GRDC investments addressing "deep dive" issues

High Rainfall Zone Southern RCSN meeting, February 2020

GRDC R,D&E Strategy - "Minimise the impact of spring radiation frost on grain yield and stability"

GRDC R,D&E Strategy - "Minimise the impact of spring radiation frost on grain yield and stability"	Improved pre-season planning for frost Growers make optimal decisions on crop choice, placement and sowing in frost-prone cropping regions. Investment outcomes - 1.2.1. Growers have more accurate knowledge of the pattern and severity of frost events across the cropping landscape. 1.2.2. Growers and agronomists use knowledge of the frequency and distribution of frost/cold events to guide crop and variety selection, crop placement and planting decisions. 1.2.3. The grains industry has access to accurate information about the relationships between the severity and timing of frost events and their impact on yields of major grain crops. 1.2.4. Growers have accurate information on the impacts of stubble load and soil management on frost severity. 1.2.5. Growers have access to varieties with improved yield in frost-affected cropping regions. 1.2.6. Plant breeders have tools to effectively reduce the frost sensitivity of major grain crops. Informed in-season management decisions Growers optimize type and timing of crop inputs in frost-prone cropping regions to minimize the impact of frost. Investment outcomes - 1.2.7. The grains industry has improved in-season forecasting tools to better predict frost events and guide risk management decisions. 1.2.8. Growers have improved knowledge of the economic value of modifying different in-season management practices to reduce frost-related yield losses. 1.2.9. Growers have access to novel and innovative in-season frost protection products. Effective post-frost responses Growers make informed decisions regarding extracting value from frosted crops. Investment outcomes – 1.2.10. Growers have access to accurate measurement tools to quantify yield loss following frost. 1.2.11. Growers have knowledge of the economic value of different salvage options and management practices which can be applied to frost-affected crops.

GRDC investments addressing this issue -

Please note this does not include relevant past investments and is a list only of investments which are currently active.

GRS11000 - Frost temperature dynamics and rapid post event identification of damage to broadacre	Frost that occurs during the reproductive stage of cereal growth cost growers millions of dollars in lost yield. The annual average cost across the Australian Wheatbelt is estimated to be $360 million dollars. There is also the hidden cost of management strategies such as delayed sowing and planting more tolerant but less profitable crops. The aim of the project is to better understand frost temperature dynamics and whether ground and drone-based thermal imagery can be used to map post-frost damage. This will give industry and growers an improved understanding of how they can optimally apply in-paddock temperature monitoring

cereals (UWA1711-006RSX)	and how to use emerging technologies such as drones and thermal mapping.
GRS11001 - Frost tolerance in wheat: Grain Research Scholarship for field-based phenotyping tools in pre-breeding (UWA1707-007RSX)	The research has three aims related to understanding physiological responses of wheat to frost in the field. Objective 1 is to determine if varieties with more asynchronous flowering can avoid frost damage owing to a spread of flowering times. Objective 2 will explore how ABA and metabolite levels differ in tissues of spikes when frosted. Objective 3 will assess membrane leakage as a result of freezing and whether plants can repair this damage. The significance of the research is a better understanding of frost damage and tolerance mechanisms, with potential future application to wheat breeding.
ULA9175069 - Development of crop management packages for early sown, slow developing wheats in the Southern region (ULA1703-004RTX)	Dr James Hunt will lead the project based on successful past leadership and coordination of the GRDC Early Sowing project which was similar in size and structure. The collaborating team have been chosen for their demonstrated ability to deliver high quality field experimental data and extension outcomes through previous GRDC projects in key environments of the GRDC Southern region. All members of the project team have collaborated previously on highly successful GRDC projects including the Early Sowing Project, Crop Sequencing Projects, National WUE Initiative and Stubble Initiatives. Output 1: Genotype x establishment time (fully factorial split plot) Output 2: Genotype x irrigation x establishment time (fully factorial split-split plot)
Frost Treatment (IMT1806-001AWX)	Establish the legitimacy and bounds of performance of a chemical frost protection treatment for cereals. The treatments bona fides have been established in University based artificial settings and the next stages are to expand to real-world field conditions and progress to TGAC and product registration underpinned by a comprehensive program of chemistry and manufacture experimentation and trials to establish maximum residue limit (MRLs), bio-efficacy and host crop safety.
Optimising canola production in diverse Australian growing environments (CSP1901-002RTX)	Canola growers in Australia need to be able to select varieties that will perform optimally in their local growing conditions. The timing of flowering is an important factor in determining sowing time and avoiding frost, heat and terminal drought. This project will generate genome marker, gene expression and phenotype datasets from a diverse panel of Australian and global canola varieties in both controlled environment and multi-site field trials. It will then use new big data analysis methods to identify the genetic and environmental pathways that control the timing of flowering in Australian and global canola varieties. The project will deliver perfect molecular markers for the flowering time regulator genes in Australia canola varieties and models that integrate genetic and environmental data to predict flowering behaviour in different growing environments. The outputs allow breeders to select optimal combinations of flowering time gene alleles to deliver new varieties adapted to Australian growing environments. The gene- and environment-based model for canola flowering will allow growers to make informed choices of varieties and sowing dates to optimise crop yields.
Improving the Adaptation and Profitability of high value pulses (chickpeas and lentils) across Australian Agroecological Zones (UOT1909-002RTX)	The fit between a crop variety and its local environment has a critical impact on productivity, and it is well known that environmental variables such as temperature, daylength and soil moisture, and exposure to abiotic stresses such as heat, frost or drought have a major influence on crop growth and performance. These factors vary widely across Australian production zones and determine where and when any given variety can be successfully grown. Growers therefore need access to a range of varieties that provide optimal adaption to local conditions across current production regions and potential expansion zones. They also need management options, such as flexible sowing dates, which allow efficient use of soil moisture, minimize disease impact, and avoid or resist extreme heat and cold events. In order to develop these varieties, and to predict their performance in different locations, we need a better understanding of how environment and crop genetics interact to determine this optimal adaptation. The timing of stages in the crop growth cycle is referred to as "phenology", and this timing plays a central role in adaptation. In addition, on a global scale, we need to understand the major differences in phenology that prevent the use of valuable exotic germplasm in Australian breeding programs. This project will develop a national strategy to address these needs, generating new information and leveraging insights from world-leading research and breeding programs internationally. It will systematically characterize the genetic and physiological variation in phenology in Australia's two major high-value pulse

	crops; chickpea and lentil. Work will combine intensive research in controlled conditions with extensive field trials across Australian production environments, to identify existing and novel variation for phenology. It will document the contribution of this variation to yield in diverse locations, generating detailed performance data and developing genetic markers and models that will guide the development and deployment of new varieties.
ACP00010 - Benchmarking and field validation of transgenic frost tolerance wheat lines (UOA1509-005SAX)	This project is designed to benchmark levels of genetic tolerance to frost and to validate lines of breeding material which have been genetically modified to contain genes which confer higher levels of tolerance to frost.
UA00162 - Screening of frost tolerance in cereals (UOA1507-003RTX)	Spring radiation frost is a significant annual production constraint for the Australian grains industry and can result in significant yield losses. It has been estimated that the direct cost of grain yield losses is in the order of $180M pa, however when indirect costs associated with delayed sowing to avoid frost damage are included, total losses may be in excess of $380M pa. In 2014 the GRDC established a National Frost Initiative with the objective to reduce the impact of frost in cereal crops. The Initiative has three research programs, Genetics, Management and Environment. Within the Genetics Program a key outcome is to identify and deliver new genetic sources of frost tolerance to Australian breeding organisations. Benchmarking trials conducted in the Australian National Frost Program since 2011 has shown that wheat is overall more sensitive to reproductive frost damage than barley, however genetic variation for susceptibility does exist within current wheat and barley cultivars. The goal of this project is firstly continue to screen commercial wheat and barley varieties for frost susceptibility and provide varietal ranking data to growers, and secondly to identify new sources of frost tolerance in wheat that is equal to that of barley. To improve the frost tolerance of wheat varieties, new genetic sources of variation need to be identified and selection tools developed so that breeding organisation can incorporate this into future varieties. This project will facilitate this by mining global wheat genetic resources for potential sources of frost tolerance. Globally there are hundreds-of-thousands of wheat accessions stored in genebanks. To strategically screen these lines, this project will use a Focused Identification of Germplasm Strategy (FIGS) which incorporates global climate and landscape data to select wheat accessions from frost prone parts of the world, with the hypothesis being that these accessions are more likely to have evolved mechanisms to cope with frost, other than avoidance through delaying flowering time (vernalisation). Shortlisted wheat accessions will be screened for frost damage in Australia using frost nurseries and standardised protocols developed within the Australian National Frost Program. Genetic analysis will be conducted to identify DNA markers associated with improved frost tolerance. These resources will be provided to Australian breeding organisations and researchers to facilitate the development of future wheat varieties with enhanced tolerance to frost.
DAW00234 - Determining yield under frost one degree at a time (DAW1401-004RTX)	This project will determine the relationship between the level of frost induced sterility and yield loss in wheat grown in the Southern, Western and Northern regions. Current frost phenotyping methods used within the Australian National Frost Program (ANFP) are based on frost induced sterility at flowering. This estimation of varietal response to frost assumes the reduction in grain number is the main yield component affected. There has been limited work evaluating the effect of frost induced sterility on yield components (grains per m2, spikes per m2 and grain weight) and final grain yield or for variation in this under frost. Hence there is the possibility that selection for material based solely on low levels of frost induced sterility may fail to identify material with that can compensate for yield loss due to reduce grain number by increasing grain size or replacing lost spikes with later tillers. If varieties can be identified with a greater ability to compensate this may provide a new opportunity to reduce financial losses to growers in frost prone regions of Australia. Fundamental to the experimental approach is conducting field frost screening in the target environments, requiring sites reflecting significant regional crop production and providing a reliable frequency of frost events. These trial locations must reflect regional crop production conditions, offer irrigation facilities to ensure a wide range of early seeding dates are possible, and have a high probability of discriminating frost events occurring during spring to provide informative levels of frost damage. The availability of skilled staff with the capacity to correctly phenotype frost damage is essential. The existing three Australian National Frost Program nodes in the Northern, Western and Southern regions meet these fundamental requirements and therefore are ideal locations to carry out this proposed research.
CSP00202 - Identification of wheat frost tolerance	The GRDC National Frost Initiative (NFI) has initiated an integrative and targeted program to improve chilling and frost tolerance in wheat using genetic, management and environmental approaches. This project will contribute to the genetic improvement of frost tolerance of Australian wheat. Wheat is a temperate climate plant and is able to induce an acclimation response during prolonged exposure to winter cold and frost

loci using a combination of genetics, biochemistry and molecular approaches (CSP1606-002RTX)	conditions. This acclimation response at the vegetative stage is lost when increased day-length induces wheat plants to flower in early spring. The reproductive stage becomes therefore vulnerable to short-term cold and frost exposure. The question is whether wheat can regain acclimation in the reproductive structures when exposed to shorter or unexpected frost events and whether there is genetic variability for this capacity in wheat germplasm If so, how can this genetic variability be reliably identified for future use in cold tolerance breeding The genetic potential to mount a (re)-acclimation response is essential for protection of Australian wheat against frost. In the previous GRDC project (CSP00143) we developed controlled environment phenotyping methods for chilling and frost tolerance in wheat. This knowledge can be used to identify markers for screening cold tolerance and improve the reliability of phenotyping methods in controlled environments. Controlled environment studies provide a tool to investigate the physiological and molecular basis of the cold response, and identify markers for germplasm selection. This project will use controlled environment phenotyping to screen four mapping populations and identify cold-tolerance loci quantitative trait locus (QTL).The outcome of the project will be phenotyping know-how, DNA and metabolite markers, as well as wheat lines with improved frost tolerance. These tools will be made available to the breeding community. Identification of cold tolerance QTL will lead to marker development and biochemical studies will identify a metabolite diagnostic tool for identifying cold and frost tolerant wheat lines. Both molecular and metabolite markers will be validated using NFI germplasm. At NFI annual meetings we will communicate our progress to NFI colleagues involved in field work, as well as pre-breeders and breeders, to make them aware about important progress and relevant changes in our understanding of cold sensitivity and how this can lead to improved and more reliable make field phenotyping approaches.
Advancing Profitable Farming Systems – Conduct Frost Risk Management Field Trials (FAR1707-002WCX, TAR1707-002WCX, BWD1707-003WCX, LIV1707-002WCX, FGI1707-003WCX, DAN1707-001SAX, DAW1607-003RTX)	These trials were conducted as part of the National Frost Initiative investment and completed in 2019. There is anecdotal evidence to support numerous farming practices that have the potential to reduce frost severity and hence damage, including nutrition, stubble burning, grazing and sowing direction. Practices that could potentially change the severity and duration of the frost events through changes in canopy temperature were assessed for frost management trials located in target production environment in the Western and Southern wheat cropping regions. Trials were co-located with other National Frost Initiative trials where practical. This project also developed protocols, experimental approaches and economic information on management practices that growers in frost-prone areas of target cropping regions can implement to minimise the financial impact of frost. The impact of management factors which may affect frost tolerance included nitrogen rate, stubble management, seeding rate, canopy management, time of sowing and crop type.
Investigating phenology diversity in germplasm to optimise profitability from April sown oats DAW1901-002RTX	Oat production area was 345,000ha in WA and 820,000ha nationally in 2016-17 (ABARES). In WA, oats are grown as grain, dual purpose and hay crops and are valued for being less susceptible to frost than other cereals. Oats have a unique farming system fit in terms of weed competitiveness and provide options to sow deep and sow early. Current milling oat varieties lack diversity in their season length. Only early to medium spring types are available (~8 days spread when sown in late May), with no late spring or winter germplasm commercially grown. Recent research indicates the potential for oats to compete with barley and wheat when sown early (Troup et al. 2017). Furthermore, the vernalisation requirement of oats can be met in most seasons and environments (pers. Comm. Biddulph, 2018). There is, however, a higher risk of grain staining when sowing current oat varieties in April (early-mid spring types). The recent changes in oat receival standards in WA have tightened for Oat2 (groats and screenings) from the 2019/20 harvest and there will be no segregation for feed grade oats. Failure to meet Oat2 standards means that there is no option to deliver to the CBH supply chain. The risk of this occurring is greater to farmers without livestock in their enterprise (i.e. medium-low rainfall region) who cannot utilise the undeliverable feed quality grain. Therefore, the potential for early sowing late spring and winter types in milling oat production systems may combat the issues of grain staining and discolouration, through avoidance of adverse weather conditions. This investment aims to: a. Screen a wide range of oat lines (including international germplasm) at two locations under controlled environment (irrigation for establishment) conditions for adaptation and suitability to WA growing conditions. b. Investigate milling oat varieties and breeding lines expected to be released, when sown early (April and May), under different nutrition strategies to determine the best-bet agronomy for growers to meet

	tightening milling oat quality specifications. Research will focus on the principal oat-growing region in the medium and high rainfall areas of the Western Region in the Albany and Kwinana Port Zones. The project extends the strong existing collaboration with the National Oat Breeding Program.
New agronomy levers for crop management: a concept study UOA1910-006BLX	This project recognises the importance of advancing new management levers (other than sowing date and N) for growers to manage complex stresses. Timing of water stress influences yield, whilst frost and heat stress can further compromise yield and profit, and increase yield gaps. To manage these environmental factors, agronomy projects (MESW, Barley Agronomy, and Optimising Canola Profitability) have demonstrated that sowing date and N matched with the correct variety phenology (genetics) are the largest management levers. Frost, heat stress and water availability will always remain a major constraint, improved yield and yield stability relies on better management practices that incorporates synergies between crop type and agronomy. We will explore new and novel management levers for wheat outlined below in targeted proof of concept studies, this will be conducted in conjunction with long term modelling approaches and grower engagement to capture the frequency and risk of the opportunity to utilise new management tools. The concept project has three main focus points: 1. Identifying novel management levers that manipulate crop phenology 2. Identifying novel agronomy management levers that limit the yield decline from later planting dates. 3. Grower/advisor engagement - test existing rules of thumbs to inform development of climatic and financial risk tools for each region.
GAPP BLG106: Quantifying the effects of abiotic stresses on pulse growth and development - (1) Temperature - effect of stubble type, load and form on the thermal response of winter pulses. (DAN1703-016BLX)	The relative importance of abiotic stresses affecting pulse production in the northern grains region (NGR) is poorly understood. The major abiotic stresses of pulses in the NGR are those associated with temperature (cold, frost, heat), water deficits and to a lesser extent waterlogging, salinity and sodicity. The potential evaporative demand for water usually exceeds the water available to the crop representing the greatest limitation to crop production in the NGR. Low-disturbance direct seeding into standing cereal stubble is the most effective practice to reduce the impact of water stress on winter pulse crops. However, surface residues can cause an increase in radiant frost risk and may also affect the micro-climate of the crop canopy impacting on floral initiation, pod set and seed development. This project will develop an agronomic and physiological understanding of the effect of stubble systems on the thermal response of winter pulses. Understanding the response of pulses to abiotic stresses will provide knowledge to improve our agronomic management and result in more efficient and effective ways to achieve and maintain attainable yields.
GAPP BLG107: Determine optimum plant types and canopy management for high yielding environments of southern NSW and establish a relationship between photothermal quotient and grain yield of canola. (DAN1707-012BLX)	Field-based research will determine the optimum plant types and canopy management strategies to maximise canola grain yield potential in high yielding environments of southern NSW. The research will also investigate the relationship between photothermal quotient (within critical growth stages) and grain number of canola. The differences in plant type to be investigated include: • Differences in phenology, focusing on determining the optimum phenology for high yielding situations comparing winter, long spring and fast spring varieties. • Differences in breeding (hybrid or open-pollinated) and differences in herbicide tolerance (especially as related to the fitness penalty associated with the triazine tolerance genetics). The differences in canopy management include: • nutrient (especially nitrogen) management strategies • use of plant growth regulators Experimental plots will incorporate treatments to determine the major drivers of grain yield potential in these environments. Research with a similar focus (on variety by sowing date interactions) is being conducted in low-medium rainfall environments of the North and South GRDC regions through the Optimised Canola Profitability project. This new project will complement that work by expanding the findings to higher yield potential environments with a greater focus on slow developing varieties, including winter types for grain yield, as well as expand the findings using controlled environment facilities to more thoroughly establish the relationship between photothermal quotient and grain yield of canola.

Improving frost and heat stress management for SA Durum growers DAS2001-005BLX	Durum is of particular importance to SA, over the past 5 years the average area sown has been 60,300ha, producing 158,200 tonnes (Crop and Pasture report). Relative to other cereals the seasonal variation in durum production is greater predominantly due to poor synchronization of crop phenology to the environment due to a number of factors including frost, heat and water stress. The best method for managing environmental stresses is to match variety with sowing date to achieve the optimum flowering window (OFP). The OFP for bread wheat has been well characterised but from field results (SAGIT project S518), we believe the OFP for durum is likely to be narrower due to the observed increased sensitivity to environmental stresses. Further experimentation is needed to quantify how severe these sensitivities to environmental stresses are for durum in comparison to bread wheat. This will allow for the OFP for durum to be more accurately modelled and therefore growers will have the ability to match variety with sowing date and better manage environmental stresses. Expected Outcomes and Outputs This project will use a controlled environment approach to explore the sterility and yield reductions of durum and bread wheat with similar phenology controls to both heat and cold periods during critical growth stages. This will allow us validate the current frost and heat stress rules in APSIM for durum and alter them in response to our results. With our results from the controlled environment trial and updated frost and heat APSIM rules we will develop OFPs for current durum growing regions in the Mid North of South Australia.

Amelioration of sub-soil constraints, especially sub-soil sodicity

GRDC investments addressing this issue -

DAV00149 - 2016.05.07 Understanding the amelioration processes of the subsoil application of amendments in the Southern Region DAV1606-001RMX (2016-2021)	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.
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.
Understanding how waterlogging affects water and nutrient uptake. (DAV00151 - D-BA)	Grain yields in the south-east High Rainfall Zone (HRZ) are well below their climate-limited potential due to a combination of agronomic, genetic and resource constraints. Crop nutrition, particularly the efficient use of nitrogen, is one of the major constraints, and this can be exacerbated when other soil conditions are suboptimal. Potential yield increases derived from cultivar or agronomic improvements are likely to be limited by hostile soil conditions, particularly those that cause temporary waterlogging during wetter periods, and those that restrict the availability of water and nutrients to the plant in drier periods. Current research in the HRZ is addressing nutrient management on well drained soils only. However, approximately 70% of soils in the HRZ are susceptible to waterlogging in wet seasons. The relationships between waterlogging events, crop root growth and access to soil water and nitrogen, and the consequences for grain yield and quality are poorly understood. Research is therefore required into how the timing and duration of waterlogging affects root development and water and nitrogen acquisition over the growing season, so that management practices can be developed to alleviate the constraints and lift grain yields. This project will use a combination of field measurements and modelling to enhance understanding of the effects of waterlogging on crop growth and water and nitrogen uptake and the consequences for grain yield and quality and identify management practices that may increase crop production on waterlogging-prone soils. As a result of this project, growers, advisers and scientists will better understand the constraints to efficient water and nitrogen usage by wheat growing in waterlogging-prone soils of the HRZ, and potential approaches for improving crop yields and quality through management.
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 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.
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/year). 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, and climate) with pH and lime results e.g. typical buffering and acidification rates based on soil type.
Understanding soils to assess amelioration potential in the Southern Wimmera FSA1908-001SAX	Soil salinity, sodicity, acidity, alkalinity, elemental toxicities such as boron, chloride and aluminium, waterlogging and compaction are significant constraints to grain production and profitability in Australia. Recent research findings showing significant yield benefits to strategic soil tillage including deep ripping practices in sandy soils has sparked a resurgence in amelioration activities in the Southern Wimmera. This was highlighted during the 2018/19 growing seasons with a number of growers commencing deep ripping programs to remove compaction and hard pans and allow crop access to water and nutrients at depth. However, a detailed knowledge of soil characteristics and constraints to root growth is required prior to undertaking any strategic soil management practice to ensure it will adequately address the most limiting constraint(s) and does not have any deleterious effects. Feedback from the Medium Rainfall Zone (MRZ) RCSN has identified that, some growers do not fully understand their soil characteristics and constraints down the profile, and as such, are unaware of the full impacts of soil amelioration practices, including deep ripping. Many growers are not undertaking a soil testing program to understand their soil constraints, especially to depth, making it difficult to assess the suitability of their soil for amelioration, which will depend upon soil type and the presence of one or more constraints. This investment is designed to aid growers' and advisers' ability to characterise soils, identify constraints to crop growth, and assess suitability of soils for amelioration to remove constraints, including return on investment for potential practices in the Southern Wimmera. The approach includes a series of soil pit demonstrations on growers' properties who have undertaken soil amelioration practices as well as a soil masterclass for advisers, based around identification of key soil constraints and the suitability and the return on investment from soil amelioration.
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

UOA1507-002RMX (2015-2020)	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.
Increased grower profitability on soils with sodicity and transient salinity in the eastern grain belt of the Western Region. DAW1902-001RTX (2019-2023)	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. 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.
Bio-solids to overcome sub-soil 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 is 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 (2018-2020)	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 sub-soil sodicity and rates of gypsum required for treating this constraint.
Re-engineering soils to improve the access of crop root systems to water and nutrients stored in the subsoil – Western Region. (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.
Tailoring an integrated solution to effectively address subsoil constraints by incorporation of chemically-balanced nano-amendments DAN1806-002AWX (2018-2020)	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.
Economics of ameliorating soil constraints in the northern region: **PROJECT A** Spatial soil constraint diagnoses (UOQ1803-003RTX) **PROJECT B** Soil constraint management and amelioration (USQ1803-002RTX) **PROJECT C** Economics of adoption (USQ1803-003RTX) **PROJECT D** Program co-ordination – communication, extension and evaluation (UOQ1803-006RTX)	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). **PROJECT A** 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, which 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). **PROJECT B** This 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. 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. **PROJECT C** 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. 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.
Victorian Grains Investment Partnership 2.2 (subsoil constraints)	Soil-based constraints significantly limit grain yield and profit throughout large areas of the southern region and nationally. Removing multiple soil constraints can achieve an 80% improvement in productivity (Sale et al 2016). Enabling crops to achieve full water use efficiency in variable soils and seasons will be vital for future grain production systems. Over the last decade there have been few breakthroughs in the management of multiple soil constraints. Current recommendations are based on past research undertaken in "old" farming systems. These practices do not account for advances in farming systems or amelioration practices. At present growers have not widely adopted soil amelioration practices. This is not surprising due to the upfront costs and risk arising from the lack of reliable prediction of where and when different soil amelioration strategies work. There is a need to understand multiple soil constraints and address the right constraint at the right place and amount, at the right time with the right management. If we can reliably diagnose the type of constraint present, we can then predict when and where amelioration strategies will be cost effective, growers' confidence in adoption will increase markedly. This project aims to increase marketable yields by 10% and production efficiency by 20% in the medium and high rainfall regions of Victoria where soil constraints have been identified. Overcoming multiple soil constraints will allow crops to use the full soil water profile and increase yield and stability of income in variable seasons. Increased adoption of soil amelioration practice will improve soil health and the sustainability credentials of the grains sector. The project will use new approaches to develop a fundamental understanding of the nature, extent and severity of multiple soil constraints on crop productivity. Soil process research will occur in controlled environments and at point-scale in the field. New approaches using existing technologies will allow the accurate identification and quantification of multiple constraints for different crops and farming systems and their relative importance in constraining crop growth and yield. Existing spatial approaches will be integrated to develop a new fundamental understanding of multiple constraints on crop productivity down the soil profile. This new understanding of priority soil constraints will underpin increases in efficiency and reliability and profitability of management interventions. New and current and combinations of tolerance, avoidance and amelioration management practices will be designed and tested for farming systems in the medium and high rainfall zones. This will include to potentially applying lime, gypsum and organic matter to reduce costs and increase efficiency, building on previous and current GRDC and other (AVR) funded projects in these areas. The project will develop new economic response functions for different soil constraints by management invention and integrate these into existing economic approach (ROSA) to help growers and advisers determine the most cost-effective soil management options for multiple soil

	constraints for their production systems. Transformational changes for growers from this project include: • FROM single soil constraint management approaches TO managing multiple and priority soil constraints. • FROM unreliable, costly, high-risk, single factor ways to manage soil constraints TO targeted and cost-efficient crop and soil management practices that use right combinations of avoidance, tolerance, and amelioration tactics. • FROM low adoption rates of practices that manage soil constraints TO growers confidently fixing the right constraint, in the right place and amount, at the right time with the right management achieving water use efficiency, increases in yield and improvements in soil health.
Post-Doctoral Fellowship – Understanding mechanisms of subsoil amelioration ULA1806-001RTX	This research Fellowship will enable Dr Jian Jin to undertake detailed soil and crop measurements at the two new field experiments established by Project DAV00149 in the districts of Kiata, in the median-rainfall zone, and Tatyoon, in the high-rainfall zone in the autumn of 2018. The work will focus on root distribution in soil layers, the functioning of the crop canopy, on water and nutrient uptake by the crop, and changes in soil structure, in response to surface and subsoil amendments. The intensive measurements will complement those already planned in DAV00149. This project will help us to understand how surface and subsoil amendments affect the soil structure and root proliferation in soil layers, crop water and nutrient uptake, and grain yield.
DAW00242 - Subsoil constraints - understanding and management° DAW1407-002RTX (2014-2019)	Subsoil constraints (SSC) include subsoil: Acidity, nutrient disorders (deficiencies, toxicities), compaction, sodicity/ waterlogging/permeability contrast and alkalinity/boron/transient salinity. These constraints reduce root depth and function to the extent that water and nutrient levels are insufficient to sustain production at or near the rainfall limited yield potential. Often the diagnostics are insufficient to enable growers to confidently identify and manage constraints. Confidence in predicting the severity and extent of these constraints is important given that many farmers are experiencing reduced margins due to drying climates and increasing costs relative to returns. This project is designed to increase profitability through efficiency and production gains associated with improved subsoil management. The gains may be in the form of amelioration but, just as importantly, they may be in the form of mitigation where the constraints cannot be profitably rectified. This project will deliver the following outputs: Critical review of current and past research into SSC and how they impact on crop production agronomically and economically. Improved knowledge and resolution of the spatial extent and distribution of soils in Western Australia with subsoil constraints. Improved grower and consultant access to soil mapping and management information through the MySoil portal. Better understanding of how different crop species and varieties respond to varying severities of subsoil constraints so that : The production and financial risks associated with each constraint can be more accurately assessed. Genotypes can be better matched to soil type. New and Improved tools for growers and consultants to manage constrained soils including : Extending the utility of Yield Prophet to better predict yields for constrained soils Improved interpretation of spatial tools (e.g. EM, Gamma and NDVI) Improved interpretation of soil water monitoring tools. Improved knowledge of tools that can be used to mitigate the effects of SSC. Calculators and economic analyses developed for growers and advisors to assess the financial implications of various intervention strategies. Action Learning Modules for farmers and consultants that will cover the types, extent, effects, diagnosis, management (amelioration, mitigation) and costs associated with SSC within WA. These outputs will result in improved yields, reduced costs and enhanced confidence by growers and their advisors in managing SSC to soil type. This proposed work builds on outputs from other GRDC funded projects including SIP08, focus paddocks (DAW00213), precision agriculture (SIP09), soil acidity, water-use efficiency initiative (DAW00193), as well as the more recently GRDC funded project on measuring and managing soil water (CSP00170).
GRS11003 - Roles of dual water:ion aquaporins in cereal osmotic stress response UOA1701-015RSX (2017-2019)	In Australia, drought and salinity are the primary stress factors that limit cereal crop productivity and yield. Enhanced tolerance of cereal crops to these stresses will have agricultural and economic benefits. Both drought and salinity tolerance has been associated with the function of aquaporins. Aquaporins are primarily water channels where subsets are also permeable to a range of other, mostly uncharged, solutes. As a model plant for cereal crops, Setaria viridis will be used to test cereal aquaporins for capacity to transport water and salt and investigate the roles of aquaporins in roots during drought and salt stress in cereals.

Development and validation of soil amelioration and agronomic practices to realise the genetic potential of grain crops grown under a high yield potential, irrigated environment in the northern and southern regions. FAR1906-003RTX (2019-2023)	This investment will develop and evaluate the effectiveness of novel soil management technologies and crop specific agronomic management practices on system profitability. Soil management technologies will focus on improving soil structure, infiltration and moisture retention on: 1. shallow and poorly structured red duplex soils 2. sodic grey clays prone to dispersion and waterlogging Crop specific agronomic practices will focus on maximising system profitability through: • optimising the return on nitrogen through improved use efficiency • improving the understanding of N-form, timing and rate in the context of irrigation timing and inter-related agronomic decisions • understanding how to consistently optimise yield (in the context of water price, input costs and commodity price) for the crops where gaps are most apparent: ▪ faba bean (the pulse crop with the most potential for irrigated systems) ▪ chickpea (an emerging high value pulse, important in crop sequence to provide a cereal disease break) ▪ durum (the major option to increase profitability of the cereal phase of rotations). Durum also has stronger straw strength compared to bread wheat ▪ canola (higher yields provide scope for significant increase in profitability) ▪ maize (the summer crop with the greatest scope to improve returns under a double cropping system) ▪ generating data to inform whole farm sensitivity analysis undertaken as part of PROC-9175816 “Optimise farm scale returns from irrigated grains: Maximising $ return per megalitre of water” increasing grower capacity to respond to varying water and commodity price through agronomic practices targeted to the unique constraints of irrigated cropping systems. This investment is aligned to, and will collaborate with and leverage investments in, the following related GRDC investments: ICF1906-002RTX: Facilitated action learning groups to support profitable irrigated farming systems in the northern and southern regions.UOT1906-002RTX: Optimising farm scale returns from irrigated grains: maximising dollar return per megalitre of water

Increasing herbicide resistance in Wild Radish populations

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

Improving weed management in pulse crops through herbicide tolerance - Part A & B (DAS00131-BA) & (DAS00132-BA) (2017-2019)	A lack of herbicide options in pulse crops limits weed control, production and area sown. This inability to adequately control weeds in pulses affects their adoption and role in farming systems, particularly given that the prevention of weed seed set in these crops is a vital tool in weed management. Suitable and safe herbicides are limited in pulses, especially for the post emergent control of broadleaf weeds, with many registered herbicides having a narrow crop safety margin. This project will develop and supply to PBA, germplasm with improved tolerance to registered herbicides and tolerance to new herbicides leading to the generation of varieties that will assist in increasing the productivity and profitability of pulses in Australia. Project Outputs: Chickpea (desi and kabuli) lines with at least 1 novel source of herbicide tolerance, field validated and delivered to PBA. The novel herbicide target decided in consultation with industry. Development of herbicide tolerant lentil germplasm from putative tolerant lines (metribuzin) developed in a previous project. Lines screened for tolerance and the most promising of these lines will be multiplied and validated through glasshouse and field dose response experiments to identify agronomically useful level of tolerance for use by the PBA lentil breeder. Selections showing low levels of damage from dicamba (faba bean and lentil) and carfentrazone-ethyl and isoxaflutole (lentil) mass field screens multiplied and assayed for tolerance under controlled conditions. Lines showing useful levels of improved tolerance will be multiplied and validated in dose response and field experiments and those with agronomically useful levels of improved herbicide tolerance delivered to PBA breeders.

	Development of cost effective, repeatable and non-destructive screening methods for stacking of herbicide tolerances in pulses and the subsequent development of lentil and faba bean germplasm with multiple herbicide tolerances. Screening methods, including the use of diagnostic markers where applicable, developed to rapidly and non-destructively identify lines from opportunistic crosses aimed to specifically improve levels of herbicide tolerance. Identification of other potentially useful herbicides for screening in pulse mutant populations. In consultation with industry, appropriate herbicides will be identified for future screening.
Australian Herbicide Resistance Initiative (AHRI) – Phase V (UWA00171)	Australian grain growers, like their counterparts in other industrialised nations continue to rely on herbicides as the most important component of their weed management strategy. In the foreseeable future there are no alternative technologies in world cropping that will achieve the results that herbicides obtain. It is now understood that novel mechanisms of resistance to different herbicide modes of action exist and will continue to evolve under global herbicide selection - a better understanding of the factors and dynamics of herbicide resistance selection will delay the evolution of herbicide resistance in weeds. Evolutionary biology and Darwinian evolutionary theory provide a very powerful framework to interpret and understand how weeds can respond to herbicide use and other pressures in modern cropping systems. Improved crop/weed management strategies evolving from increased knowledge and understanding of the herbicide resistance phenomenon will ultimately benefit the Australian grains industry and represents a significant contribution towards achieving sustainable cropping systems. In AHRI, the 2015-2020 project encompasses three research programs; Resistance Evolution, Resistance Mechanisms and Resistance Management, plus a Communications program. All programs have a high level of engagement in delivering activities in all three GRDC regions. **1 - Resistance evolution:** Essential for monitoring on-going herbicide sustainability, field survey work will quantify herbicide efficacy and herbicide resistance evolution in key cropping weeds. Resistance surveys have been conducted for Ryegrass, Wild oats, Barley grass, Brome grass, Wild radish and Fleabane and testing for resistance has commenced. Ongoing research to highlight the importance of maintaining optimum herbicide efficacy (rates) has commenced together with evolution studies to predict the onset of resistance to new herbicides, ways to delay resistance onset and resistance management techniques. This information will be captured in the PERTH and RIM models for use in Australian cropping and disseminated widely. **2 - Resistance mechanisms:** Understanding how Australian crop weeds achieve resistance to powerful herbicides is of benefit to the nation and globally. AHRI is the international leader in this research area and attracts considerable ARC grant funding and industry support AHRI is working to establish the biochemical and molecular genetic basis of novel herbicide resistance in Australian major crop weeds and to ensure this information is widely disseminated and, when relevant, incorporated into management strategies. This fundamental AHRI biochemical/molecular research underpins an understanding of how to sustainably manage herbicides and minimise resistance. **3 - Resistance management:** The focus of this program is aimed at maximising crop production/sustainability while minimising crop-weed and herbicide resistance problems in Australian grain crops. This program has a national focus with the development of weed control solutions to fit cropping systems in each of the Western, Southern and Northern production regions. Harvest weed seed control (HWSC) systems have been developed as a major AHRI activity in response to the escalation in herbicide resistance and because of an identified opportunity to target weed seed production during grain crop harvest. The major annual weeds infesting Australian cropping; annual ryegrass, wild radish, brome grass and wild oats, all retain high proportions of their seed production at maturity. This attribute (biological weakness) is taken advantage of by targeting this seed for collection (harvested) during commercial grain crop harvest (Walsh and Powles 2007). **4 - Communication:** AHRI is committed to delivering AHRI's and other relevant research to the Australian broadacre cropping industry in an engaging manner, promoting greater awareness of herbicide resistance and educating industry stakeholders on strategies to increase crop yields and sustain herbicides. Tools to

	communicate AHRI messages include delivery of website, online courses, live webinars, face-to-face presentations, social media and targeted events.
New uses for existing chemistry (UQ00080)	The overall objective of the project is to identify new uses for existing registered pre- and post-emergent herbicides for the site-specific management of Feathertop Rhodes grass (FTR), awnless barnyard grass (ABYG), fleabane, sowthistle, brome grass, barley grass, and wild radish present in crop and fallow situations. Pot and field trials were conducted to explore the potential for the use of older herbicides either alone or in mixtures for the control of Feathertop Rhodes grass (FTR), awnless barnyard grass (BYG), fleabane, common sowthistle, barley grass, brome grass, and wild radish in different regions. The mixture of Product A plus Avadex Xtra provided suppression of brome grass in barley. Sakura plus trifluralin and high rates of Product B were the most effective herbicide for pre-emergent control of barley grass. A number of mixtures and sequential applications were found effective in controlling common sowthistle and flaxleaf fleabane. Three tank-mix treatments effectively controlled awnless barnyard grass; however, sequential applications exhibited higher levels of control. Herbicide tank mixtures and sequential applications were not effective on mature feathertop Rhodes grass under field conditions. Fluridone (Group F) showed promising results for wild radish control.
Cultural management for weed control and maintenance of crop yield UOA1707-005RTX (2017-2022)	Project to ascertain best bet combinations of cultural and chemical weed control tactics for each agro-ecological sub region. Herbicides remain the primary method of weed control in cereal crops because they are very cost effective, hence why farmers are reluctant to adopt integrated weed management (IWM) until they have a serious herbicide resistance problem. When resistance exists, farmers generally change to other modes of herbicide action (including herbicide-resistant crops); however, when resistance to multiple modes of action exists, farmers are forced to adopt more radical nonchemical or cultural control options. Crop competition is widely accepted as an important tactic for suppressing weed growth and maintaining crop yield. Agronomic choices influence crop competition, including crop species and cultivar, row spacing, crop density and row orientation. All these tactics have been shown to impact on the control of in-crop weeds. For wheat, while cultural factors such as row spacing, seeding rate, row orientation, nutrient placement, time of sowing and swathing/time of harvest are known to contribute to effective weed management, these management tactics have not been studied extensively in factorial combinations in different environments to demonstrate their relative contributions in a farming system. While significant effort has been focused on competitive agronomy in wheat and other cereals, much less effort has gone into crops such as canola. To advance this research, it is expected that more data will be needed on existing genetic variability of competitive ability in canola x agronomic region x agronomic practice. Using a limited number of diverse canola genotypes validation data could be collected on the existing genetic variability of competitive ability x agronomic region x agronomic practice. Adopting a holistic systems approach should deliver more practical information to growers on likely outcomes of specific agronomic IWM strategies. Growers can then make informed investment decisions.
WeedSmart (UWA00172)	WeedSmart is established by industry to ensure herbicide options are available for future generations. WeedSmart provides a consistent, single voice for the herbicide industry, linking stakeholders to world renowned herbicide resistance and agronomic research. WeedSmart Phase 3 builds on the strong and effective brand established in Phases 1 and 2 by continuing to work with growers and industry to increase awareness and to provide solutions to keep herbicides working.
Pilot workshops - why weeds grow where they do and how to control them PLN1905-001SAX (2019-2020)	Weeds are estimated to cost Australian agriculture more than $2.5 billion per year, with in-crop weed competition costing around $1 billion per annum for Western Australia (WA). The overall annual weed cost to grain growers equates to $117 per hectare. The most expensive weeds in relation to yield loss are annual ryegrass, wild radish and wild oats. WA growers spend 3 times more than any other state on harvest weed seed management (13 million nationally) using tools like windrow burning, chaff carts, seed destructor and other methods. As a result of the importance of this issue, GRDC investment into the area of herbicide resistance alone over the past 25 years has returned a benefit-to-cost ratio of $3.50 for every dollar invested (Llewellyn et al 2016), however weeds with herbicide resistance are an increasing problem in grain cropping enterprises. The aim of this investment is to extend the knowledge and a whole of systems approach through a series

	of workshops about why weeds grow where they do; and how management decisions impact on the density, type and range of these weeds in the Geraldton and Kwinana West port zones using an expert panel consisting of growers, consultants, advisors and researchers. By April 2020, deliver at least three (3) extension pilot events per port zone in Geraldton and Kwinana West port zones (6 in total) providing a whole of systems approach to managing weeds. The workshop should consist of some hands- on demonstration and learning; with the balance being current updates of research and grower case studies/presenters. It is preferable that these events will be run through local grower groups but do not need to be standalone events. It is expected that consultation with a range of stakeholders including grower groups, Geraldton and Kwinana West RCSNs, growers, agronomists, consultants, researchers and other will occur to decide upon topics and presenters.
CSP00182 - Genetically improving wheat's ability to outcompete weeds CSP1307-006RTX (2013-2020)	The cost of weeds to Australian agriculture is estimated at an annual $4 billion through crop yield loss and seed contamination. This value continues to rise with increasing crop value, and as herbicide resistance becomes increasingly more widespread. Currently 25 different weed species display at least some level of resistance to widely deployed herbicides. New herbicides may be used to assist in ryegrass control but ryegrass has the capacity to develop resistance to other herbicide groups resulting in multiple genetic resistances. Indeed, herbicide-resistant ryegrass is common throughout Australia and it is poor control of ryegrass that makes wheat the weakest link in weed management in Australian cereal rotations. Research has shown that ryegrass can produce large amount of seed even when new herbicides such as Sakura and Boxer Gold are used in current wheat cultivars. There is clearly a need to improve the competitive ability of wheat cultivars so that weed populations can be managed more effectively on Australian farms. Wild oats, annual ryegrass and wild radish together contribute to significant reductions in wheat yields while adding to the growing weed-seed bank with each wheat crop sown and harvested. The result of poor weed control is then a reduction in wheat crop yields (of up to 90%) and a potential reduction in the yields of following crops. Further, it is estimated that herbicide costs are $80-100 per ha for wheat further reducing returns to growers. Integrated weed management (IWM) has proven to be economically beneficial in managing herbicide resistance, and in minimising the size of weed seedbanks over time. The IWM employs a range of tactics for the effective, long-term management of weeds (e.g. pre- and post-emergent herbicides and sowing competitive crops). Herbicides remain the most cost-effective weed management option but herbicide resistance and the threat of few new herbicide chemistries will place greater reliance on the deployment of more competitive varieties. We demonstrated the potential for development of weed-competitive wheat genotypes in a previous GRDC project (UA61 and UA00112). Breeders have demonstrated interest in this germplasm indicating the potential for commercial delivery of competitive wheat varieties. The aims of this project are to develop: a robust and repeatable screening methodology for improved weed competitiveness for use in commercial breeding programs understanding of those morphological/physiological factors contributing to improved competitiveness development and release of elite spring wheat germplasm containing traits with improved competitiveness for use as parents in breeding of new weed-competitive varieties. Together, the project in collaboration with commercial breeding programs will deliver disease resistant, milling quality weed competitive varieties.
Agvet R2#008 Grant Agreement - Lupins x wild radish & other broadleaf weeds - Priority Use FMC1707-003OPX (2017-2022)	The Commonwealth has provided the GRDC with Grants as part of the Assistance Grants – Access to Industry Priority Uses of Agvet Chemicals grants programme under the Australian Government's Improved Access to Agvet Chemicals initiative. The purpose of the Grant is to provide the Grantee with funding assistance to generate data sufficient to support an application to the Australian Pesticides and Veterinary Medicines Authority (APVMA)
CSP00181 - Molecular control of wild radish using SP11 protein (2017)	This investment is designed to reduce the economic impact of herbicide resistance to the grains industry through the development of new non-chemical weed control strategies. Measured through grower use of non-chemical weed control practices through GRDC impact surveys.
UA00156 - Emerging weeds (Seed-bank biology of emerging	Changes in farming systems, weed management practices and climate have contributed to the change in weed flora on Australian farms. Much of the Australian research on weed seed biology was undertaken prior to the intensification of cropping and before the introduction of no-till systems. It is quite likely that

weeds) (UOA1505-001RTX) (2015 - 2020)	the biology of the weed species has changed in response to the changes in crop management practices. This change in weed behaviour in response to management practices has been aptly illustrated by recent research on barley grass and brome grass. Furthermore, many of the weed species other than annual ryegrass and wild oats have not been adequately investigated. The project aims to quantify the behaviour of weed seedbanks of emerging weed species in terms of variation in seed dormancy, seed persistence, pre-harvest dispersal, reproductive output and competitive effects on crops.
Low weed seed bank persistence under sustained integrated weed management UWA1711-005RTX (2017-2019)	The combination of huge farms, scarce labour and low margins together with the reality of a short growing season means that cropping operations and weed control are done in a repetitive and predictable manner. Pest species love this consistent and repetitious environment as they can adapt and persist, as evident in the widespread evolution of herbicide resistant weeds. In order to manage this weed threat, Australian growers have developed combinations of herbicide and non-herbicidal weed control techniques which tackle weeds at different stages of the weed lifecycle or intercepts and destroys weed seeds before they enter the soil seedbank. Using these effective tools, some leading growers have been successful in greatly reducing weed seed banks (Walsh et al 2013). However, despite years of effective weed control, low weed numbers still persist. The persistence of weeds, despite excellent and sustained weed control poses two important agronomic questions: 1. Are these persisting weeds a result of inefficiencies in weed control or has there been a genetic change in these weed populations enabling them to evade repetitively used weed control practices? 2. If genetic adaptations have evolved in weed populations then, how can they be controlled? This investment seeks to quantify if weed adaptation is occurring in order to inform weed management decision and future investment in weed control research.
A simple and innovative test for real-time detection of resistance in weeds UWA1807-001AWX (2018-2020)	Food security for a rapidly increasing world population is becoming a very important concern. Food production should be achieved through efficient and sustainable use of resources. Crop production can be severely constrained by weed infestations and in the last 70 years herbicides have allowed the safe removal of damaging weedy plants reducing human and animal labour and destructive soil cultivation. Correct herbicide use is generally safe to the environment and has minimal carbon foot print compared to other weed management techniques (e.g. mouldboard ploughing). Yet, the overreliance of the herbicide technology has led to the evolution of herbicide-resistant weeds that are now threatening sustainable food production. This investment is designed to minimise the risk of resistance evolving in weeds and direct new research towards alternative technological solutions to weed resistance control. The expected outcome is to develop innovative and sustainable solutions for safe weed control and build capacity in basic and applied agricultural research to support to the Australian grains industry.
GRS (Emily Mackie) - Development of herbicide cocktails with a novel mode of action for circumventing resistance mechanisms. ULA1903-001RSX (2019-2022)	This project aims to discover new inhibitors of two enzymes that are essential for amino acid production in plants, and to combine these inhibitors into a multivalent herbicide cocktail. The use of multivalent herbicides is a novel strategy to reduce the downstream development of resistance in weeds, which threatens the utility of nearly all currently used herbicides. Such herbicides with new modes of action will increase crop yields and quality by effectively managing weeds resistant to current herbicides. In turn, profitability of grain growers will be increased, and the costs of weed management will be minimised. These benefits align with the GRDC priority to effectively and sustainably manage weeds, whilst minimising input costs.
UCS00020 - Weed management in the southern region mixed farming systems - strategies to com° UCS1306-001RMX (2013 - 2019)	This research will deliver new knowledge on the distribution and biology of weed species as influenced by adoption of farm management practices across southern Australia. The findings of this project will result in the development and demonstration of new and effective chemical and cultural management strategies for major weeds in the southern grains and mixed farming region. This knowledge will identify why specific weeds are a problem in continuous cropping and mixed farming systems, determine their various impacts upon crop, pasture and livestock productivity and evaluate management practices that will be appropriate for these weed species in a changing environment in which herbicide resistance has proven to be problematic. The project outcome will result in growers optimising the use of chemical and non-chemical weed control tactics in the context of continued profitable no-till farming practice and the potential integration of profitable livestock enterprise while reducing the cost of weed control. The project will specifically deliver

	information about: The extent of herbicide-resistant weeds across southern Australia in broadacre crops and pastures and the impact of weed infestation on crop productivity and livestock (carcass quality) in mixed farming systems. Changes in weed flora in response to farm management practices and changes in weed biology in response to a changing environment. New chemical and cultural weed management practices for application to broadacre and mixed cropping farming systems, leading to novel methods for enhanced control of weeds and prevention of herbicide resistance in no-tillage production systems and mixed farming enterprises. The development of effective management strategies for strategic use against particular weeds or the implementation of cost-effective weed management in mixed cropping systems with pasture rotations will prove critical in limiting the spread of new and emerging species as well as those species developing herbicide resistance. This will lead to positive impacts on crop and livestock productivity and performance in the Southern Region.
UCS00024 - Surveillance of herbicide resistant weeds in Australian grain cropping° UCS1507-001RTX (2015-2020)	Herbicide resistance in weeds is a major problem in farming systems of the Southern and Western Regions and is increasing in the Northern Region. Understanding the threat and extent of resistance present at a district level can encourage growers to take timely action to reduce the impact of resistance. This project will conduct regional surveys across the Northern, Southern and Western Regions to deliver information about the extent of herbicide resistance in key weeds, changes in resistance patterns over time and identify potential emerging resistance threats. Summarised results on resistance status and mapping information will be delivered to growers, agronomists, consultants and industry through GRDC updates, media articles, Australian Herbicide Resistance Initiative (AHRI) insights, and in peer-reviewed journals regularly throughout the project.
RDP00015 - Grain Weeds Advisory Committee° RDP1507-001RTX (2015-2020)	The Grain Weeds Advisory Committee (GWAC) will work to provide integrated weed management strategies for the major crop-weed threats to Australian grain production. GWAC will also provide strategic weed investment advice and recommendations to the Grains Research and Development Corporation (GRDC).The GRDC expects that the project will result in growers using a sustainable combination of effective genetic, cultural and chemical weed management tools to reduce current losses from weeds and minimise control costs. The outcome for grain growers and their advisers is being able to cost effectively identify weed populations and implement weed management plans to manage risks of herbicide resistance. GWAC consists of a committee of leading weed researchers from across Australia. GWAC has the following three goals: 1. Provide national R,DE leadership to minimise weed impacts on the grains industry 2. Promote a culture of stewardship for weed control practices 3. Identify opportunities for professional development and capacity building
UQ00080 - New uses for existing chemistry° UOQ1507-001RTX (2015-2020)	Herbicide resistance is a major problem in Australian grain cropping, reducing the herbicide choices available to growers and increasing their costs. There is a need to increase the availability and flexibility of controls for herbicide-resistant weeds, including new herbicide uses. This project will develop data sets for registration of new uses for existing herbicides. It will broaden the choice of herbicide uses available to growers through identifying new uses for existing registered pre- and post-emergent herbicides and getting those new uses on labels or permits. The main output of the project will be the development of new herbicide treatments for the site-specific management of Feathertop Rhodes grass, awnless barnyard grass, fleabane, sowthistle, brome grass, barley grass, and wild radish present in crop and fallow situations.
DAS00168-BA - Regional Agronomy SA - Improving weed management in high break crop intensity farming systems UOA1703-022BLX (2017-2020)	Weeds and their associated control are a major limitation and cost to the Australian grains industry. A recent industry survey suggest that both these factors have increased significantly over the past fifteen years, particularly in high intensity continuous cropping systems based on no-till and stubble retention. In the past these systems have relied heavily on in-crop herbicide control options, however due to the limited availability of new herbicides combined with the rapid development of herbicide resistance weeds, new whole of system integrated approaches to weed management are now required for effective sustainable control. The farming systems of southern Australia are somewhat unique in Australia due to the range and intensity of break crops grown providing both new weed control problems but also different tactical weed control

	opportunities. While herbicide resistant rye grass and to a lesser extent brome grass and wild radish still present major problems, a number of broadleaved weeds limit production of some or all break crop options available to growers. The rapid availability of multiple crops with group B "IMI" herbicide tolerance has offered new weed control options in these farming systems. However the long term strategic use of this technology along with the judicious use of effective integrated weed management (IWM) practices will be required to not only control weeds but sustain the long term viability of high break crop intensity farming systems in southern Australia. The project has two aims: 1. provide SA farming system groups, growers and their advisors with successful and sustainable integrated weed management strategies that allow effective weed control of the major weeds in high break crop intensity rotations which incorporate new herbicide tolerant break crop options, no-till and high stubble retention, 2. to build regional agronomic research capacity in South Australia (SA) through the training and retention of a skilled agronomist based at Clare in the Mid North/Yorke (MN/YP) Peninsula region of SA and which supports other regional agronomists to deliver R,D & E project outcomes to all cropping regions of the state. The project will have five components: The development of effective weed management strategies for rapidly reducing and maintaining low seed bank numbers of key broad leaved and Group A 'dim' resistant rye grass weeds in tight cereal/break crop rotations of southern Australia. This will occur by: measuring weed populations in strategically targeted commercial "focus paddocks", concentrating on those with high break crop intensity and known major resistant and broadleaved weed backgrounds, following the implementation or not of a few selected key targeted weed control strategies, targeted trial plot research in high break crop intensity systems that incorporate no-till and stubble retention. The development of herbicide recommendations required for maximising weed control in 'IMI crop' and part 'IMI crop' rotations in line with current stewardship guidelines, including quantifying the impact of Group B residues on yield, biomass production and nodulation/N fixation of subsequent 'non-IMI crops'. Targeted rotational residue trial plot research will occur in high break crop intensity systems that incorporate no-till and stubble retention. An improved understanding of the effectiveness and impact of agronomic IWM tactics such as crop competition, plant population, east to west planting direction, sowing date, row spacing, inter row sowing and incorporation of new herbicide tolerant pulses on weed control and crop performance in southern region pulses, and where gaps exist in cereals and canola. Targeted trial plot research addressing some or all of these tactics in high break crop intensity systems that incorporate no-till and stubble retention will occur. Collaboration and Communication with industry stakeholders.
UWA00171 - Australian Herbicide Resistance Initiative - Phase 5 (UWA1506-003RTX) (2015-2020)	Commencing in 1997 as a GRDC initiative, Australian Herbicide Resistance Initiative (AHRI), was created to be a research team of critical mass to tackle the major herbicide resistance problems challenging Australian grain cropping. With GRDC funding, plus initial Department of Agriculture and Food Western Australia (DAFWA) support, AHRI commenced in 1998 at the University of Western Australia, and has grown to be a major centre of expertise. With the envisaged GRDC AHRI negotiated project 2015-2020 and with support from all three GRDC regions we propose to continue strong collaborations, already established in each of the Western, Southern and Northern GRDC regions to deliver research that is highly relevant. In AHRI 2015-2020 we envisage three AHRI research programs; Resistance Evolution, Resistance Mechanisms and Resistance Management, plus a national Communications program. All programs will continue to have a high level of engagement in delivering activities in all three GRDC regions. In addition to the AHRI 2015-2020 negotiated project there are two GRDC tender led research projects: Harvest weed seed control and targeted tillage. All programs will continue to have a high level of engagement in delivering activities in all three GRDC regions.
UWA00155 - New Chemistry Options for Wild Radish Control° (2012-2017)	Wild radish poses a significant threat to sustainable crop production throughout the Australian dryland cropping regions; the widespread evolution of populations with multiple herbicide resistances preventing the effective chemical control of this weed in crop production systems. As herbicides will remain the most effective weed control tool for the foreseeable future, the industry needs alternate herbicide options for the effective control of wild radish within Australian crop production systems. This research was aimed at identifying such herbicide options and facilitating their progression through product development. Through national and international industry networks, AHRI researchers sourced alternate herbicide

	options for the selective control of wild radish populations present in Australian crop production systems. Candidate herbicides were subjected to a primary screen to assess their efficacy on characterised herbicide-resistant and susceptible populations. Effective herbicides identified in the primary screen were then progressed to a more extensive secondary screening stage. Secondary screening examined each herbicide selectively on a range of crop species and the effective dose response range of herbicide treatments on wild radish populations. Additionally, studies investigated the effects of environmental influences such as temperature and moisture stress on herbicide treatment activity. At the tertiary screening stage herbicides were field tested to validate their efficacy in selectively controlling wild radish populations present in Australian crop production systems. Candidate herbicides will be identified for product development, with AHRI researchers working with the industry to expedite the progression of identified herbicide treatments to market.

Develop new markets for broad and faba beans plus improved grain marketing through expanded or differentiated markets for faba beans

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

Pulse Breeding Australia: Faba Bean Breeding (UA00163)	The development of improved varieties of faba bean will result in more reliable production with reduced inputs for disease management and enable the expansion of the crop to new areas of production. This will contribute to GRDC goal of increasing the component of pulses in cropping systems from 7 to 10% in the next 10 years. Faba bean is one of the major cool season food legume crops internationally, with a global production of approximately 4 million tonnes per annum. It has been cultivated in Australia since 1980 with major areas of production in the temperate and Mediterranean-type environments in South Australia and Victoria, where it is generally grown in higher rainfall districts, and in the sub-tropical environment of northern New South Wales (NSW). There is also potential for expansion of the crop into irrigated cropping systems in northern Victoria (Vic), and southern NSW, into the Western Districts of Vic and into slightly lower rainfall areas on the fringes of the current traditional faba bean production area with the development of new, adapted varieties. Faba bean crops are grown over diverse environments therefore a range of varieties that carry traits required for adaptation to the contrasting environments, such as variation in day length, temperature, rainfall patterns, soil type and dominant diseases, is required for the Australian industry. Faba beans are susceptible to a number of fungal and viral diseases and control of these requires significant inputs in both time and money. Resistance to the major diseases has been identified and progress has been made in combining resistance to several diseases in adapted genetic backgrounds. Further breeding and evaluation is required to identify the highest yielding of these lines for release as new varieties. In recent years there has been significant research into new traits to incorporate into Australian pulse varieties, and several important traits have been identified in faba bean. These include tolerance to several herbicides, resistance to a new pathotype of Ascochyta blight and tolerance to heat. This project will commence the introduction of these traits to a range of elite breeding lines with the long-term objective of developing more robust varieties with a wider range of adaptation and improved weed management options. Faba bean is a high protein, staple food in many countries in the Middle East and north Africa, and Australia is one of three major suppliers to these markets, together with France and the United Kingdom. There is a limited market with strong competition among the exporting countries and it is important to produce a high quality product that will ensure continuity of supply to maintain market share. Expected outcome: This project will develop new faba bean varieties that have greater yield than current varieties, better adaptation to the major production regions in Australia and improved disease resistance. Improved germplasm incorporating new traits, such as herbicide tolerance, will be developed for the longer-term benefit to the faba bean industry. Outputs: • Identify a potential release line for the southern region with significant yield improvement over current varieties in identified regions to enhance expansion of faba bean production. The line

	will have a good level of resistance to Ascochyta blight and chocolate spot, good standing ability and quality suited to the Middle East food markets. • Identify a potential release line for the northern region with significant yield improvement over current varieties. The line will have a good level of resistance to rust and a manageable level of resistance to bean leaf roll virus and chocolate spot, early flowering and maturity and quality suited to the Middle East food markets. • High yielding, agronomically stable advanced germplasm with combined resistance to diseases and incorporating new traits such as herbicide tolerance. Methodology: The breeding program will be conducted as a component of Pulse Breeding Australia (PBA) and coordinated by The University of Adelaide. The major breeding and evaluation nodes will be based at the Waite Campus, University of Adelaide, and at Sydney University Plant Breeding Institute Narrabri. Significant contributions will be provided by South Australian Research and Development Institute and NSW Department of Primary Industries in the areas of disease resistance and regional evaluation. The project will build on the efforts of previous breeding programs that have developed methods for breeding faba beans and identified new sources of disease resistance and lines with good adaptation in different production regions in Australia.
DAV00134 Continuation - Diagnostic services for pulse germplasm enhancement and breeding programs DAV1902-004RTX (2019)	The Australian winter pulse industry (field peas, chickpeas, faba beans and lentils) is expected to increase substantially in the near future, driven by the need to protect farm incomes through crop diversification and because of their ability to fix atmospheric nitrogen, lowering input costs. The use of legumes as a rotation crop has also shown to dramatically reduce stubble-borne wheat diseases like crown rot. However, the increase in pulse area and production may amplify its own disease and pest problems. Viral diseases are of particular concern to pulses and, unlike most fungal diseases, legume viruses may have several legume hosts and some also have non-leguminous hosts. This project focuses on providing the virus diagnostic services required to screen pulse germplasm for virus resistance and to ensure freedom from seedborne viruses during the breeding and variety development processes. Tissue blot immunoassay (TBIA), has become the virus diagnostic method of choice for surveys and variety improvement work as it is reliable and economic and can handle the large number of individual plant samples needed for surveys or variety improvement. The established Australian Grains Genebank (AGG), led by the Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR), and physically based at their Horsham Centre, represents the national, consolidated deposit of all major grain germplasm collections. Australia has been a major beneficiary from the importation and utilisation of genetic resources in grains. AGG represents a consolidation of national resources to import, distribute and preserve valuable genetic resources from around the world for utilisation by researchers and plant breeders in Australia. The long term financial commitment to AGG by DEDJTR and GRDC fulfils Australia's international responsibilities and commitments to conserve and distribute germplasm for use in improving global food security. AGG constitutes a one-stop shop for grains germplasm in Australia, thus improving the efficiency of germplasm introduction, quarantine, storage and maintenance, and information management, which will enable researchers and breeders to utilise international germplasm for the benefit of the grains industry. The current phase of the project is a 4-year commitment to build, maintain, and run the AGG as part of a long-term commitment by DEDJTR, GRDC, and state governments that have germplasm deposited in this facility.
GOG00009 - The Grains & Legumes Nutrition Council (2017)	GLNC is a not-for-profit company limited by guarantee and a recognised health promotion charity. As the independent authority on the nutrition and health benefits of grains and legumes, GLNC provides a platform for organisations from across the grains and legumes value chain that have a pre-competitive interest in promoting the health and nutrition benefits of grains, grain-based foods and legumes. As the independent authority on the nutrition and health benefits of grains and legumes, GLNC's mission is to promote grains and legumes nutrition as part of a balanced diet through evidence-based information cultivating good health.

AEG00006 - Grain Quality Market Insight - Asia AEG1504-003RMX (2015-2019)	Market information is the foundation of the Meeting Market Requirements Strategic Theme. In order to deliver highest value to growers and the industry, GRDC must understand the requirements and dynamics of current domestic and export grain markets for feed and food grains. This project will: Review, collect and document quantitative and objective data on end-users' quality and functionality requirements in Australia's primary markets for cereals, pulses (including lupins) and oilseeds. The collection and documentation of the objective and quantitative market information will assist industry stakeholders in understanding current and future primary grains market dynamics. The two outputs will help pre-breeder, breeders, grains researchers, investment bodies and marketers to better understand market needs and will assist these stakeholders in making informed investment decisions based on market requirements. The collaborative objective is to: • AEGIC, GGL, FGC, DEDJTR, and DAFWA - Review the level of information available on the five minor crops (lupins, field peas, mung beans, chickpeas and lentils), then collect and analyse quantitative and objective data on end-users' quality and functionality requirements for these five grains in their top markets, so that the relative value propositions for improving each of their key functional traits can guide GRDC's investment decisions.
DAV00158 -DEPI BA-2-Quantifying the value of pulse grains DAV1607-006BLX (2016-2021)	This project will develop and optimise phenomic-based technologies to quantify seed composition and the functional value of pulses. The technology will be deployed into PulseBin Project 1 to enhance genomic selection for screening germplasm to identify optimal quality traits, This will contribute to improving the value of pulses by enhancing the processing characteristics functional properties and relative value. Further value that may be captured to meet specifications for pulse processing by export markets are being evaluated in a detailed GRDC project led by AEGIV (AEG00006). This project includes Joe Panozzo as a participant., Market intelligence gathered within AEG0006 where applicable will be incorporated into this project to enhance the outcomes. Historically seed traits have served both as grading standards at receival and also defined the specifications for processing by the export marked. The traditional processing of pulse grains consists of either, primary processing such as fractionation of seed components, high-pressure extrusion or baking. In the previous project DAV132, we successfully developed algorithms based on image analysis for lentils and field peas to determine seed size distribution which could replicate the Grain Trade Australia standard sieving methods with an accuracy of greater than 95%. The development of high-throughput methodologies were successfully implemented into the PBA field pea and lentil breeding programs. As with all mathematical based models, there is a requirement for on-going cross validation to account for changes int eh genetic pool of the variability due to seasonal effects altering the seed phenotype. In the next phase of the project, refinements to existing algorithms to improve the precision will be undertaken. The developments include applications to measure seed composition in lentils, field pea, chickpeas and provide the breeders and researchers the ability to improve functional properties of grain and associated nutritional value of pulses through genomic selection and conventional breeding. Additionally, data collected on seed composition may be used by the food industry to develop new food products with enhanced wellbeing traits, or for industrial applications other than the current traditional split and dehulled product. These developments will increase opportunities available to Australian Pulse growers. A component of this project will be to apply the tools developed to identify germplasm with starch and protein quality traits which will enable Australian pulses to expand into markets beyond the traditional Indian markets. Specifically we will be investigating starch properties for human food use (comparted to cereal starch), vermicelli noodles (China) and as a food binder (e.g. Aquaculture). We will extend the application of phenomic technologies by developing NIT calibration to determine seed composition on both a bulk seed basis , which will be used by breeding programs, and separate NIR calibrations on single seeds that can be used as a genetic screening tool.

	Wil will also develop hyperspectral imaging calibrations to determine the within seed variability of chemical composition and seed structure which can be linked to functionality and processing characteristics. These methodologies will be applied to germplasm enhancement programs as high throughput method for improving seed and functional traits. Additionally we will apply nuclear magnetic resonance and mass spectrometry to quantitate starch, sugars, phytates and phenolic metabolites which are associated with enhanced health and wellbeing.