cause disease. Unlike these other pathogens though, no effectors have been identified for Z. tritici and the disease itself is very poorly understood. Rapid progress could be gained in terms of identifying effector proteins or small molecules. As noted above, Z. tritici harbours differential susceptibility/resistance on different wheat lines so there must be genotype specific factors involved in the interaction. These effectors are likely to control the host specificity and thus the success of disease. As such, progress needs to be made in identifying and characterising the role of effectors for Z. tritici.
National improved molecular diagnostics for disease management. (DAS00137)	This project will reduce the costs and losses through Improving grower management of crop soilborne diseases. This will be achieved by industry increasing cost effective adoption of fungicide resistance management plans to 50% and increasing cultural management strategies as a key control strategy to 40% of growers surveyed by GRDC. This will be achieved through the delivery of the following objectives: 1. New knowledge, tools and technologies that provide an effective balance of genetic, cultural and chemical options for control and that support the integrated management of crop disease and impacts on yield, quality and crop returns. 2. Manage and prioritise emerging pathogen risk by improving knowledge of epidemiology for current and emerging diseases through systematic survey and modelling. 3. An Increased focus on emerging diseases affecting grain quality and production, and improved molecular diagnostic field monitoring, early warning tools and models which will reduce costs and losses for growers. 4. Increased grower and advisor use of an integrated approach using resistant varieties, cultural management and fungicide use options to support crop planning and in-a-op disease minimisation. 5. Advisors will have targeted plant disease training so that growers can have access to independent information to manage crop disease appropriate to their geographic circumstances and crop rotations.
Regional Agronomy SA - Improving disease management through improved agronomic practices (DAS00167-BA)	This project forms part of the broader SARDI and GRDC bilateral regional agronomy research effort and will employ a research agronomist based at the Primary Industries and Regions South Australia (SA) Port Lincoln regional office in the Eyre Peninsula region of SA. The agronomist will work closely with a range of industry stakeholders in addressing regional issues and opportunities. A key output of the research project will be the development of sustainable management strategies that enable growers to sustainably control a range of crop diseases. The research agronomist will also work closely with the rest of the bilateral team to ensure that the research findings from their work are communicated to industry. A further key output of this project is to develop the skills and capabilities of the Research Agronomist (LEP), to enable them to be of significant benefit to SARDI, GRDC collaborating research agencies, the grains industry sector, agribusiness, chemical companies, farming system groups and growers in the field of agronomic research. The Research Agronomist (LEP) will work with the rest of the SARDI/GRDC bilateral project team, GRDC, related groups within SARDI and other agencies, to develop their skills in research, agronomy, farming systems and especially in field pathology related issues. This will improve the capacity of the R&D sector of the industry to address and overcome critical limitations and research gaps in the profitability and sustainability of southern Australian farming systems. Guided by a literature review, this project will identify at least three field crop diseases where improvements in management are possible and then instigate a range of field experiments and paddock surveys to produce a range of integrated disease management strategies aimed at improving the efficacy of current best management practice. An example of how an improved knowledge of agronomy and the need to develop new strategies in line with changes in farming practice may come about from the high incidence of aerial blackleg observed in recent years. This is thought to have arisen as a result of a trend towards earlier sowing of canola, which has led to the canola plant being more physically developed by the time blackleg spores are released in early winter, hence the disease attacks a different part of the plant

	to where it has traditionally. Possible management strategies could involve investigating differing varietal development characteristics that lead to the plant flowering in a preferred window that reduces the risk to the more difficult to control aerial blackleg infection.
9176339 - Managing eyespot in intensive cereal, stubble retention farming systems in South Australia (DAS1807-005BLX)	Eyespot has been an increasing problem in cereal crops in South Australia over the last five to ten years and our knowledge of the epidemiology and management of this disease under Australian conditions is limited. This project aims to provide eyespot management recommendations to Industry by developing a pot-based screening method for assessing resistance levels in commercial varieties; improving our understanding of the epidemiology of eyespot and the factors affecting inoculum build-up and break-down; and by disseminating findings and management recommendations in written and oral formats.
Disease epidemiology and management tools for Australian grain growers (DAW1810-007RTX)	This project will result in improved decision making for management of disease in cropping resulting in improved profitability and reduced financial risk for Australian grain growers. This outcome will be achieved by production and delivery of management tools and targeted risk information. The accuracy of these tools and information will be ensured through detailed epidemiology experiments, and collaborative testing performed across Australia. The project will undertake a detailed quantitative prioritisation process to ensure that the project focuses on the management tools and information that will have the largest benefit for industry. This prioritisation process will account for the total impact of each disease, and on the information gap that exists relating to management of each disease. The project will conduct detailed epidemiology, disease management and validation experiments in all relevant grain growing regions targeting sclerotinia and blackleg upper canopy infection of canola; yellow leaf spot and Stagonospora nodorum blotch (SNB) of wheat; net blotches of barley; Ascochyta and Botrytis diseases of pulses; and other diseases as determined according to the prioritisation process. The project will maintain, deliver and further develop existing management tools and products for blackleg of canola and blackspot of field pea, and will incorporate management of upper canopy infection for blackleg. The project will release management tools for sclerotinia of canola, stripe rust of wheat, powdery mildew of mungbean and yellow-spot of wheat. The project will develop and test prototype decision tools and modelling frameworks for further prioritised disease, where candidates include net blotches in barley; yellow spot and SNB complexes in wheat; botrytis diseases in pulses; and ascochyta blight in chickpea. The project will develop improved electronic information flow processes. Providing access to up-to-date weather, disease risk, fungicide, and disease resistance information for growers, and providing accurate tool use metrics, even in conditions where mobile data access is intermittent.

Issue No. 60 - Uncertainty in the rotational break time required for Eyespot inoculum breakdown in stubble, reduces confidence and leads to prophylactic fungicide applications in cereals

GRDC investments addressing this issue

Preliminary evaluation of fungicide efficacy for control of Eyespot in wheat and extension of cost-effective management strategies (AAG00002)	There are no chemical options registered for treatment of eyespot in Australia. Although the main control method has been to apply fungicides at GS 30-32. The effectiveness of control with fungicides depends on the activity of the fungicide itself against eyespot, the severity of the disease, weather conditions at susceptible stages, coverage of susceptible plant parts and timing of application. Objectives - 1. To compare the efficacy of a range of foliar applied fungicides for eyespot control 2.To compare fungicide efficacy at two application timings
Improving grower surveillance, management, epidemiology knowledge and tools to manage crop disease in South	The aim of this project is to identify disease threats, including emergency issues, and inform on management strategies for plant diseases that are impacting on the South Australian grains industry. Costs and losses to the grains industry will be reduced through improving grower management of crop diseases. Disease surveillance reports and management advice packages from active pathologist field surveillance will be developed and appropriately updated for cereals, pulses and oilseeds, and

Australia (DAS00139)	delivered annually. This includes emerging pathology issues such as virus management, ascochyta blight of pulses and white grain in cereals. A co-ordinated regional pathology strategy document will be updated and delivered annually to ensure that all stakeholders (growers, advisors, researchers, chemical companies and plant breeders) share this information as part of a nationally consistent extension effort. Seasonally appropriate, timely plant pathology capability and capacity in disease diagnostic support and appropriate rapid response to significant outbreaks of new and emerging diseases will be delivered as required. Pathotype changes, including virulences and fungicide resistances, will be monitored in coordination with centres of excellence, and information relayed to growers, advisors and breeding programs to enable improved crop type, variety, and fungicide selection to manage disease in the cropping season. An extension program will consist of timely electronic reports delivered in response to disease development dependent upon seasonal conditions. Annual technical support to deliver grower and advisor training in disease management will include publications and electronic media for best practice disease management in the context of cost-effective crop protection practice.
Regional Agronomy SA - Improving disease management through improved agronomic practices (DAS00167-BA)	Guided by a literature review, this project will identify at least three field crop diseases where improvements in management are possible and then instigate a range of field experiments and paddock surveys to produce a range of integrated disease management strategies aimed at improving the efficacy of current best management practice. Diseases of field crops in the Southern Region currently cause growers considerably in terms of loss of yields and grain quality as well as the expenses associated with controlling disease. Murray and Brennon (2012 a,b,c & d) estimated that diseases of wheat currently costs growers in the Southern region $62 .10/ha, disease in barley costs $53 .27 /ha, disease in oilseed crops costs $63/ha and disease in pulse crops costs $37/ha. Disease control can be provided through genetic resistance, cultural methods and through the application of fungicides. An understanding of agronomy and farming systems, can be used to improve the performance of disease management by incorporating genetic resistance, cultural controls and fungicides to provide sustainable, cost effective strategies to match the risk of disease to various agro-ecological environments.
9176339 - Managing eyespot in intensive cereal, stubble retention farming systems in South Australia (DAS1807-005BLX)	Eyespot has been an increasing problem in cereal crops in South Australia over the last five to ten years and our knowledge of the epidemiology and management of this disease under Australian conditions is limited. This project aims to provide eyespot management recommendations to Industry by developing a pot-based screening method for assessing resistance levels in commercial varieties; improving our understanding of the epidemiology of eyespot and the factors affecting inoculum build-up and break-down; and by disseminating findings and management recommendations in written and oral formats.

Issue No. 29 - Sub-soil constraints — understanding how acidity, sodicity, nutrients and structure limit yield, quantifying the economic impact of amelioration techniques, management of sub-surface and sub-soil acidity*, genetic advancements, soil amelioration and drainage strategies to reduce the impact of waterlogging

***= investments addressing the management of sub-surface and sub-soil acidity are included in summaries of investments addressing soil acidity on page 22**

<u>GRDC investments addressing this issue -</u>

Increasing production on sandy soils in low and medium rainfall areas of the Southern Region (CSP00203)	To maximize opportunities to increase crop water-use and yield on sandy soils, it is important to improve our ability to diagnose and manage a range of soil constraints including physical and chemical impediments to root growth, and the biological capacity to cycle and supply nutrients. The 'Sandy Soils' project aims to improve cost-effective diagnosis and management of under-performing sandy soils in the low-medium rainfall zone of the Southern region. **Diagnosis of constraints** to crop water-use and productivity in sandy soils is difficult. There are a number of known constraints within these systems, including high penetration resistance, pH related issues (both acid and alkaline), and biological cycling and nutrient supply. Activities completed include sampling transects across 9 underperforming sandy soil sites and characterising key parameters

	associated with the profile. The characterisation data will be used in conjunction with field trial activities to diagnose the most likely primary constraints and how they impact crop water-use. Characterisation has also included herbicide residues which has been highlighted as a potential emerging issue in the Southern region. Analysis of samples from 9 sites suggest that Glyphosate and its breakdown product (AMPA) are commonly present in sandy soils (0-30 cm) at concentrations that range between 0.7 and 6.1 typical applications. At all sites AMPA accounted for >80% of residue load. Other herbicides were either not found (Prosulfocarb, imidazolinones, Triclopyr, MCPA) or found at very low concentrations. A short-term assay did not indicate that germination of lucerne was inhibited in these soils. The impact of AMPA on root development and function as the plant matures is unknown. **Field activities** within the project include continued monitoring of existing amelioration trials, as well as establishment of new trials that include both mitigation and amelioration activities. Field trials are targeted towards regional/site constraints. The amelioration trials focus on: a) understanding the longevity of effects associated with incorporation (spading) of topsoil, organic matter, clay, and/or nutrition; b) understanding and optimising the use of organic matter to overcome physical and nutritional constraints in conjunction with physical interventions (deep cultivation, ripping, inclusion, or spading); and c) annual seeding strategies to develop a permanent fertility strip. Mitigation trials focus on: a) understanding effects of nutrient placement depth; b) seeding strategies for repellent soils and increased fertility; and c) agronomic optimisation including crop variety and type. Understanding the **longevity of yield benefits** associated with incorporation (spading) of topsoil, organic matter, clay, and/or nutrition is being addressed through continued monitoring of trials established in 2014 at Brimpton Lake, Karoonda, and Cadgee. Data indicate ongoing yield benefits, with spaded treatments yielding ~0.5 t ha^{-1} better than the control at Brimpton Lake (lupins) and Karoonda (wheat). At Cadgee (lupins) the spaded treatment had no yield gains, treatments with clay tended to yield higher, and the combination of clay plus organic matter had double the yield of the unmodified control. To understand these effects, characterisation of the amended soil profiles in 2018/19 will quantify differences between key soil parameters. The **new field program** established three trial sites in 2017 (Ouyen, Lameroo, Yenda), with a further 4 new sites (Carwarp, Waikerie, Murlong, Bute) in 2018. Early results from Ouyen (VIC) on a deep sand with high penetration resistance and poor nutrient supply, indicate: a) yield benefits from ripping at 30 cm but not at 20cm; b) deep placement of nutrients had no effect in this season on yield above the physical impact of ripping; c) spading of nitrogen rich organic matter (vetch, chicken litter, compost) resulted in yield gains between 0.6 and 1.0 t ha^{-1}; d) one pass spade-and-sow approach resulted in rapid ground cover, but establishment counts were lower and more variable compared to the no-till control. Early results at Yenda (NSW) were impacted by a difficult season with little rain and multiple frosts. In this season, there was little impact from physical disturbance from deep cultivation (30 cm) or ripping (30 cm). There were however yield responses (+0.9 t ha^{-1}) to N (either urea or chicken litter), but potential was limited due to haying off. The variety trials suffered high variability in yields likely resulting from the dry conditions and multiple frosts. A trial at Lameroo (SA), looking to establish a permanent zone of improved fertility through annual seeding practices, represents an establishment year. The trial includes a cross-soil component to evaluate paddock-scale benefits and trade-offs in using an on-row sowing approach. The second trial on the sandy soil, tests the benefits of annual beneath seed banding of various ameliorants (organic matter, clay, charcoal). No significant effects on plant growth and grain yield were measured in the establishment year. **Machinery optimisation** and soil (discrete element method, DEM) modelling has been used to support the implementation of both Yenda and Ouyen amelioration trials. At Yenda this helped to inform the deep cultivation process (double pass at two depths, at a defined speed) ensuring a balance between shattering the compacted layer, and surface disturbance/unevenness. Similarly, the implementation of spader-seeding was optimised at the Ouyen trial, including a validation trial utilising dyed sand that provided a valuable visual for field walks. The modelling work continues to evaluate: a) the impact of forward speed, rotary speed, operation depth, field conditions, and tine/blade design on field performance of soil mixing approaches; b) validate the modelling and impact of mixing of plant growth parameters in the field; c) inform soil sampling strategies to ensure a representative sample can be taken when sampling the field experiments. Data from multiple seasons will be used for an economic and risk modelling activity to analyse the field scale return on investment, gross margin impact over time and investment payback periods of the most promising trial results. The potential benefit will be estimated under a range of climatic and commodity conditions using combinations of biophysical and bioeconomic tools.

Understanding the amelioration processes of the sub-soil application of amendments in the Southern Region (DAV00149)	In many cropping areas in Victoria, a significant constraint to profitable crop production is the frequent occurrence of poorly structured clay soils that are inherently compacted, which can lead to water logging under high rainfall conditions. These unfavourable soil conditions inevitably hinder crop growth and consequently reduce economic crop productivity. In the high rainfall zone of Victoria, waterlogging during the long, cool growing season can severely restrict root growth in crops that seriously prevents nutrient uptake. In addition to this problem of poorly structured surface soils, a further major constraint for crop production related to the nature of the subsoil. A key factor is that the surface soils tend to become waterlogged early in the growing season when winter rainfall exceeds evaporation, and the relatively impermeable clay layer prevents deep infiltration of the collected water into the subsoil. Further, later in the growing season, restricted rainfall and poor water retaining qualities in the topsoil means that there may not be sufficient water available above the clay layer for healthy crop growth. The lack of surface water combined with physical subsoil constraints restricts the growth of deep crop roots through the clay layer, denying both water and nutrient absorption. The application of amendments (both organic and inorganic) can markedly improve crop growth on a range of soil types that dominate grain production in the medium and high rainfall zones of south east Australia. A comprehensive Scoping Study involving an in-depth analysis of current and previous research (published and 'grey literature'), combined with a workshop involving a diverse range of stakeholders (technical experts from a range of disciplines and organisations, consultants and growers) was published that identified both key knowledge gaps and a detailed research plan to determine the processes underpinning grain yield responses to subsoil ameliorants in south-eastern Australia. A series of glasshouse and field trials have been instigated throughout SA, Vic and Tas, and existing trials established under previous projects have been revisited. These indicate part of the beneficial impact of amendments on crop growth appears to be related to improvements in nutrient supply, as well as improvements in soil structure; this effect however depends on the nature of the particular subsoil. Wheat responses to soil amelioration are strongly associated with improvements in root growth (at least on poorly structure, sodic subsoils). Whereas 'More is better' seems to apply to crop responses to the rate of application of amendment in a controlled environment, this may not be the case in the field where water nearly always limits grain production and that there is a real risk of the crop 'haying off'. A review of machinery needed to apply amendments to subsoils based on both current and previous research (Australian and international), as well as the experiences of commercial machinery companies and individual farmers, is nearing completion. Some of the learnings from this review were used to design and construct a new subsoiler design for research targeting the application of both organic and inorganic amendments and nutrients in field based research experiments. Access to suitable machinery (and favourable seasonal conditions/rainfall, both in the period between amendment application and sowing, and later at grain filling) appears critical if the full yield potential of applying amendments (organic or inorganic) into dense poorly structured subsoils is to be achieved.
Biosolids to overcome subsoils constraints in the Victorian grain growing soils (FED1806-001AWX)	It is claimed that incorporation of organic amendments to the top 30-40 cm soil layer, a practice that has now been termed subsoil manuring, can markedly improve the soils physical and chemical properties, particularly those which are closely related to enhance root growth and therefore crop productivity. Recent attempts at subsoil manuring have utilised several types of organic and inorganic matter, including chicken manure, gypsum, inorganic based fertilizers, lucerne pellets and crop stubbles. These treatments have been used individually and/or as mixtures. However, notwithstanding the fact that these previous efforts to ameliorate the properties of dense clay subsoils have provided promising results, attempts at adoption of the practice of subsoil amelioration has been slow, predominantly due to high upfront costs. Therefore, the key to this project is the investigation of a viable option to overcome the shortage of low-cost organic matter for subsoil manuring. The project (in collaboration with DAV00149) will investigate the possibilities of using biosolids as a subsoil ameliorant. Biosolid material is one of the more freely available manure resources Australia-wide, and numerous studies have been conducted on the possibility of using it as an amended fertilizer in agriculture. Indeed, biosolids have been shown to have numerous benefits as an organic nutrient-rich compound which can be innovatively used in agriculture to improve crop productivity. It

	is relevant to note that even though biosolids are widely used in worldwide agriculture, only 31% of the total production of biosolids are used in agriculture in Victoria, which is the lowest usage across Australia for agricultural purposes. It appears that there is possible community confusion between the terms sludge and biosolids, and we identify here that these terms simply imply the physical differences in the appearance of this material, with sludge appearing as a slurry and biosolids appearing as a soil like matrix. This clearly implies that sludge is operationally different to handle than biosolids, and the basic steps involved in the production of biosolids are (a) collection of raw sewage, (b) treatment of sewage to the desired health related levels, (c) settling and removal of watery sludge to produce the required biosolids. These biosolids can then be regarded as an established, nutrient-rich product that is ready for convenient, safe and beneficial end use. In the investigations related to this project, biosolids will be further treated in order to improve its physical and chemical characteristics for use as a subsoil ameliorant. In one of the treatments, biosolids will be mixed with sawdust, another cheaply sourced available organic matter which can be used to help improve the soil physical properties of the compact clay soil layer. Trials will be conducted to represent both high and intermediate rainfall zones, with different rates of manuring tested against wheat crop productivity, soil physio-chemical and microbial properties, leaching of heavy metals to the deep soil layers, heavy metal accumulation and remobilization into the wheat crop and grains. Based on previous sub soil manuring studies, we expect that subsoil manuring with amended biosolids can significantly increase the grain yield in both high and intermediate rainfall zones in Victoria. The anticipated outcome of this project is to assist Australian grain growers in achieving improved profitability through increased grain yields. At the same time, manuring intervention will improve hostile subsoils, which will have long-term, positive impacts on productivity and profitability in the agricultural industry.
Tactics for improving rooting depth and crop yield on sodic soils - West (MIG1801-001SAX)	Sodicity at depth is a sub soil constraint that restricts rooting depth and the amount of sub soil moisture the root can access. Like many other sub soil constraints, sodic soils restrict plant growth and development and result in lower grower returns from these unproductive sections of their paddocks. The project aim is to evaluate possible strategies for growing more grain on soils that have been identified as sodic at depth, specifically in the medium-low rainfall environments. Success will be achieved if management strategies are identified that increase plant growth, rooting depth, crop yield and profit. Through the establishment of two gypsum rate trials on soils confirmed sodic, the rates of gypsum required to re mediate sodic subsoils will be observed by researchers and growers. They will have the opportunity to observe the changes to rooting depth and crop yield over the three year time period of the trial. Through observation and supporting measurements and evaluations, growers will then have confidence in gypsum rates that have shown to increase plant rooting depth and their ability to access stored soil moisture. Access to soil moisture, soil water levels and crop rooting depth will be assessed through the use of soil pits during the season. The objective of the project is to improve crop rooting depth and access to stored soil moisture so that plant growth and crop yield are increased, providing growers on these soil types with more profitable cropping systems. At the end of the project growers in the Northern Agricultural Region of WA will have an increased understanding of subsoil acidity and rates of gypsum required for treating this constraint.
Tailoring an integrated solution to effectively address subsoil constraints by incorporation of chemically-balanced nano-amendments (DAN1806-002AWX)	The nature and impact of subsoil physicochemical constraints on crop productivity and profitability of grain production in Australia have been well established. Subsoil physicochemical constraints include transient salinity, acidity/high alkalinity and impacts associated with sodicity (transient waterlogging, high soil strength). Most soils in the cropping region contain one or more subsoil physicochemical constraints that can limit effective root growth and water and nutrients use by crops. As a result, grain yields are significantly less than water limited potential resulting in major financial penalties for growers. The on-going challenge for the grains industry is how best to manage these constraints. This project will address this issue by looking at innovative chemical and engineering solutions to manage hostile soils in broad acre grain production. The conceptual framework of the project is developed around a novel approach for the effective utilisation of a new generation of amendments products: Investigating the potential of nano-sized amendments to boost the agronomic impacts and economic benefits of incorporated chemically-balanced organic matter into constrained subsoils. In this project,

	we will harness recent advances in development of new nano- amendments (e.g. nano-gypsum, nano-lime) and iteratively evaluate these using a suit of advanced methods to examine amendment chemistry in soils and to effectively incorporate these amendments at the paddock level.
Deep placement of nutrients in the northern region (UQ00078)	Macronutrient balances (nitrogen [N], phosphorus [P], potassium [K]and sulphur [S]) are negative across the northern grains region – more nutrients are being removed than are currently being applied. This depletion of the soil fertility resource base has been the principal driver for growers responding with fertiliser applications, primarily N and P. Traditionally, N fertilisers have been applied pre-plant for cereal and oilseed crops, while a smaller amount of P is applied with seed at-sowing as a 'starter' application. Phosphorus and K are immobile nutrients in the soil, i.e. where you put them is where they stay. The P applications into the surface layer are contributing to increasing availability in that part of the profile. However, crop requirement is greater than what is able to be met through starter fertilizer applications alone, or from root uptake from the top 5-10cm layer which can be dry for long parts of the growing season. Nutrient requirements are being met largely by extraction from soil layers below the top 0.1 m, with this extraction widening the difference in plant availability between the surface (enriched) and sub-surface (depleted) layers. Research is already demonstrating that substantial yield responses can be recorded when immobile nutrients like P and K are placed in subsoil layers where roots are prolific enough to ensure good crop recovery and soil moisture availability is such that an extended period of root activity is achievable. This varies from season to season, but if active roots in a nutrient- enriched profile layer can acquire nutrient at a time when yield potential is being established (e.g. through tillering in cereals), yield responses can be substantial. To date, research has focussed on demonstrating the quantum of crop responses with different crop species at different nutrient addition rates in soils with varying subsoil P and K status to determine critical soil test values indicating a crop response. There has been little research conducted to optimize product choice, application strategy and product compatibility when nutrients are co-located. This project will deploy a combination of field, glasshouse and laboratory studies to explore these issues and develop comprehensive deep placement guidelines for growers across the northern grains region. There are a variety of fertilizer products (granules, liquids, organic materials) available in the market that can supply a specific nutrient (e.g. P) or a combination of nutrients, with the latter increasingly being considered in situations where multiple nutrient limits have been identified. There is a clear need to develop better guidelines for industry that identify the most effective fertilizer product and form to overcome a specific subsoil constraint and maximize crop responses – both in the target crop and as a residual benefit in subsequent crop seasons. This project will determine the most effective fertiliser form (granular, liquid, suspension) and the most effective product formulation (e.g. calcium phosphate, mono and di-ammonium phosphate, organic) for achieving crop responses when applied in subsoil layers to address a particular nutrient constraint. It will also explore the impact of fertilizer application method (tines, discs, zonal tillage, direct high pressure injection) on crop recovery, with key trade-offs involving the amount of soil disturbance and potential moisture loss/seed bed roughness with the volume of nutrient enrichment, the cost of ground-engaging equipment, horsepower requirements and reliability of performance under different moisture conditions and soil types. The project will also determine the compatibility of components in fertiliser blends (NPKS) designed to overcome multiple nutrient constraints in subsoils. These products are typically applied together in spaced bands and applied at high rates consistent with infrequent deep placement opportunities.
UA00159 - Improving wheat yields on sodic, magnesic, and dispersive soils°	This five-year project is led by the University of Adelaide (Prof. Glenn McDonald) and is a collaboration between research organisations in WA, Victoria, NSW and Queensland. It is a multidisciplinary team that brings together plant breeders, soil scientists, plant physiologists, agronomists and crop geneticists. The purpose of the work is to develop strains of wheat with improved tolerance to a number of stresses associated with sodic soils, which wheat breeders can use to increase wheat yields in the future. It will involve a network of national trials to evaluate performance of different varieties of wheat on sodic soils. A crossing and screening program among the superior lines identified will then be conducted to combine the desirable traits into elite lines. The project will also develop genetic tools to help wheat breeders select for tolerance to sodic soil.

Updated nutrient response curves in the northern and southern regions (UQ00082)	Soil testing is a key strategy in the efficient use of expensive fertilizer and other nutrient inputs, ensuring that the mix of nutrients applied match the fertility status and crop demand for the likely seasonal conditions. However, for soil testing to be effective in both these roles there needs to be a well-documented relationship between the soil test result and the likely response to applied nutrients. An analysis of the available soil test-crop response information in the Better Fertiliser Decisions (BFDC) database conducted at the initiation of the More Profit from Crop Nutrition II (MPCN2) program identified gaps that existed for key crops, soils and regions. The majority of these gaps related to (i) crops that are either new to cropping regions and/or occupy a relatively low proportion of the cropped area (e.g. grain legumes broadly and oilseeds in the northern region); (ii) emerging nutrient constraints (like potassium [K] and sulfur [S]) that have previously been adequately supplied in soils with moderate clay contents; or (iii) to issues associated with changing profile nutrient distributions resulting from a combination of reduced tillage and fertilizer management strategy (e.g. especially elements with limited mobility like phosphorus [P] and K). While some of the initial projects funded under MPCN2 have been targeted at these gaps in knowledge, the on-farm trials run with grower groups/consultants have not been as effective as hoped due to a number of factors. These include (i) the relatively low frequency in the crop rotation and the narrow planting windows of the target crops, reducing the number of site-years of data from the trials established; (ii) the need to revisit response relationships in the 'well researched' species like wheat to account for issues of changing profile distribution and fertilizer application strategies (e.g. deep placement to address subsoil depletion, or accounting for subsoil enrichment due to long histories of fertilizer application); (iii) poor choice of experimental sites, due to a combination of inadequate pre-sowing soil testing and choice of sites based on the quality of the research collaborator rather than the likelihood of the site being fertilizer responsive; and (iv) an inability to adequately cover the range in seasonal conditions and crop yield potentials that reflect crop nutrient demand and fertilizer recovery in relatively short 3 year projects. This project will ensure that by 2020, growers and their advisers in the northern and southern regions will have access to updated nutrient response data in the BFDC database for a wide range of crop species and nutrient responses. This will be achieved by running a smaller number of intensely managed sites across the Northern and Southern regions, with sites chosen on the basis of very specific characteristics (including in-field variability and a vertically stratified assessment of nutrient availability. Tighter control of agronomic practices and crop sequences and a more detailed approach to soil and plant sampling will ensure each experimental data set can be interpreted in terms of fertilizer recovery, crop response and the economics of fertilizer use. While this approach will necessitate a less geographically dispersed series of experiments, it will allow a tighter focus on the gaps in soil test-crop response relationships the project is trying to address. Each site will have an establishment year, where a range of fertilizer rates and tillage practices are used to establish a range in soil test values for the nutrient in question, with crop response related to the performance of an unfertilized control. In subsequent seasons, soil sampling will redefine the soil test range for the next crop season, and a soil test-crop response relationship can be derived for that site-season combination. Extrapolation beyond these sites will be achieved by growing a benchmark species (e.g. wheat or sorghum) in each season, along with the target species.
Fertiliser form and soil interactions when applied in high concentration bands (UQ00086) Post-Doctoral Fellow aligned UQ00063	As reliance on fertilizer grows and an increasingly complex mix of nutrients are required to achieve water limited yield potentials, the interactions between product choice, fertilizer placement, moisture dynamics and crop acquisition are increasingly determining the profitability of fertilizer decisions. Recent examples include the demonstrated need to place phosphorus (P) and potassium (K) deeper in the soil profile, to address nutrient depletion in subsoil layers where prolonged root activity and nutrient acquisition occur but where nutrient replenishment is limited. GRDC has substantial current investments quantifying crop responses to applications of P and K fertilizers into the depleted subsoil layers (UQ00063) and the residual value of those deep applications (UQ00063 extension); optimizing the P and K application strategies, working with issues such as rate*band spacing interactions, the degree of soil disturbance required during deep placement and the pros and cons of liquid and granular formulations (UQ00078); and developing soil test-crop response relationships to fill gaps for less well researched combinations of crops and nutrients in the Better Fertilizer Decisions for Cropping database (UQ00082). These projects are all strongly focussed on testing crop responses under field conditions in growers fields, and distributed across the major production centres in Qld and NSW (in addition to Vic and SA in the case of UQ00082).

	Whilst there is considerable field research activity addressing the issues of placement of P and K, there has been very little mechanistic research into the fertilizer – soil interactions that underlie effective application strategies. Specific questions are arising around the most effective form of P fertilizer to maximize P bioavailability in the short and longer term (e.g. mono-calcium and mono or di-ammonium phosphates – MCP, MAP and DAP, respectively) when applied in bands in soils with differing clay contents, pH, P sorption capacity and Ca status. Anecdotal evidence from UQ00063 has suggested that MCP may only be effective as a deep P source in specific soil types, but ineffective in others. While MAP seems to be providing more consistent benefits, little work has been undertaken with other P sources or forms (e.g. liquid formulations such as ammonium polyphosphate or MAP suspensions). The limited previous research published in the literature that has investigated fertilizer reaction products has generally focused on single soil types. However, our field evidence demonstrates that the fertilizer behaviour and availability varies markedly between soils – the current research will address this important knowledge gap. Industry need clear guidelines on the suitability of different P products for use in specific soil types, and that information requires a more in-depth understanding of the soil-P fertilizer interactions in key soil types. The other emerging research gap also involves banded fertilizer applications, but in this instance is focussed on understanding the interactions between fertilizer products when applied in mixtures at high in-band concentrations. This is particularly relevant when deep bands are being applied in fields to address multiple nutrient deficiencies (e.g. of P and K), when growers are using P- or N&P- enriched K bands to encourage root proliferation and enhance crop recovery, or when growers are combining N applications with deep P/K banding to reduce the number of passes during fertilizer application. There are already examples from UQ00063 where the addition of KCl to deep-banded MAP/ammonium thiosulphate blends resulted in the complete elimination of substantial P and S responses in the year of application and a subsequent crop season. Improved guidelines for growers, advisors and the fertilizer industry on the limitations of potential co-location of nutrients in concentrated bands will rely on an improved understanding of the mechanisms driving such responses.
Improved sampling methods to better predict nutrient availability and supply for soils in the Western region (CSP1801-004RTX)	The stated outcome for this research proposal is "By December 31, 2020, a new methodology(s) for collecting soil samples will increase the accuracy of determining plant available nutrients in Western Region soils and result in growers making better fertiliser decisions." In this project we will work collaboratively with other projects examining nutrient use efficiency in WA (particularly 9175716 and 9175701) to deliver a standard method for collection of soil samples, based on soil type and farming system. Specifically in this project, we will examine previous research and data sets where variation in nutrient availability has been quantified either spatially or with soil depth for specific crop management practices. Where gaps exist in available data, we will set up and monitor appropriate agronomic trials, in collaboration with activities under 9175716 and 9175701, to generate data on the impact of crop management practices on nutrient distribution, and subsequent crop growth. We will also use crop growth models to determine the value of nutrients of various depth distributions in a seasonal context (including available soil water at sowing). In collaboration with activities under 9175716 and 9175701, we will engage with farmer groups, advisors and leading farmer groups, advisors and leading farmers, and soil sampling providers to ensure that our findings are relevant and rapidly disseminated within the farming community.
Nutrient re-distribution and availability in ameliorated and cultivated soils in the Western Region (DAW1801-001RTX)	The area of soil used for crop production that is being modified with mechanical soil amelioration is increasing rapidly in the Western Region; however, there are significant knowledge gaps for nutrient management. Mechanical soil amelioration is being adopted to ameliorate soil water repellence, soil compaction, herbicide resistance and soil acidity, and in some cases, more than one of these constraints occur within a paddock. Mechanical soil amelioration is being completed with mouldboard ploughs, rotary spaders, disc ploughs, and deep rippers with and without inclusion plates. All of these mechanical approaches introduce spatial variation in soil nutrient supply, root growth, or both. However, at present, there is a significant knowledge gap in how crops utilise soil nutrients and respond to nutrients applied as fertilisers after amelioration. This project will deliver new knowledge to improve nutrient management on ameliorated soils through a program of research that integrates different spatial scales, and extension. The project includes work on soil N processes and the fate of soil organic matter in soils that have been treated with mechanical soil amelioration. This work, in combination with a detailed study on the effect of a change in the spatial distribution of soil nutrients on root growth and soil water uptake, will be used

	to guide the design of subsequent field experiments, and extrapolate results from these. Field-plot experiments will be used to examine whether mechanical soil amelioration interact i.e. does the plant-availability of soil nutrients change after mechanical soil amelioration? And, does nutrient use efficiency change? The knowledge gained from this work will be fused with paddock scale experiments that utilise natural variability in soil nutrient supply to elucidate the factors that determine yield response to a nutrient. This integrated approach to research will deliver the knowledge base required to improve nutrient management on ameliorated soils. This collaborative proposal brings together the capacity to deliver the research and extension required. The skill base of the group is broad and deep, and includes: field crop nutrition, soil N processes, geostatistics, decision support, spatial modelling and crop simulation modelling. The team has a proven capacity to identify the research questions that need to be addressed to improve profit, complete laboratory, glasshouse and field experiments and simulation modelling. The team also has the capacity to deliver a project with integrated research and extension. The project will deliver extension to at least 300 growers, advisors and industry professionals each year. Extension will be delivered at field days, research updates and workshops in collaboration with PROC-9175173 and 9175172. This project will operate as part of a research program in collaboration with PROC-9175173 and PROC-9175172, under the umbrella of the Western Region Nutrition Program, facilitated by SoilsWest. Assoc. Prof Hoyle is allocated 0.05 FTE for the coordination of work between this proposal and PROC 9175171 and 9175172.
Economics of ameliorating soil constraints in the northern region: Spatial soil constraint diagnoses PROJECT A (UOQ1803-003RTX)	Approximately 75% of Australian soils have single or multiple constraints that limit agricultural productivity, and in the Northern Region, these commonly take the form of sodicity, acidity, salinity, and compaction. Project A is part of an integrated body of work that will provide growers with tools to identify a) what constraints are present and where these occur (Project A); b) what management strategies can be used to increase yield (Project B) and profitability (Project C); and c) how strategies can be effectively communicated and demonstrated to growers (Project D). Specifically, Project A will use a global archive of Landsat satellite imagery in combination with the methodology developed in the GRDC project UQ00081 to produce paddock scale yield maps. In UQ00081, remote-sensing data was combined with ABS SLA-level yield statistics data to enable prediction of yield for any location and for any year with remote-sensing data. This methodology will be extended to produce yield maps at a paddock scale across the Northern Region. These yield maps will then be integrated with landscape attributes (DEM) and soil maps (SALI and SALIS) to provide growers with a best-bet prediction of where constraints occur (location and depth), and what constraint is present. This framework will be delivered as a web-based tool (ConstraintID), and demonstrated to growers and advisors in collaboration with Project D. Once constrained areas have been identified, proximal soil sensing techniques (EM38, Dual EM38, and the techniques developed by DNR00008 and US00087) and diagnostic soil kits will be developed to identify the type of constraints present. Proximal techniques will be used to provide detailed maps of the spatial variability of soil constraints and where these occur across the experimental sites established by Project B, and help demonstrate these techniques to growers. Simple soil kits will also be developed to allow on-site soil analyses by growers to diagnose what soil constraints are present. It is envisaged that georeferenced soil test information will then be fed back into the web-based yield mapping tool to help growers diagnose soil constraints (type and severity). The ability to use this information to manage constrained areas using variable rate techniques and site-specific soil and nutrient management methods will also be trialled on the experimental sites established by Project B. This experimental work will form the basis of decision frameworks that will allow growers to identify areas with the greatest potential to respond to precision amelioration / nutrient management techniques, and when it may be possible to move to higher value crops following amelioration. These frameworks will be validated using the bioeconomic framework developed in Project C (including modelling of the temporal yield response using APSIM). The project team that has been assembled contains skilled technical experts in soil constraint identification and mapping from UQ, DSITI and NSW OEH. The group has a proven track record in the use of automated mapping and proximal soil sampling, having previously developed methodology

	capable of manipulating Landsat imagery to produce yield maps, and use proximal soil sampling to identify and characterise constraints. The group brings access to state of the art research facilities, has staff based in key regional locations with intimate knowledge of field sites, growers, soils and production systems, and has extensive experience in the coordination, management, monitoring, and evaluation of projects for the timely delivery of high quality outputs. The group is highly experienced in the communication of project outcomes to a diverse range of stakeholders, and is skilled in the tailoring of key messages for different groups. The proposed budget of $897 955 with in-kind support of $1,325,372 to be provided by the partner organisations thus represents significant value for money for growers.
Economics of ameliorating soil constraints in the northern region: Soil constraint management and amelioration PROJECT B (USQ1803-002RTX)	Soil sodicity (in both surface and subsoils) can significantly reduce grain production (>$433M in the Northern Region alone) through reduced infiltration of rainwater, poor crop establishment and limitations to root growth and functions which subsequently restrict the crops' access to soil water and nutrients. Actual grain yield on sodic soils is often less than 50% of potential yield. Acidity, salinity and compaction further constrain such environments yield potential, which is why this project focuses on sodicity as the major constraint with the others as compounding and interacting factors. Specifically, this proposal will develop and demonstrate improved management strategies for these soils in the northern grain growing regions of Australia. The project will work with grain growers, grower groups and consultants to identify the best management options for the range of constrained soils across the different cropping systems the northern region. This project will develop a decision framework that will improve the long-term profitability of grain production on such soils. A range of extension activities will be carried out throughout the project ensuring that the project delivers information to the industry through Project D. Ideally, extension will focus on improving skills of advisors, consultants and growers to identify, diagnose and manage problem soils. Uniquely, the project intends to build into the decision tool capability for rapid determination of soil stability based on cheaply measured soils factors. This will provide soil-specific and spatial capability to aid management. Working closely with Project C, economic management thresholds will be determined; that is, where to amend constraints, where to adapt to constraints and where to apply a mixture of both at the spatial scale with an associated risk. The project seeks to improve the long-term profitability of grain production by collating and reviewing the existing information regarding traditional and new/novel management options. The project will integrate learnings from field experiments and communicate with growers and advisor communities in collaboration with the Coordination and Communication project team.
Economics of ameliorating soil constraints in the northern region: Economics of adoption PROJECT C USQ1803-003RTX	The project anticipates delivering an economic assessment framework and tool for growers and advisors to evaluate the economics of amelioration options against soil constraints at the paddock and farm scale. The tool, based on a digital platform that will emulate similar technologies created by USQ and creates the opportunity for adding further research learnings over time from on-site soil samples. USQ can offer considerable leverage opportunities in the soils, technology and economics research area. USQ is already developing a web-based soil economic tool (HSG) and jointly supporting the Qld Government with a financial analysis of farming systems tool (AG Margins: http://agmargins.net.au/). Further USQ is able to leverage from similar soil work for the cotton industry (Increase yield through improved management of soil constraints in cotton farming systems) and through its work as a research partner in the $40m CRC for high performance soils designed to help farmers bridge the gap between soil science and farm management by giving them the tools and knowledge to make decisions on complex soil management issues. The proposed GRDC soils project will also make use of existing access to APSIM and previously mentioned tools (e.g. HSG and AG Margins), as well as those that have previously received investment from GRDC (e.g. On-line crop production model Yield Prophet). The aim where possible is to integrate existing tools and data from project A & B in supporting the building of the new economic assessment framework. The project will look at investment cost/hectare separate to normal input costs. This allows for a separate cost evaluation of amelioration to allow it to be classed as a farm investment. This may allow for cost to be depreciated over time. Importantly required timeline for anticipated changes is identified and the outlook of residual benefit (treatment stability). This cost will be compared to returns from current yield vs potential yield over time. The investment in dollars can be divided by the

	expected yield differential multiplied by the market price over time to show if anticipated returns is greater than cost. Such a bio-economic framework, will look to deliver simple cost benefit scenarios to determine break-even point or payback period for farmers and agronomists in the paddock.
Economics of ameliorating soil constrains in the northern region: Program co-ordination – communication, extension and evaluation PROJECT D UOQ1803-006RTX	Approximately 75% of Australian soils have constraints that limit agricultural productivity. In the Northern Region, these commonly take the form of sodicity, acidity, salinity, and compaction. These constraints may occur singly or in combination, at the soil surface or in the subsoil, and they tend to occur heterogeneously across paddocks and properties. Project D is part of an integrated body of work that will provide growers with much needed knowledge and capacity to enable them to identify what constraints are present on their properties and where these occur (Project A), and what management strategies will alleviate these constraints to increase yield (Project B) and the profitability of these strategies (Project C). Project D will coordinate and guide the operations of Projects A, B, and C to enable high quality science, communication and collaboration between the groups and maximise synergies and benefits between projects. It will also be responsible for coordinating the communication, extension and evaluation of the whole program's results to growers and advisors to facilitate learning, and ultimately, practice change towards more profitable management of soil constraints in the Northern Region. Program coordination and internal communication will be overseen by a committee that will develop and annually review a 'Coordination and Collaboration Strategy' to ensure an integrated program. This strategy will ensure clear and consistent internal communication so that activities across the projects are well aligned with effective integration and communication between Projects A, B, C and D. To do this all projects will need to be aligned to the overall program goals hence the strategy will be developed and negotiated by the committee. This committee will include the leaders of Projects A, B, C and D, and a GRDC representative. This will ensure the projects remain on track and successfully deliver project outcomes. Internal communication will include face-to-face annual meetings with all program staff (A, B, C and D), and quarterly teleconferences with the leaders of Projects A, B, C and D. Peer review will be a pivotal component of annual team meetings to achieve rigorous critique, analysis and continuous improvement across the whole program. A negotiated MERI plan will ensure the program is thoroughly monitored, evaluated, adapted as needed, with impacts reported across the life of the program. External communication and extension will coordinate, collate, develop and deliver the key project messages. A communications plan will outline the details of a theoretically informed extension strategy which will be used to ensure the information and insights generated from Projects A, B and C (and from past research) are packaged and extended, via multiple platforms, to increase awareness, facilitate learning, and so help growers and advisers to develop and implement strategies to profitably manage soil constraints on their own farms. This strategy will use focus groups, action learning workshops, field days, broader extension material and surveys. An Evaluation plan and log frame will be developed in negotiation with the whole team, to guide individual projects' and whole program activities and clearly delineate the impact of program.
Seeding systems to improve cereal crop establishment on heavy textured soils - West (CFG1802-001SAX)	This project will demonstrate to growers the most profitable tyned seeding system for improved cereal crop establishment on medium to heavy textured soils in the eastern wheatbelt. This will be achieved by establishing a trial site to assess a range of furrow closing options (4) and down force pressures (2). The results will be compared to standard practice of growers within the region. The project aims to highlight the need to select the best furrow closing system on heavy textured soils to improve crop emergence and grain yields. Taking a more than single year approach will account for varying seasonal conditions.
Ripper Gauge Demonstration sites Albany port zone - West (SCF1802-003SAX)	The Albany port zone, through the GRDCs Regional Cropping Solutions Network (RCSN), have identified that soil amelioration through deep ripping and controlled traffic farming (CTF) to manage issues such as non-wetting topsoils, compaction, waterlogging as a major priority to farmers in the region. Compaction is affecting up to 75% of WAs agricultural soils and conservative estimates of the costs, through lost production, are approximately $333m annually (Bennett, 2014). Subsoil constraints have also been identified as the highest priority by the Stirlings to Coast Farmers (SCF) R & D committee in 2017. The Gillami Centre and Southern Dirt have also rated the issue highly. The potential gains from removal of soil constraints are massive in the high rainfall zones. This is the main reason SCF members have so much interest in ameliorating subsoil constraints. SCF members

	have a strong history of investing money to ameliorate soil constraints in the last 10-20 years. Spreading and incorporating clay plus annual lime spreading are now a regular component of SCF member budgets. The SCF will collaborate with two other grower groups, Southern Dirt and Gillamii, to establish four deep ripping trial sites in the Albany Port Zone. Southern Dirt will manage two trials in the north of the Albany port zone and SCF will manage two trials in the southern APZ with assistance from Gillamii. The machinery required for each soil type and site may be different because we need solutions that are designed to alleviate the major soil constraints in that environment. DPIRD researchers will provide technical advice and assistance to the project on an in-kind basis. The main objective of the project is to test which types of machinery are best suited to different soil types across the Albany port zone. This trial work will also promote the benefits of Controlled Traffic Farming methods by demonstrating the potential yield gains from removing subsoil compaction to farmers across the region. We will also demonstrate how easily soil can become re-compacted after a ripping treatment. The ripping gauge trial sites will be an important tool to show farmers real-life examples of compaction and the negative effect on crop yields. An economic analysis will also be undertaken, of the impacts that each deep ripping machine has on farm productivity and, most importantly, continue to measure this difference for three years after treatment. Analysis of the yield gains or losses compared to the untreated control is simple to calculate and will be converted into dollars per hectare ($/ha). Grain quality and grading will be confirmed by CBH in-kind testing and a reference price can be taken from the day of harvest. The trial results will be widely disseminated through extensive grower group networks across the APZ, the support of other grower groups and researchers in the region. The three grower groups directly involved in establishing the trial sites have excess of 800 members spread over the Albany port zone. During the three-year trial period we expect to reach each of these farm businesses through the various extension activities. Additional farmers in the port zone will be reached via print and social media. We will aim to have an article outlining the project published in either the Farm Weekly or Countryman which is distributed state wide. We would like to collaborate with grower groups running ripping gauge sites, from other port zones in WA. This project represents excellent value for money for the GRDC investment proposed. The total budget (total cash and in-kind cost) is estimated to be $224,100 over 36 months, including $61,400 of in-kind contributions from SCF and other grower group members and project partners.
Ripper Gauge Demonstration sites - Esperance Port Zone SEP1802-004SAX	The practices of soil amelioration (deep ripping) and controlled traffic farming can be confusing for some growers due to soil variability and varying options for treatment. There is indecision as to what treatments suit what soil types, and what their economic benefits are (if any) in the short, medium and long term. Also, combined approaches to ameliorate more than one constraint can be worthwhile, but there are still some soil types that people are nervous about touching due to associated risks (such as hostile subsoils and erosion concerns). Strategic tillage practices have also been found to compact again over time following amelioration, often and greater levels than prior to treatment. Currently, the solution is to repeat the deep ripping process every few years, with the period between deep ripping dependant on the soil type and amount of wheeled traffic on the paddock. This is a costly repetitive process that may become unsustainable in the long term as soils become compacted to greater depths with successive tillage treatments and larger/heavier machinery. This project aims to evaluate and demonstrate the benefit of soil amelioration across a wider range of soil types that are common to the WA grain growing region. Demonstration sites will be established at 4 locations in the Esperance Port Zone to fill the gaps in knowledge of economic return from the amelioration over time. This project will link in with other groups in Western Australia working on the same topic. SEPWA will work in closely with Ravensthorpe Agricultural Initiative Network (RAIN) and the North Mallee Farm Improvement Group to ensure priority soil types in the Esperance port zone are covered. As a result of this project, growers will have an increased awareness of the benefits of amelioration

	and also controlled traffic practices the give the greatest benefit and longevity for the major soil types of the region.
Using soil and plant testing data to better inform nutrient management and optimise fertiliser investments for grain growers in the southern region (ASO1806-001RTX)	We have brought together a diverse team with complementary skills and capacity to deliver this project which will highlight to growers and advisers the benefits of soil and plant sampling and other nutrient management practices to better inform nutrient investments. This team includes: Agronomy Solutions (Dr Harm van Rees&, Dr Sean Mason0, CSIRO (Dr Rick Llewelyn & Dr Therese McBeat) Landmark, Hart Field-Site Group (Dr Sarah Noack), AgCommunicators, Australian Precision Ag Laboratory (Dr Ryan Walker). Our team have developed a comprehensive extension plan which includes workshops, field walks and field research which will be delivered in a way that encourages practice change and adoption of nutrient management practices. Throughout the life of the project we will critically assess the economic results of the growers participating in the demonstration against the initial economic analysis. Our research team and accredited lab and agronomists will ensure we collate accurate information and translate this into communication and extension outputs such as workshops and field walks. Our program will involve approximately 100 growers across South Australia and Victoria across 2019 and 2020. A grower group in Tasmania will be utilised to expose Tasmanian growers to the project. An interactive Soil and Plant roadshow, which brings experts to the regions, with hands on activities will be geared at driving practice change. The demonstration program will total 600 paddocks across the southern region, aiming at implementing 300 strip trials, installing confidence in the adoption of soil testing. These strip trials will be thoroughly investigated through delivery of yield maps, satellite imagery, plant tissue sampling and biomass cuts. The proposed plan results in 4,800 soil tests annually, totalling 9,600 through the life of the project. This will result in testing of a total of approximately 100,000 individual analyses. Landmark's extensive network of agronomists and growers gives the project a sound platform to deliver the demonstration sites across the southern region. Hart Field Site Group and other farming systems groups will undertake strip trials in the vicinity of the field sites, allowing project exposure through their networks. Our strategic partnerships ensure we gain access to grower members, agronomists and industry across the southern region. Each of our partners has agreed that we can utilise not only their networks but their existing communication platforms such as their social media pages (Facebook and Twitter), e-newsletters and websites. We have estimated that we have a combined distribution database of more than 20,000 individual growers, agronomists and industry in the southern region. This contribution will add great value to the communication outputs proposed by GRDC. We have also developed a clear communication strategy ensuring all project outputs are communicated at peak times aligning with periods of peak soil testing or when information is of most benefit. We have ensured our outputs will be promoted across delivery platforms such as existing GRDC channels i.e. With the Grain, Ground Cover, social media and traditional media.
GRANT: A holistic approach to seep management for preventing land degradation in the landscape (MSF1812-002OPX)	The National Landcare Program aims to protect, conserve and provide for the productive use of Australia's water, soil, plants and animals and the ecosystems in which they live and interact, in partnership with governments, industry and communities. Protecting and restoring our soils, water, vegetation and biodiversity underpins the productivity and profitability of agriculture, fisheries and forestry industries and will assist these industries to become more resilient and able to effectively respond to changing climate, weather and market conditions (such as the need to demonstrate environmental credentials to access markets). Sandy seeps have become a significant issue on the dune-swale landscapes in the dry areas of SA and Victoria, making productive farming soils saturated, untrafficable, and weed infested, eventually becoming saline and prone to erosion. Seeps have become more evident in the last decade, due to farming system changes coupled with high rainfall periods. Farmers identify that poor crop water use on the sand dunes along with effective summer weed control and greater retention of soil moisture has led to the expansion and formation of seeps lower in the landscape. This NLP project led by Mallee Sustainable Farming aims to apply a 'tool box' approach to seep management by: 1. Using new and existing remote sensing tools to identify areas at high risk for seep expansion;

	2. Preventing seep formation by demonstrating high water use options for different systems; 3. Categorising seep severity and applying the best treatment options to remediate the seep area.
Re-engineering soils to improve the access of crop root systems to water and nutrients stored in the subsoil (Western Region starting 2019). DAW1902-003RTX	This investment will address multiple interacting soil constraints within the crop root zone through strategic combinations of soil amelioration techniques or from soil profile re-engineering. Soil profile re-engineering is the fundamental redesign of soil profiles to achieve dramatic improvements in critical measures of cropping performance including water and nutrient use efficiency, grain yield and grower profitability. Multiple interacting soil constraints are reducing Plant Available Water (PAW), grain production and long-term profitability of crops across most of the 12 M ha of sandplain soils in the medium-high rainfall zone (van Gool 2018) of the Western Region. Subsoil compaction, subsoil acidity and soil water repellence each occur over more than 50% of these sandplain soils, which mostly comprise of deep sands and texture contrast soils (sand over distinct clay or gravel horizon; duplex). About one-third have low soil water storage (van Gool 2016). These combined constraints result in shallow crop root systems (<30cm), poor access to subsoil water and up to a 50% gap between actual and potential grain yield (Betti et. al. 2018; Davies et.al. 2018; van Gool 2011). The effective rooting depth for unconstrained grain crops on deeper sandplain soils in WA is 150-250cm (Hamblin and Hamblin 1985; Hamblin and Tennant 1987; Hamblin et. al. 1988). Multiple interacting constraints and low plant available water result in lost yields with an estimated value of $1.2 Billion per year (Peterson, 2016). Current soil amelioration options (liming, deep ripping, spading, mouldboard ploughing) address one or more constraints to a depth up to 40cm. The potential yield benefits of addressing multiple constraints through complete soil profile re-engineering to a depth of 80cm is unknown. Soil re-engineering aims to increase plant available water so crops achieve 95% of rainfall limited yield potential. Soil amelioration has predominantly been adopted on deep sands and sandy earths with more limited adoption on sandy gravels and texture contrast soils. The 4.8M ha of sandy texture contrast soils present particular challenges as they can have a layering of both sandy and heavy-textured soil constraints and depth to the clay B-horizon can be highly variable. Developing diagnostic and targeted amelioration packages for these soils represents a substantial opportunity to dramatically improve grain production and profitability. The project will do this through: 1. Identifying the most profitable and long-lasting soil amelioration and amendment strategies for managing multiple interacting soil constraints. 2. Re-engineering the soil profile through a combination of deep soil loosening; reconstituting profile layers and deep placement of nutrients and soil amendments. If soil re-engineering could overcome the 1.0-1.4 t/ha yield gap (van Gool 2011) on 20% of the 12 M ha this would equate to a further $600-$840 million per year in yield benefits that would flow directly to grain growers. 3. Extension and upgrade of the recently released Ranking Options for Soil Amelioration (ROSA) financial model (Petersen et al. 2018) to incorporate the economics and benefits of re-engineering will be a primary output of this project. This tool is essential in helping growers understand the costs and benefits of soil amelioration and re-engineering strategies. Our current agronomy and farming systems research has been limited by often being undertaken on constrained soil or soils where only a single soil constraint has been addressed. Innovative high-risk soil re-engineering will provide a new increased yield potential that will underpin new agronomy and farming systems research in the future.
Increased grower profitability on soils with sodicity and transient salinity in the eastern grain belt of the Western Region. (DAW1902-001RTX)	The purpose of this investment is to explore and develop management options for cropping soils constrained by sodicity and transient salinity across the low rainfall eastern grainbelt of Western Australia. Interacting combinations of sodicity and transient salinity, often associated with high subsoil pH, ion toxicities (mainly boron) and poor subsoil structure, interact to constrain crop yields by reducing water extraction by crop roots (Hamza and Anderson 2003; McDonald 2006; Nuttall et al. 2003a,b; Rengasamy 2002). Growers across the estimated 2.5 million ha of sodic soils (van Gool et al. 2018; van Gool 2016) in the eastern grain belt of Western Australia are missing out on 0.5–1.5 t/ha of

	yield in their wheat crops (van Gool 2011, Mulvany et. al. 2018). Petersen (2015) estimated the impact of sodicity on lost crop production of at least $130 million per year. In the low rainfall eastern grainbelt, many growers attempt to profitability manage these constrained soils by opportunistically cropping them in better seasons or after fallow or by minimising costs and accepting lower productivity across all years (Kirk 2014; Nixon 2017). To improve the reliability and profitability of grain production on these soils growers require viable options to mitigate or ameliorate soil constraints (Kirk 2014; Paterson 2015). To capture missed yield crops need increased plant available water on these soil types. Combined approaches which improve water harvesting onto crop rows, targeted amelioration of the soil rooting zone, together with options that increase soil water in the root zone and reduce evaporative losses can improve crop water supply (Mulvany et al. 2018). Current evidence indicates these approaches could increase yields by 20-30% in high rainfall years and 40-140% in medium to low rainfall years (Mulvany et al. 2018). New applied research will evaluate the benefit of different options to improve water capture and availability, and use economic modelling to determine the profitability and reliability of such approaches. This investment will develop soil mitigation and amelioration options and combinations that increase crop available water supply and will generate data to enable a cost-benefit model to guide soil management decisions. National and international research, networking and potential future collaboration will be explored through several study tours, which, combined with the projects research outcomes, will inform future research opportunities.
High work rate 'plough and sow' technology for farm-scale sandy soil amelioration (South) (MSF1806-001AWX)	As grain growers reach the upper limit of production gains with existing agronomic practices and varieties, they are becoming more focused on addressing the soil constraints that inherently limit crop performance, particularly in production limiting sandy soils in the southern region. These areas are often under low rainfall where growers have fewer available resources to invest in costly amelioration practices such as clay spreading and spading. As a soil inversion alternative to high cost mouldboard ploughing, disc ploughing has generated considerable interest in recent years as it offers a low-cost approach to soil amelioration that can demonstrate effective outcomes using modified old plough technologies. However, in the southern region context, significant drawbacks have been identified including the low speed of operation (2-6km/h), one way ploughing constraints, not well suited to up/back GPS guided work patterns for paddock zone amelioration, partial soil inversion (30-70% burial) and limited strength of older plough frames originally designed to accommodate diameter disc blades now being adapted for deep ploughing with 30-36 diameter disc blades. In addition, the delays and difficulties in subsequent sowing into very loose soil profiles with very little residues lead to erratic crop establishment and significant risks of wind erosion. This GRDC Innovations Project will develop a plough and sow proof of concept prototype of a high work rate soil inversion disc plough that will have the capacity to simultaneously deep plough and sow a crop in a one pass operation. This will offer a significant upgrade in effectiveness and efficiency of the sandy soil amelioration operations by ploughing and minimise the risk of soil erosion that currently limits the adoption of existing technology. The prototype will be developed using innovative design solutions to improve the soil inversion performance of plough discs and incorporate a seeding capability in to a one pass operation. The design will be achieved in collaboration with the Agricultural Machinery at the University of SA and the Adelaide based industry partner John Shearer Ltd. The high work rate plough will undergo field performance assessments and validation in collaboration with Mallee Sustainable Farming and the GRDC Sands Impact project to demonstrate the capabilities of the prototype and quantify its performance against other soil amelioration practices.
Understanding how waterlogging affects water and nitrogen use by wheat (DAV000151) Ends June 2019	Waterlogging is recognised as a significant constraint to grain yields in the south-east High Rainfall Zone (HRZ) but development of management solutions is hampered by our inadequate understanding of the formation of waterlogging, its effects on soil and crop processes and consequences for productivity and profitability of grain production systems. The project is using a combination of field measurements and modelling to understand (i) where, when and to what extent waterlogging occurs in the dominant (texture contrast) soils of the Victorian HRZ and (ii) how waterlogging affects soil conditions, crop growth and functioning (particularly nitrogen and water uptake) and grain yield and quality. The knowledge will enable the development of management approaches to achieve higher crop yields and quality on waterlogging-prone soils. A literature review has been completed describing our current understanding of waterlogging and

	consequences for crop growth and functioning in the HRZ, including water and N uptake, grain yield and quality. This synthesis of current knowledge is informing the modelling and experimental activities in the project and the interpretation and communication of findings. Collaboration and data sharing has been established with Southern Farming Systems (SFS) to enhance the field and modelling studies and the communication of findings to industry. A unique and extensive dataset on soil water status across the HRZ that was collected through the SFS soil sensor network is being used to develop and test modelling systems to analyse and understand the development of waterlogging in space and time. The first stage modelling of water status of texture-contrast soils in the HRZ has been completed (using the CAT model) to assess the location, timing and extent of waterlogging in the region. The model outputs have been tested against field data from 36 sites that was collected by the SFS soil sensor network over the previous 2-5 years. Whilst still being validated, the model enables prediction of spatial extent and frequency of waterlogging at a much finer scale than previously available and is one of the important components in determining the economic benefit of intervention strategies. Experimental protocols have been developed to collect data on soil, plant and environmental parameters of relevance to waterlogging in field grown crops. Understanding of waterlogging processes has previously been hindered by the difficulty in obtaining important data under realistic conditions. This project is taking advantage of recent advances in sensing technology to record soil water and aeration status and crop root growth, in conjunction with established sampling and analysis techniques (details in attached document). Three field experiments were conducted to compare the effects of differing degrees of waterlogging on the soil and the crop (wheat). Two of the experiments were located on commercial properties that are part of the SFS soil moisture probe network and one at DEDJTR Hamilton adjacent to field experiments being conducted under DAV00141. The data, which was collected using a combination of electronic sensing technology and traditional sampling and analysis methods, is currently being analysed. Initial data suggests soil oxygen levels can drop dramatically during periods of waterlogging, potentially leading to rapid root damage and reduced plant growth. Preliminary results will be presented and discussed in late March at a meeting of the project team with the hosting growers, GRDC, SFS and DAV00141 project leader. Project background and early results from the project were presented to growers and advisors at a SFS field day in Glenthompson (September 2018) and to a breeding company (AGT) representative during a field visit at Hamilton (October 2018). There was considerable interest in better understanding waterlogging and in developing further options for managing it.

Issue No. 48 - Soil acidity is increasing as liming programs and rates are not keeping up with rates of acidification

<u>GRDC investments addressing this issue</u>

RSS00010 - Soil acidity is limiting grain yield – SA (ended June 2018)	Soil acidity has increased across South Australia agricultural areas, partly due to more productive farming systems. Key agricultural practices leading to increasing rates of acidification in broad acre areas include the removal of products, and increasing rates and inefficient use of nitrogen fertilizer. Surface soil acidification is now occurring on previously non-acid soil types of low buffering capacity. Sub-surface acidification is becoming more widespread in some areas. Approximately 20% (2,033,000 ha) of SA's agricultural land has surface soil acidity (0-10cm) or is considered acid prone and this is expected to double over the next 40 years. Liming rates have been well below the annual acidification on the acid prone areas. This project has supported the national effort to effect step change in the management of soil acidity across the Southern region by coordinating and delivering a South Australian component. The project aimed to increase awareness amongst farmers and agribusiness, develop tools and increase the liming rate. Key components included: 1. identification of barriers to lime use 2. establishment of project steering committee and state acidity committee 3. increased acidity awareness with advisers and farmer groups 4. development and improvement of decision tools 5. provision of acidity information and development of the web site

	https://agex.org.au/project/soil-acidity/ 6. support to regional activities including trials and demonstrations. As a result of the project growers and advisers more aware of critical pH levels, economic impacts, subsoil acidity and new techniques to manage acid soils. There is increasing soil testing of surface and subsurface pH. In recent years lime sales increased by 40% and in areas were acidity is emerging improved awareness and targeting of treatment. Treatment of soil acidity, mainly with lime, will result in better soil health, better use of fertilisers and higher production levels. The key recommendation from a SA perspective is that future projects will need a strong focus on emerging acidity (i.e. new areas where acidity is developing) and on treating subsurface layers particularly under a no till cropping regime. These are considered as priorities for both extension and applied research. These link well to key areas where more information or research was identified by various events which included: • subsoil acidity and amelioration • lime source comparison testing and quality • incorporating lime and lime movement under modern farming techniques • reducing N fertiliser/acidification practices • pH mapping and spreading • acid tolerance of lentils and beans
Soil acidity is limiting grain yield - Southern Victoria ° (SFS00026) (ended June 2018)	Acidification of cropping soils is occurring across South West Victoria. Soils are typically pH of 4.8 (CaCl2), with rising levels of aluminium and are acidifying at about 0.3 pH units every 10 years. Recent trial work conducted by Landcare groups show lime application responses for sensitive crops such as canola at pH levels previously thought to be non-responsive. Significant reduction in crop yields may be occurring without farmers and advisors being aware of the losses. The contributing factors to soil acidification under the current farming systems are well understood, as are the best practice management systems. The disconnect has been that adoption of these practises, of soil testing to depth to determine pH and development of appropriate management plans, which must include the appropriate application of agricultural lime where soil pH is less than the recommended targets, has been less than optimal. For such change in practice to be achieved a whole of industry approach was required and this project combined a reference committee, on-going education, extension and training of key private and government advisors/consultants who then support growers into the future. The industry reference committee comprised of representatives from government departments and private enterprise who have experience from the lime pit to the farm and of the administrative aspects including mining (of agricultural lime) and transport. The group revisited the major barriers to adoption of liming by growers and propose solutions to overcome them while at the same time considered additional challenges posed by the desired doubling of lime use. I This project has refined the recommendations for using lime on crops in the high rainfall zone of southern Victoria. It is part of a national project to address increasing soil acidity in the cropping industry. The project provided yield response data to include in a lime benefit model, create locally relevant facts on lime and soil acidification and assisted in co-ordinating complementary lime work on pastures, as well as creating a 'lime expert' residing within Southern Farming Systems.
N fixing break-crops and pastures for high rainfall zone acid soils (DAN00191) - ended June 2018	There is a lack of profitable nitrogen fixing break-crop options for low pH soils in the southern high rainfall zone (HRZ). There is a pressing need for a profitable legume rotation option. This project addressed three key problems cited by GRDC:1) the need to reduce reliance on fertiliser nitrogen; 2) managing herbicide resistance; 3) improving integration of livestock into cropping systems. Activities in Year 1 addressing the issues involved: (a) A project reference committee chaired by a GRDC Southern Panel member and with representatives from NSW DPI and Southern Farming Systems, CSIRO and Holbrook Landcare Network was established to consider the results from a review of past and current research of N fixing break-crops in the HRZ acid soil zones, and feedback from grower focus meetings and an online survey. This process (i) assisted in identifying factors limiting implementation of effective crop sequence management in the HRZ, (ii) identified research priorities, and (iii) guided the extension and

	evaluation plan; (b) An assessment of the yield potential and N-fixing effectiveness of pulse crops in regional NVT (National Variety Testing) trials in the HRZ assisted in identifying the degree to which plant breeders are contributing to solving the agronomic limitations identified; (c) A survey of paddocks of collaborating farmers was conducted with the aim of obtaining hard data to assist explanation of the farmers' N-fixing crop experiences. These paddock surveys identified potential biotic and abiotic handbrakes to N fixing break-crop growth and also collected seed of weeds believed to be resistant to herbicide. Soils on the survey farms were characterised to identify chemical and physical plant growth handbrake; (d) Information collected from the survey farms informed subsequent experimentation and assisted in the location of appropriate sites and collaborators for the on-farm trials. Commencing in 2015, two staggered crop sequence trials, each lasting two years, were established at two trial sites, one located in VIC and the other in NSW; (e) Soil collected from collaborating farms was used in glasshouse pot studies to identify locally relevant problems. The glasshouse studies focussed on factors that are difficult to assess in the field, e.g. the impact of different soil pH level on the residual activity of sulfonylurea herbicide and associated effect on root pruning and N fixation. Results from such trials are important for the management of any herbicide resistant weeds. The project had 150 farmers across these zones implementing a crop sequence management system incorporating N fixing break crops using clearly defined processes and agronomic guidelines that allowed managers to evaluate crop sequence performance.
Identifying low pH tolerance and effective rhizobia for wild Cicer to improve adaptation to acid sandy soils (UMU00044)	Current recommended chickpea (Cicer arietinum L.) varieties for 2014 (PBA Striker, PBA Slasher, Neelam and Ambar) are considered to be moderately resistant (PBA Striker) to resistant (PBA Slasher and Neelam) for Ascochyta blight,and adapted to both southern and western Australia conditions of low rainfall and short growing season. These varieties have overcome some of the abiotic and biotic constraints identified as limiting chickpea yield across Western Australia (WA). Current recommendations for chickpea across WA, confine production to sandy loam to clay textured soils with soil pH CaCl2 of 5.5 to 9. A DAFWA study of land capability assessment for production of chickpea leaves only 3 % of land in the south west agricultural region of WA considered to have high capability and 23.7 % to have fair capability for chickpea production (White et al. 2006). Assessment of soil pH across south west WA has 70 % of surface soils and 50 % of subsurface soils with pH CaCl2 below target levels of 5.5 and 4.8 respectively. In WA, at low pH (pHCaCl2 less than 4.5) aluminium, which is abundant in these soils, is solubilised releasing ions that are highly toxic to roots and bacteria. Aluminium toxicity inhibits cell division and reduces root elongation of plants. Severe symptoms of aluminium toxicity include brown stubby roots and decreased fine branching roots. Such effects on root growth not only impair nutrient acquisition by crops but may also limit symbiotic development as well as exacerbate drought by restricting access of roots to soil and stored soil water. A recent GRDC funded program has built on the collections of wild relatives of chickpea (wild Cicer) collected from south eastern Turkey. Whilst these wild relatives are not fertile with the domesticated C. arietinum L., the incorporation of traits from these wild relatives into the chickpea breeding program may allow chickpea to be produced in areas currently considered to have fair and poor capability. The wild Cicer collected is to undergo a wide program to phenotype traits which may be used to improve domesticated chickpea in breeding programs. This project will investigate the tolerance of wild Cicer accessions to low pH and sandy soils. These accessions then have potential to be included in the chickpea breeding program specifically to target acid sands including the areas where lupins are currently grown in WA.
Innovative approaches to managing subsoil acidity in the southern grain region (DAN00206)°	Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500-800 mm) of south-eastern Australia. Approximately 50% of Australia's agriculture zone (49-50 M ha) has a surface soil pH below optimal levels (pH < 5.5 in calcium chloride) and half of this area also has subsoil acidity. Soil acidification is accelerated by nitrate leaching under certain crop rotations, by the use of ammonium-based fertilizers, and by the regular removal of plant products, such as grain or hay. The major constraint to plant production on acid soils is aluminium toxicity which inhibits root growth even at very low concentrations. Smaller root systems limit nutrient and water uptake and increase

	the vulnerability of plants to periodic droughts. The surface application of lime is a common practice used to combat soil acidity. However, lime movement is very slow and take years to ameliorate subsoil acidity. In fact, at the current commercial recommended rates (2.5 tonne/ha in the high rainfall region in NSW), most of the added alkalinity is consumed in the topsoil with very little remaining to counteract subsoil acidification. Therefore, more aggressive methods are required to ameliorate subsoil acidity. This project led by Dr Guangdi Liwill investigate more aggressive ways, such as the deep placement of lime to the subsoil where it is most needed, with or without organic amendments to achieve more rapid changes to pH at depth. Other novel materials, such as calcium nitrate fertiliser, nano-lime and slicate-based materials, either separately or in combination, will be tested in different soils with different crop species in both controlled environments and under field conditions. Detailed studies are essential to increase our understanding of these plant-soil interactions and the mechanisms involved. The aim of the project is to manage subsoil acidity through innovative amelioration methods that will increase productivity, profitability and sustainability on farms. At the completion to this project, it is expected that at least 50% of grain growers at risk of significant yield loss due to subsoil acidity (10% or more of potential water-limited yield) will adopt innovative techniques and methods with novel materials and products as part of the most profitable cropping system for their farms to prevent or ameliorate subsoil acidity.
DAW00236 - Soil Acidity is limiting grain yield° (ending June 2019)	Coordinating the improved management of soil acidity in Western Australia and the GRDC Southern Region. This project led by Dr Chris Gazey from DPIRD will coordinate a national effort to effect a step change in the management of soil acidity in the Western and Southern GRDC regions. Soil acidity as a land degradation issue and a constraint to sustainable and profitable agriculture in Western Australia and Australia is widely recognised by growers, state and federal governments and R D & E funders. It is estimated that soil acidity costs WA agricultural producers $498 million per year in lost productivity. The contributing factors to soil acidification under the current farming systems are well understood, as are the best practice management systems. The disconnect has been that adoption of these practise, of soil testing to depth to determine pH and development of appropriate management plans, which must include the appropriate application of agricultural lime where soil pH is less than the recommended targets, has been less than optimal. The expected outcome of this project is a doubling of agricultural lime use in Western Australia from the 2010 base. For such change in practice to be achieved a whole of industry approach is required and this project will drive that change through the coordination of an industry wide working group, on-going education, extension and training of key private and government advisors/consultants who will then support growers into the future. The industry working groups will comprise representatives from government departments and private enterprise who have experience from the lime pit to the farm and of the administrative aspects including mining (of agricultural lime) and transport. The group will be asked to revisit the major barriers to adoption of liming by growers and propose solutions to overcome them while at the same time consider additional challenges posed by the desired doubling of lime use. It is envisaged that the group will propose 'mini-projects or investigations' to address the issues raised and these will form part of the activities of the project. The project aims to work closely with three grower groups, the Liebe group, West Midlands group and the Moora Miling Pasture Improvement group, to test and improve a range of tools. Existing and new information including data from lime trials, publications and recommendations will be used to develop or improve a collection of simple calculators which will enable growers to make informed decisions to ensure that they are confident about the management decisions they make including an understanding of the likely outcomes if the levels of soil acidity on their farms is not managed appropriately.

Innovative approaches to managing subsoil acidity in the Western Region (DAW00252)°	Soil acidity costs WA agriculture an estimated $500 million per annum in lost productivity. Soil acidity in the Western Region has continued to get worse despite a recent and encouraging increase in the rate of use of agricultural lime to more than 1.6 million tonnes in Western Australia in 2014. Approximately 70% of surface soils and, of greater concern, 50% of subsurface soils (below 10cm) are below the recommended Department of Agriculture and Food, Western Australia (DAFWA) minimum targets of pHCa 5.5 and 4.8. Subsurface acidity (low soil pH) reduces crop yield through the effects of toxic aluminium restricting root growth and therefore access to moisture and nutrients later in the season. Soil acidity is one of the few soil constraints to agriculture for which there is a profitable solution. However, treatment and management of subsurface acidity requires a more direct and aggressive approach than surface or topsoil acidity. The surface application of lime to treat soil acidity is becoming more common. For the WA wheatbelt, use of agricultural lime is currently around 60% of the annual application rate estimated to be necessary to treat existing and on-going acidification. Surface application of lime to treat subsurface acidity is a slow process and the delay is exacerbated in low rainfall farming systems dominated by a strong adoption of no or minimum tillage because of the reduced cultivation and mixing of the soil profile. For a number of reasons, strategic tillage has gained favour in recent years to bury herbicide resistant weed seeds, disturb and mix water repellent topsoil and incorporate nutrients that have become stratified. Increased tillage is the ideal opportunity to incorporate agricultural lime (and potentially other neutralising products or products that may assist the movement of conventional lime) to depth. This project will work with a number of grower groups, principally, but not entirely, in the Western Australian eastern wheatbelt to understand more fully and improve the effectiveness of tillage to incorporate lime to depth and if subsurface amelioration of acidity can be improved through the addition of organic matter or other novel products. The extent to which acidification rates might be able to be reduced through the use of 'alkalising fertilisers, such as calcium nitrate, will also be determined as a possible economically viable adjunct to traditional amelioration. Detailed controlled environment studies will be undertaken to test and develop recommendations for the field trial treatments. Detailed studies are essential to increase our understanding of these plant-soil interactions and the mechanisms involved. The aim of this project is to provide recommendations and information to growers on innovative methodologies to effectively and economically manage subsurface acidity. It is expected that at least 50% of growers at risk of significant yield loss due to subsurface acidity (10% or more of potential water-limited yield) will adopt the recommendations and manage this risk when it is cost-effective to do so, or apply other management options as part of the most profitable cropping system for their farm to increase productivity and/or sustainability on farms.
Incorporating lime to depth in duplex wheatbelt soils (FGI1801-001SAX)	The aim of this trial is to quantify the value of lime applications by different incorporation methods and compare the economic and agronomic returns of each. This trial will also include an application of a rapidly acidifying Elemental Sulphur to demonstrate how soils and crops will perform in 10 years into the future if no action is taken to maintain pH levels. Growers in the area vary the timing and rate of applications, with some applying a consistent amount annually, some applying a blanket amount on certain paddocks every few years and some applying varying rates as required depending on soil type and pH. Analysis will be conducted reviewing each application of lime rate and the effects between the different incorporation methods. The trial will compare the economic benefits of each treatment; as well as the potential loss of production and decline in pH through the acidifying treatment. It is pertinent for growers to evaluate the most practical and economical methods to manage soil pH in duplex soils. The results from each treatment will assist in building a database across various seasons; to demonstrate how different applications respond and influence soil pH across the profile. The effect on germination and development, plant nutrient uptake and yield on duplex soils will be recorded. This trial will highlight any complacency growers may have around soil pH maintenance, with the application of the acidifying treatment.

GRANT: Building the resilience and profitability of cropping and grazing farmers in the high rainfall zone of Southern Australia (SFS1812-001OPX)	The National Landcare Program aims to protect, conserve and provide for the productive use of Australia's water, soil, plants and animals and the ecosystems in which they live and interact, in partnership with governments, industry and communities. Protecting and restoring our soils, water, vegetation and biodiversity underpins the productivity and profitability of agriculture, fisheries and forestry industries and will assist these industries to become more resilient and able to effectively respond to changing climate, weather and market conditions (such as the need to demonstrate environmental credentials to access markets). Soil acidity is recognised as a significant regional constraint across the HRZ (previous GRDC report estimated this at $1.4 billion/yr). At a regional scale it is considered a high priority across most of the proposed project area. This NLP project covers the equivalent of the high rainfall RCSN area of the southern region. The information / activity will actively involve all relevant influencers and by involving various groups will be representative of the different farming systems. The CeRDI at Ballarat University (and their links to the High Performance Soils and Food Agility CRCs) will be developing and linking spatial information (local soil maps, soil test data, climate) with pH and lime results e.g. typical buffering and acidification rates based on soil type.
Spatial variability of soil acidity and response to liming in cropped lands (DAV00152 - D-BA)	Soil acidity is a major soil limitation in many cropping soils, particularly in higher rainfall areas. Liming the whole paddock with one rate to treat surface acidity, is the main method of overcoming acid soil problems. Growers have seen that this approach is not always economic. Horizontal and vertical variations in soil pH within a paddock may be a factor in this outcome. Growers have little information on spatial (horizontal and vertical) variability in soil pH to manage production limiting soil acidity. This is compounded by regional variations in soil pH that make it difficult for growers to use yield-response information for liming from outside their region. This project will provide information on within-paddock variation in soil pH and related soil properties, in different regions of the Victorian High Rainfall Zone (HRZ). We will map the horizontal and vertical variations in soil pH across 10 cropping paddocks in the HRZ in Victoria, to demonstrate to farmers how soil pH varies spatially and the economic benefits of targeting management of soil acidity to different zones within each paddock. Novel methods, such as geostatistics and field spectropscopy (e.g. Mid InfraRed), will be applied to 10 paddocks to model and map variations in surface soil and subsurface soil pH at the paddock-scale. Soil survey data will be used to relate paddock pH maps to different landscapes across Victoria's HRZ. Mapping will provide data on the distribution of soil acidity in surface and subsurface horizons and identify the risk of acidification. Lime test strips will be applied to low and high pH zones within each paddock to demonstrate how liming affects soil pH, other agronomically important soil properties such as exchangeable aluminium, and yield. These responses, together with other data, will be incorporated into a Variable Lime Benefit Demonstrator. The 'Demonstrator' will be used to to create spatial outputs for soil acidification risk, lime rates and economic benefits of targeting soil acidity. This will be complemented with two-case studies examining the effectiveness of lime improving crop yield and economic benefits from a whole farm perspective for typical rotations. Project findings will help growers to make more informed decisions on managing variability in soil pH and to supply input data for a GPS controlled lime spreader. The impact of this project will be to reduce the uncertainty currently present in lime decision making in the HRZ and enable farmers to better manage risks, both to farm profitability and to soil health from ongoing acidification.
Improving N Fixation in Lentils (AGC00006)	Ag Grow Agronomy and Research plan to design, implement, manage and report on a trial designed to gain a better understanding on nodulation in lentils. The trial would be aimed at improving N fixation through enhanced nodulation in lentils, and may have benefits in other pulses. Lentils are becoming a key part of the cropping rotation (12,000ha planned for this year in our clients alone) and give growers another option in growing a legume cash crop, managing weeds, disease and provide a nitrogen fixing opportunity. The Issue is that lentils nodulate the worst of our pulses in the area on acid soils. Being a relatively new crop in the area there is a need to investigate how they best nodulate and whether management practices or application techniques impact on their success.

	The trial will be designed around investigating new and commonly used inoculants and rates and management techniques that enhance the nodulation process in lentils. We would welcome suggestions working with other agencies such as CWFS/GOA and replicating this project over a wider region, so long as the budget was amended accordingly.
Improved Adaption of Barley to Acid Soils (UMU00046)	Soil acidity with high levels of toxic aluminium is the largest (in area) soil constraint limiting sustainable barley production in Australia. In the GRDC project, 'Improved adaptation of barley to acids soils', we have identified acid soil tolerant germplasm, developed diagnostic molecular markers and released the first acid soil tolerant barley variety, Litmus. Litmus has demonstrated yield advantages of up to 30% on acid soils. In independent agronomy trials, Litmus has yielded the same or better than Hindmarsh in 77% of trials on sites with an acid sub-soil (sub-soil pH Ca< 4.8) and in 70% of trials on sites with a neutral sub-soil (sub-soil pH Ca 4.8 - 6.5) in 63 trials. Litmus barley is also competitive with standard wheat varieties such as Calingiri and Wyalkatchem on acidic, sandy textured soils. However, when soil pH drops to 3.9, nearly all of the barley varieties are susceptible whilst tolerant wheat varieties still have some root growth. Further research is required to identify better acid soil tolerant barley and/ or to develop different gene combinations for improved tolerance. The appearance of blue aleurone in Litmus has become a significant hurdle for the adoption of this variety. Grain Trade Australia receival standards have a nil tolerance for blue aleurone grain in malt barley deliveries and a maximum allowance of 1 in 100 grains in feed barley. Blue aleurone in barley is very similar to late maturity alpha-amylase in wheat. It is controlled by genetics, but its expression is highly impacted by environmental conditions. Consequently, it is difficult for barley breeders to select against this trait based on phenotypic screening. The gene for blue aleurone is located on chromosome 4H and is closely linked to the acid soil tolerance gene. The widespread use of the acid soil tolerant gene in major breeding programs in recent years means that a high proportion of barley breeding material may also have the blue aleurone gene. This gene can be likened to a 'time bomb' in advanced breeding material and could result in significant economic losses for breeding companies and the barley industry. We need to take immediately action to develop diagnostic screening methods so that breeding programs can eliminate the blue aleurone gene from their germplasm and breeding lines. Progress has also been made in understanding the genetic control of other common soil constraints including salinity, waterlogging and boron tolerance in the last decade. However, there is a poor understanding of the relationship between these tolerances and improved yield in barley. Building on the success of the current barley acid soil tolerance project, UMU00038, this project aims to deliver the following outputs - 1. Diagnostic markers for enhanced acidity and alkalinity tolerance identified and validated across a minimum of 200 diverse lines from a set of elite barley germplasm followed by marker delivery to Australian barley breeding entities. 2. New knowledge about the interaction between tolerances to abiotic stresses including acidity, alkalinity, waterlogging, salinity and high boron. 3. Phenotyping protocol for the blue aleurone defect developed, validated and delivered to pre-breeders and breeding entities by 2018. 4. Germ plasm with non-blue aleurone xenia 3 locus (blx3) developed and tested in appropriate field conditions by 2018. 5. A cost-effective strategy for the elimination of the blue aleurone defect established and applied by March 2020.
Increasing the effectiveness of nitrogen fixation in pulse crops through development of improved rhizobial strains, inoculation and crop management practices DAS1805-004RTX	Recent expansion of the pulse industry is seeing crops increasingly grown in new and marginal environments that are responsive to rhizobial inoculation. In these situations, the viability of the pulse crop is strongly dependant on the availability of competent inoculant strains of rhizobia and best practice application of those rhizobia. Nitrogen fixation and yield is further influenced by crop management practices including the use of pesticides. This project will improve the viability and profitability of high value pulses (bean, lentil and chickpea) in marginal environments through the provision of improved inoculant strains, the assessment of inoculant delivery technologies in those environments and improved understanding of pesticide impacts on the symbiosis. To encourage practice change, the benefits will be demonstrated in twelve

	research and validation trials per annum across southern region in collaboration with key influencers of the pulse industry. Specifically, the program will: • Complete the evaluation and commercialisation of a new acid tolerant strain of rhizobia for bean and lentil. • Isolate, test and short list improved rhizobia for chickpea. • Provide an objective assessment of inoculant technologies across a range of marginal environments and sowing conditions. • Quantify the impact and develop strategies that minimise the impact of crop protection and herbicide applications on pulse N fixation. • Establish a regionally based inoculation technology field trial platform to support pulse extension programs. This project will build on the foundations laid in previous Nitrogen Fixation Program projects (DAS00128 and UA00138) that have identified limitations to N fixation in the region, selected elite rhizobial germplasm with strong prospects for commercialisation and built working relationships with pulse breeding and agronomy programs. The project will be delivered by applied N-fixation researchers from the South Australian Research and Development Institute and University of Adelaide, collaborating with southern pulse agronomy and farming system groups in SA and Victoria.
Simple Identification of On-Farm Lime Sources in the Western Region (LIE1803-002SAX)	A relevant, grower friendly factsheet will be developed, via desktop review and grower interviews, that will support growers to make decisions regarding the use of on-farm lime sources. The desktop reviews will be undertaken by Joel Andrews, Map IQ, and Rebecca Wallis, Liebe Group. Extension of the factsheet will be undertaken by the Liebe Group and Merredin and Districts Farm Improvement Group (MADFIG), and further through the RCSN networks.

Issue No. 10 - Access to local spray application training for local operators including in the border areas of Victoria and New South Wales to increase spray efficiency and reduce off-target damage

GRDC investments addressing this issue

Practical and applied workshops and communications to promote key messages and resources to maximise the effectiveness of spray applications in the Southern Region (BWD1803-005SAX)	Crop protection products are used extensively in the grains industry and are an important part of grain growing operations to control weeds, insects and disease and to maximise grain productivity and profitability. In recent times, media reports have highlighted several instances of off-target spray drift, causing significant damage to neighbouring crops. This project will provide training that improves the efficiency of spray applications to improve profitability on-farm which also promoting practices which minimise spray drift. By the projects conclusion in 2020, at least 180 growers and spray operators across the GRDC Southern region will have increased their knowledge base around effective spray applications. The project team, led by BCG, includes Bill Gordon (Nufarm), Jorg Kitt, Graeme Tepper and the Ag Excellence Alliance. The core project activity is a series of practical and applied workshops (a minimum of 24 across the life of the project) to be held across the GRDC southern region in areas identified as highest priority for this type of training. This prioritisation (output 1) will be based on historic access to similar training, areas where spray drift can have significant adverse consequences and/or areas identified by the project team as having a lower understanding of the subject matter. Workshop format will be based on an existing workshop format, developed and delivered by Bill Gordon and ongoing since 2012. This workshop in its current format, plus Bill Gordon's expertise is demanded by industry and is currently being delivered across Australian grain growing regions, including a Longerenong workshop in conjunction with BCG in January 2018. Topics covered will include sprayer set-up, product choices, weather conditions and other resources available to help reduce spray drift to ensure industry is using products responsibly and maintaining grower awareness. Continual refinement of the workshops will occur to ensure that the project team respond to local and or emerging issues.

	Communications will be leveraged to ensure that target audience members who cannot attend a workshop are still able to access project key messages and resources. Communications from this project will build on existing GRDC communications developed over the past five years. Including GRDC GrowNotes™ spray application manual, fact sheets: pre-harvest, pre-emergent and in-crop herbicide use. A wide array of communications will be used such as factsheets, GroundCover articles; media releases and interviews, webinars; podcasts; video and grower case studies but not limited to these only. Social media will be used extensively where appropriately to further promote the project.
Best Practice Spray Efficiency and Spray Equipment Setup Discussion Days (PROC-9175793) In procurement	Off target spray drift continues to be a key issue across many agricultural industries including but not limited to grains, cotton and horticulture. Despite best practice spray guidelines being available on the GRDC website, GRDC survey data indicates growers value face-to-face training especially for understanding how to practically implement the guidelines on commercial equipment

Issue No. 22 - Summer weed spraying in conditions conducive to inversions and/or with inappropriate spray quality (droplet size) creates a high risk of drift and off-target damage

<u>GRDC investments addressing this issue</u>

Evaluation of pesticide tank mix impacts on nozzle spray quality (UOQ1805-007SAX)	Services: To conduct evaluations in the wind tunnel facilities at UQ Gatton campus to determine the impact of pesticide tank mix on spray performance by: • Measuring the physical property parameters for a range of chemical active x adjuvant tank mixes • Spraying these mixes through various nozzles to measure droplet size and therefore determine a spray quality. • A technical report and extension material will be produced highlighting the relationships between tank mix and spray quality. Data is to be collected and analysed to ensure its suitability for future addition to the Australian Ground Spray Calculator.
Updating GRDC spray application resources (BGC1811-001SAX)	Resources, guidelines, nozzle charts, detailed Grow Notes, guides etc. being updated.
Air Inversion Modelling to Manage Spray Drift (MRE00002)	In earlier research (MRE00001) it was determined a relationship exists between turbulence and stability over the wheatfields region of Katanning in Western Australia and that the relationship can be correlated to hazardous spraying conditions; Research in MRE00002 examines the available data from the GRDC sponsored Profiling Automatic Weather Stations (PAWS) research towers which commenced in mid-2016 in the Clare Valley and Loxton region in South Australia. The South Australian data has been examined to determine the validity of models of inversion risk developed from GRDC sponsored PAWS towers around Katanning in Western Australia in 2013-2016. From 2017 data has been included from CRDC sponsored PAWS in QLD and NSW. The purpose of this research is to provide observational evidence supporting the validity of inversion risk modelling at different locations.
Understanding the value of Delta T for ground spray application with VC, XC and UC spray qualities (in procurement)	The use of Delta T as a spray decision parameter has been widely adopted by Australian ground spray applicators, despite its inception being related to the application of fine spray quality from aerial application. Delta T describes the relationship between temperature and humidity and its value as a spray parameter is two-fold, relating to the risk of evaporation of a droplet, as well as giving an indication of how well a chemical can penetrate and translocate within a plant. As growers have shifted to using VC, XC & UC spray quality due to regulatory changes in 2,4-D application, the impact of evaporation on these larger droplets is less. Consequently, the current Delta T charts (developed with fine spray quality) that recommend spraying to between 2 and 8

	have limited application. Further research is required to redefine the Delta T parameters when spraying with VC, XC & UC spray quality, ensuring that spray efficacy is maintained, and spray drift minimised. Studies will evaluate spray efficacy and drift potential over a range of Delta T values when using VC, XC or UC spray quality applied by ground application.