GRDC investments addressing "deep dive" issues and update on R,D&E Strategy to minimise the impact of spring radiation frost

Low Rainfall Zone Southern RCSN meeting, February 2019

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

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.

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.
GRS11000 - Frost temperature dynamics and rapid post event identification of damage to broadacre cereals (UWA1711-006RSX)	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 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 (Chickpea And Lentil) 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 accession 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 loci using a combination of genetics, biochemistry and molecular approaches (CSP1606-002RTX)	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 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. a. This investment aims to: 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 and management of sandy soils

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

Increasing production on sandy soils in low and medium rainfall areas of the Southern Region (CSP00203)	Sandy soils are a valuable production resource in the cropping regions of Southern Australia, accounting for 5 Mha of the land cropped in the region. A large gap between actual yield and water limited yield potential on sandy soils in the low rainfall cropping zone of south-eastern Australia has been identified as have opportunities for the management for the constraints to productivity using combinations of mitigation and amelioration strategies. In order to support growers with problem sands to consider trialling practices to overcome the constraints to crop water-use we will provide a framework for them to: ▪ Identify problem sands ▪ Identify the primary constraints to crop water use and their relative impact ▪ Identify treatments to address constraints ▪ Identify funds, skills and equipment required to trial potential practice changes. ▪ Measure the success of each practice ▪ Identify the most useful timing and extent of implementation on-farm. As a result, an R & D effort to deliver this outcome is planned to establish the nature and extent of the constraints, to measure the degree to which the problem controls the yield gap between yield attained and yield potential and to develop appropriate and cost-effective management strategies with robust estimates of return and risk of investment. In order to deliver a consistent approach we will define a constrained sandy soil as one where the constraint to crop root exploration occurs within the sandy layer and the treatments explored will focus on mitigation and/or amelioration of the constraints within this sandy layer.
GRANT: A holistic approach to seep management for preventing land degradation in the	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,

landscape (MSF1812-002OPX)	weather and market conditions (such as the need to demonstrate environmental credentials to access markets). Sandy seeps have become a significant issue on the dune-swale landscapes in the dry areas of SA and Victoria, making productive farming soils saturated, untrafficable, and weed infested, eventually becoming saline and prone to erosion. Seeps have become more evident in the last decade, due to farming system changes coupled with high rainfall periods. Farmers identify that poor crop water use on the sand dunes along with effective summer weed control and greater retention of soil moisture has led to the expansion and formation of seeps lower in the landscape. This NLP project led by Mallee Sustainable Farming aims to apply a 'tool box' approach to seep management by: Using new and existing remote sensing tools to identify areas at high risk for seep expansion; Preventing seep formation by demonstrating high water use options for different systems; Categorising seep severity and applying the best treatment options to remediate the seep area.
High work rate 'plough and sow' technology for farm-scale sandy soil amelioration - South (MSF1806-001AWX)	As grain growers reach the upper limit of production gains with existing agronomic practices and varieties, they are becoming more focused on addressing the soil constraints that inherently limit crop performance, particularly in production limiting sandy soils in the southern region. These areas are often under low rainfall where growers have fewer available resources to invest in costly amelioration practices such as clay spreading and spading. As a soil inversion alternative to high cost mouldboard ploughing, disc ploughing has generated considerable interest in recent years as it offers a low-cost approach to soil amelioration that can demonstrate effective outcomes using modified old plough technologies. However, in the southern region context, significant drawbacks have been identified including the low speed of operation (2-6km/h), one way ploughing constraints, not well suited to up/back GPS guided work patterns for paddock zone amelioration, partial soil inversion (30-70% burial) and limited strength of older plough frames originally designed to accommodate diameter disc blades now being adapted for deep ploughing with 30-36 diameter disc blades. In addition, the delays and difficulties in subsequent sowing into very loose soil profiles with very little residues lead to erratic crop establishment and significant risks of wind erosion. This GRDC Innovations Project will develop a plough and sow proof of concept prototype of a high work rate soil inversion disc plough that will have the capacity to simultaneously deep plough and sow a crop in a one pass operation. This will offer a significant upgrade in effectiveness and efficiency of the sandy soil amelioration operations by ploughing and minimise the risk of soil erosion that currently limits the adoption of existing technology. The prototype will be developed using innovative design solutions to improve the soil inversion performance of plough discs and incorporate a seeding capability in to a one pass operation. The design will be achieved in collaboration with the Agricultural Machinery at the University of SA and the Adelaide based industry partner John Shearer Ltd. The high work rate plough will undergo field performance assessments and validation in collaboration with Mallee Sustainable Farming and the GRDC Sands Impact project to demonstrate the capabilities of the prototype and quantify its performance against other soil amelioration practices.
Identifying low pH tolerance and effective rhizobia for wild Cicer to improve adaptation to acid sandy soils (UMU00044)	Current recommended chickpea (Cicer arietinum L.) varieties for 2014 (PBA Striker, PBA Slasher, Neelam and Ambar) are considered to be moderately resistant (PBA Striker) to resistant (PBA Slasher and Neelam) for Ascochyta blight,and adapted to both southern and western Australia conditions of low rainfall and short growing season. These varieties have overcome some of the abiotic and biotic constraints identified as limiting chickpea yield across Western Australia (WA). Current recommendations for chickpea across WA, confine production to sandy loam to clay textured soils with soil pH CaCl2 of 5.5 to 9. A DAFWA study of land capability assessment for production of chickpea leaves only 3 % of land in the south west agricultural region of WA considered to have high capability and 23.7 % to have fair capability for chickpea production (White et al. 2006). Assessment of soil pH across south west WA has 70 % of surface soils and 50 % of subsurface soils with pH CaCl2 below target levels of 5.5 and 4.8 respectively. In WA, at low pH (pHCaCl2 less than 4.5) aluminium, which is abundant in these soils, is solubilised releasing ions that are highly toxic to roots and bacteria. Aluminium toxicity inhibits cell division and reduces root elongation of plants. Severe symptoms of aluminium toxicity include brown stubby roots and decreased fine branching roots. Such effects on root growth not only impair nutrient acquisition by crops but may also limit symbiotic development as well as exacerbate drought by restricting access of roots to soil and stored soil water. A recent GRDC funded program has built on the collections of wild relatives of chickpea (wild Cicer) collected

	from south eastern Turkey. Whilst these wild relatives are not fertile with the domesticated C. arietinum L., the incorporation of traits from these wild relatives into the chickpea breeding program may allow chickpea to be produced in areas currently considered to have fair and poor capability. The wild Cicer collected is to undergo a wide program to phenotype traits which may be used to improve domesticated chickpea in breeding programs. This project will investigate the tolerance of wild Cicer accessions to low pH and sandy soils. These accessions then have potential to be included in the chickpea breeding program specifically to target acid sands including the areas where lupins are currently grown in WA.
Nutrient re-distribution and availability in ameliorated and cultivated soils in the Western Region (DAW1801-001RTX)	The area of soil used for crop production that is being modified with mechanical soil amelioration is increasing rapidly in the Western Region; however, there are significant knowledge gaps for nutrient management. Mechanical soil amelioration is being adopted to ameliorate soil water repellence, soil compaction, herbicide resistance and soil acidity, and in some cases, more than one of these constraints occur within a paddock. Mechanical soil amelioration is being completed with mouldboard ploughs, rotary spaders, disc ploughs, and deep rippers with and without inclusion plates. All of these mechanical approaches introduce spatial variation in soil nutrient supply, root growth, or both. However, at present, there is a significant knowledge gap in how crops utilise soil nutrients and respond to nutrients applied as fertilisers after amelioration. This project will deliver new knowledge to improve nutrient management on ameliorated soils through a program of research that integrates different spatial scales, and extension. The project includes work on soil N processes and the fate of soil organic matter in soils that have been treated with mechanical soil amelioration. This work, in combination with a detailed study on the effect of a change in the spatial distribution of soil nutrients on root growth and soil water uptake, will be used to guide the design of subsequent field experiments, and extrapolate results from these. Field-plot experiments will be used to examine whether mechanical soil amelioration interact i.e. does the plant-availability of soil nutrients change after mechanical soil amelioration? And, does nutrient use efficiency change? The knowledge gained from this work will be fused with paddock scale experiments that utilise natural variability in soil nutrient supply to elucidate the factors that determine yield response to a nutrient. This integrated approach to research will deliver the knowledge base required to improve nutrient management on ameliorated soils. This collaborative proposal brings together the capacity to deliver the research and extension required. The skill base of the group is broad and deep, and includes: field crop nutrition, soil N processes, geostatistics, decision support, spatial modelling and crop simulation modelling. The team has a proven capacity to identify the research questions that need to be addressed to improve profit, complete laboratory, glasshouse and field experiments and simulation modelling. The team also has the capacity to deliver a project with integrated research and extension. The project will deliver extension to at least 300 growers, advisors and industry professionals each year. Extension will be delivered at field days, research updates and workshops in collaboration with PROC-9175173 and 9175172. This project will operate as part of a research program in collaboration with PROC-9175173 and PROC-9175172, under the umbrella of the Western Region Nutrition Program, facilitated by SoilsWest. Assoc. Prof Hoyle is allocated 0.05 FTE for the coordination of work between this proposal and PROC 9175171 and 9175172.
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: Identifying the most profitable and long-lasting soil amelioration and amendment strategies for managing multiple interacting soil constraints. 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. 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.
Post-Doctoral Fellowship: Understanding causes of physical constraints in sandy soils and implications for targeted deep tillage (CSP1906-009RTX)	Physical constraints to crop water-use are prevalent in sandy soils of the Southern Region, but the nature of the physical constraint and crop responses to strategic deep tillage varies significantly. Barriers to adoption include variable yield responses, concerns over short-term ripping effects, and the erosion risk of spading/mixing approaches. A lack of understanding around the behaviour of physical constraints hampers the ability to improve diagnosis and to predict the response to deep tillage in different sand types. The relative role of high bulk density and/or chemical cementing in limiting crop water-use in different sand types is thought to play a role in these different responses but is poorly understood. In the low rainfall environment, understanding the relationship between soil strength and moisture through the growing season is important to better predict the likely responses to physical amelioration across different seasons.
Demonstrating the benefits of soil amelioration and controlled traffic practices across a broad range of soil types in Western Australia. (WMG1803-002SAX)	Soil amelioration is a key part of farming systems in Western Australia to overcome soil limitations to crop production. The removal of soil constraints such as compaction and water repellence through strategic tillage practices generally leads to increases in crop production in successive years. One of the limitations that threatens the longevity of these benefits is that the soil can re-compact over time following amelioration, often leading to levels higher than before amelioration. Currently, the solution is to repeat the deep ripping process every few years, with the period between deep ripping dependant on the soil type and amount of wheeled traffic on the paddock. This is a costly repetitive process that may become unsustainable in the long term as soils become compacted to greater depths with successive tillage treatments and larger/heavier machinery. While there is a good network of demonstration sites established across the port zones of WA, there are a number of soil types where the benefit and longevity of soil amelioration practices are unknown. The adoption of controlled traffic practices by growers is one tool that can potentially increase the longevity of soil ameliorative practices, by reducing soil compaction from wheel traffic by confining this to permanent wheel tracks across the paddock. However, the potential of controlled traffic practices to increase the longevity of amelioration treatments has only been evaluated on a narrow range of soil types. This project aims to evaluate and demonstrate the benefit of soil amelioration across a wider range of soil types that are common to the WA grain growing region.

Increasing farming system profitability and longevity of benefits following soil amelioration (DAW1901-006RTX)	The purpose of this investment is to identify management changes that will preserve the benefits of soil amelioration and maximise profitability for growers. The research will determine the most profitable crop rotations, species choice and seedbed preparation that maintain the long-term benefits of soil amelioration while managing the risks, such as wind erosion and poor crop establishment. The amelioration process involves 4 phases. 1) Pre-amelioration site preparation, amendment application; 2) Amelioration implementation phase with large logistical and time input; 3) 2-3 year post amelioration transition phase characterised by soft soil, large flush of nutrition, acute short-term wind erosion risk and high crop responsiveness; 4) New stabilised yield potential phase where site has settled and immediate tillage effect on nutrient release has dissipated. Research and consultant analysis indicates that amelioration of sandplain soils is highly profitable. Factors that limit adoption or benefits of soil amelioration include uncertainty about how to sustain long-term benefits, poor crop establishment and potential for erosion in the year following amelioration (RCSN 2018). This project will address the timing of amelioration, rotations and species choice immediately following soil amelioration (transition phase) to capitalise on improved yield potential in subsequent seasons (post-transition phase) and suppression of biotic constraints. Increases in crop production on these soils are dependent on effective crop establishment. This project will investigate the main factors affecting establishment including seedbed preparation (soil consolidation) and furrow formation. The crop establishment element of the research will investigate the effect of amelioration and seedbed preparation on herbicide activity and plant establishment of lupin, wheat and canola where crop safety with currently used herbicides is has shown to reduce plant stands. Alternative amelioration timing and implementation systems aim to maximise the profit obtainable from amelioration while minimising the risk of wind erosion and poor crop establishment in the first few transition years following the amelioration. Shifting the timing of amelioration to winter or spring with a following late sown cereal, summer crop or cover crop could have multiple benefits. These include: • Undertaking amelioration when wind erosion risk is low; • Undertaking amelioration when soil moisture conditions are likely to be ideal and • Allowing time for soil to settle and consolidate and having some stubble cover to ensure effective establishment and optimum yield outcomes in the first full cropping year. The profitability of this approach needs to be determined as it may increase the opportunity of growing a high value break-crop in the early transition years when yield response can be at its highest. Crop rotation and species choice may consolidate the benefits of soil amelioration by: 1. sustaining the suppression of weeds, pests and diseases; 2. improving soil fertility; 3. improving subsoil root access through re-generated root channels ('biological ploughing') which could increase subsoil water and nutrient access (Henderson 1989; McCallum et al. 2004; Nuttall et al. 2008).
DAS00169-BA - Improving sustainable productivity and profitability of Mallee farming systems with a focus on soil improvements	The aims of the agronomy program within the bilateral agreement are that relevant and targeted research is undertaken in the main cropping regions of SA, that delivery of research outcomes to the regions is via locally relevant validation trials and that regional capacity is maintained in applied research and with farming systems groups. At the core of this bilateral initiative, is the recruitment, retention and training of the next generation of agronomists required to serve farmers' needs in the regions. As part of the bilateral agreement a research agronomist position has been created within SARDI to deliver applied research and validation in the SA Mallee, to be based after training and induction at Loxton. This position will be based within the Farming Systems science area of SARDI which has a key focus on low rainfall farming systems and will be supported and mentored by staff within that science area and by other scientists and technicians also based at the Waite Research Precinct e.g. (within the Agriculture flagship of CSIRO, University of Adelaide and Rural Solutions SA). The Mallee environment is a major but fragile agricultural production zone in southern Australia. Farming systems are dominated by large scale family farms which integrate cropping and livestock production across widely varying soil types in an environment characterised by low and variable rainfall. Many of these soils are coarse textured and highly weathered which makes them vulnerable to wind erosion, conducive to soil borne diseases and often very infertile. Crop and pasture production is constrained by these soil based limitations which results in poor conversion of the low and erratic rainfall into saleable commodities. This position will support local FS groups and other relevant organisations (e.g. NRM boards) to directly address and overcome productivity and sustainability constraints in the Mallee zone of SA, with the results

	being directly applicable to other Mallee systems of southern Australia. The incumbent will use these groups and other relevant organisations (e.g. Low rainfall RCSN) to identify high priority issues, add value to their existing D and E activities and initiate their own to address these high priority issues. Due to the fragile and constrained nature of many Mallee soils, this position will have a focus on soil-based constraints and develop skills and experience in this important area.

Effective summer weed control including issues identified by the RCSN -

"Herbicide options and tips and tactics for summer weed control because restrictions on the use of important products has meant that spraying may not be able to occur under optimum conditions as the window for spraying has narrowed"

"The loss of glyphosate as a major tool through either regulation or resistant weed species would significantly impact on the profitability and sustainability of farming systems in low rainfall zone"

"Phenoxy herbicides – alternatives"

GRDC investments addressing this issue

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

Practical and applied workshops and communications to promote key messages and resources to maximise the effectiveness of spray applications in the Southern Region (BWD1803-005SAX)	Crop protection products are used extensively in the grains industry and are an important part of grain growing operations to control weeds, insects and disease and to maximise grain productivity and profitability. In recent times, media reports have highlighted several instances of off-target spray drift, causing significant damage to neighbouring crops. This project will provide training that improves the efficiency of spray applications to improve profitability on-farm which also promoting practices which minimise spray drift. By the projects conclusion in 2020, at least 180 growers and spray operators across the GRDC Southern region will have increased their knowledge base around effective spray applications. The project team, led by BCG, includes Bill Gordon (Nufarm), Jorg Kitt, Graeme Tepper and the Ag Excellence Alliance. The core project activity is a series of practical and applied workshops (a minimum of 24 across the life of the project) to be held across the GRDC southern region in areas identified as highest priority for this type of training. This prioritisation (output 1) will be based on historic access to similar training, areas where spray drift can have significant adverse consequences and/or areas identified by the project team as having a lower understanding of the subject matter. Workshop format will be based on an existing workshop format, developed and delivered by Bill Gordon and ongoing since 2012. This workshop in its current format, plus Bill Gordon's expertise is demanded by industry and is currently being delivered across Australian grain growing regions, including a Longerenong workshop in conjunction with BCG in January 2018. Topics covered will include sprayer set-up, product choices, weather conditions and other resources available to help reduce spray drift to ensure industry is using products responsibly and maintaining grower awareness. Continual refinement of the workshops will occur to ensure that the project team respond to local and or emerging issues. Communications will be leveraged to ensure that target audience members who cannot attend a workshop are still able to access project key messages and resources. Communications from this project will build on existing GRDC communications developed over the past five years. Including GRDC GrowNotes™ spray application manual, fact sheets: pre-harvest, pre-emergent and in-crop herbicide use. A wide array of communications will be used such as factsheets, GroundCover articles; media releases and interviews, webinars; podcasts; video and grower case studies but not limited to these only. Social media will be used extensively where appropriately to further promote the project.
GRDC Australian Glyphosate Sustainability Working Group (ARN00001)	Produce the latest information on the status of non-selective herbicide resistance and effective management strategies relevant to their farming systems through a nationally coordinated extension program that includes a specific web site, media releases and extension materials. Integrated weed management training programs will be modified to incorporate the latest developments. A consistent message on the management of glyphosate, paraquat and Group I resistance is extended across Australia. Web site - http://www.glyphosateresistance.org.au Facebook - https://www.facebook.com/Australian-Glyphosate-Sustainability-Working
GRDC – Bayer Crop Science Herbicide Innovation Partnership (HIP00001)	Investment in herbicide discovery. Increasing capacity of Bayer the leading cereal herbicide multinational. Australia lifted to priority 1 status in preliminary screening (equal with EU, USA and South America) with 10 Australian weeds in primary screening and primary field screening of molecules occurring in Australia.
Improving IWM practice of emerging weeds in the southern and western regions (UA00149)	This project will provide new tools that will allow better understanding and control of summer weeds: fleabane, windmill grass, Feathertop Rhodes grass, tar vine, button grass and sowthistle/milkthistle, in the Southern and Western Regions. It will also provide new tactics for the control of herbicide-resistant wild radish, barley grass, brome grass and Indian hedge mustard in the Southern and Western Regions. Research seeking to understand the incidence, density and emergence patterns of emerging summer weeds (fleabane, sowthistle, windmill grass, Feathertop Rhodes grass, button grass and tar vine) has shown that these species are becoming widespread across the grain growing regions. They prefer to germinate from the soil surface, meaning they become more common in no-till systems. Most species have a wide temperature range for germination, meaning they can emerge at any time of the year when conditions are favourable. However, in Mediterranean environments they tend to emerge during spring and persist into summer.

	Generally, these species have low levels of seed persistence in the seed bank and seed banks can be exhausted within 12 months, provided effective control occurs. Control studies have shown that common summer fallow herbicide applications are generally not effective. Double knock applications are more effective. Pot studies and field trials show that residual herbicides applied during winter can reduce emergence of these weeds in spring and where registered may prove more effective than relying on summer sprays. Crop competition in the cereal phase is also helpful at reducing population numbers in summer. Control of herbicide resistant wild radish requires a 2 spray approach to be effective. One spray needs to be applied early, either as a pre-emergent or an early post-emergent application. Due to its persistent seed bank, at least 3 years of effective control are required to run down seed banks. Control of herbicide resistant barley grass requires the use of effective pre-emergent herbicides along with crop competition in cereals and crop-topping in pulse crops and pastures. Glyphosate resistance in some species, such as fleabane, windmill grass and Feathertop Rhodes grass, is occurring on roadsides and may move from there into cropped fields. The results of the research are being delivered to growers through field days, fact sheets, GRDC Updates and other avenues.
Australian Herbicide Resistance Initiative - Phase V (UWA00171)	Sub Project investigating targeted tillage and also focussing on low seed bank farming systems and corresponding ecological weeds changes 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.
Locally important weeds (DAW00257)	This project will undertake research to quantify the biology and ecology of eight (8) locally important weed species, 4 in the western region and 4 in the southern region. The weed species have been selected following a consultation process with the Regional Cropping Solutions Network (RCSN) and major Grower groups, with the final input and decision coming from GRDC. Weed species include matricaria (Oncosiphon spp.), marshmallow (Malva parviflora), stinking lovegrass (Eragrostis cilianensis) and Feathertop Rhodes grass (Chloris virgata) in the western region and Lincoln weed (Diplotaxis tenuifolia), wild vetch (Vicia sativa), caltrop (Tribulis terrestris), and Lake Boga poppy (Hypercoum pendulum) in the southern region. These weeds are of local importance but have not been the subject of major prior research projects.
Virtual fencing for better crop integrated weed management CSP1906-008RTX (2019-2022)	This investment will test the use of targeted grazing in a crop, pasture and summer fallow setting using virtual fencing for 'zonal' or patch grazing aimed at maximising weed control value and minimising crop and environmental impact.
Intelligent Robotic Non-Chemical Weeding UOS1806-002AWX (2018-2020)	Site-specific weed management is based on the ability to accurately identify and precisely apply weed control treatments. This approach to weed control results in substantial control cost savings (60-90%), depending on weed density, as well as the reduction in environmental and off target impacts. At present, in large-scale grain production systems site-specific weed control can only be used in fallow situations with manned spray rigs using optical sensors to detect weeds. Autonomous systems capable of site-specific weed control amongst crops has been developed for horticultural and grazing livestock production systems that use vision and spectral sensors with machine learning techniques and directed spray technology to identify and control weeds present. This same team is proposing to develop an autonomous platform suited for large-scale grain production systems that uses laser weeding and site-specific control. It is proposed that this autonomous platform will operate continuously through the period from late-post emergence to anthesis. During this extended two-month period the autonomous vehicle would target low density weed populations present in crops as survivors of early season herbicide treatments or late emerging plants. During this period the need to control weeds is for the prevention of inputs the seed and, therefore not the urgency for preventing yield loss due to crop competition effects. The project will bring together the robotics and machine learning capabilities of the Australian Centre for Field Robotics (ACFR) who have a decade track record on developing autonomous systems for the agriculture industry, with the internationally recognised photonics capability of the Sydney Astrophotonic Instrumentation Laboratories (SAIL), and the Weed Research group at the Plant Breeding Institute.
Validation of spray droplet movement under different surface air inversion conditions	For many pesticides it is an APVMA mandatory requirement not to spray when surface temperature inversions exist. The current label statement "Do not spray if an inversion exists" is non-discriminatory as it determines that all inversions pose the same risk; when in fact they do not. Inversion detection of itself does not define the severity of inversion conditions and not all inversions pose the same risk. Some pose the 'typically expected'

UOQ1902-006RTX (2019-2020)	risk; being the potential for quite-high pesticide concentrations slowly drifting across or just above the surface whilst others little if any risk. Field studies conducted with commercial scale broadacre ground spray equipment will determine the spray droplet movement under differing surface inversion conditions. These studies will be used as part of the validation potential new inversion detection technologies, providing data to meet the regulatory requirements for approval of any such new technologies. Currently, applicators rely on basic clues to detect inversions which inevitably lead to many missed events and false alarms. Extension of the research and anticipated outcomes in providing growers supportive spray-application decision technologies will lead to economic, environmental and social advantages by reducing pesticide drift impacts.

Sprayer calibration / application workshops to increase spray efficiency and efficacy BCC1910-001SAX (2019-2022)	This investment proposes the engagement of an extension specialist to educate WA broadacre grain growers (particularly the new generation, those with new machinery and/or grower employees) on how their spray equipment should be best set-up and calibrated. The investment also presents an opportunity to discuss with growers the best practice for getting product to the target and avoiding spray drift issues. Workshops will deliver to attendees current 'best practice spraying' information, enabling them to make correct and effective decisions across different spraying situations.
	
	Working closely with grower groups or other relevant groups (where no active grower group exists) to deliver the workshops, the workshops will specifically include:
	
	• Sprayer set-up
	    ▪ Calibration
	    ▪ Stability
	    ▪ Ground speed
	    ▪ Hydraulic nozzles v's PWM
	    ▪ Different spray controller systems
	• Operational efficiency
	    ▪ Travel time / distance to filling points
	    ▪ Use of batching / mixing equipment
	• Efficacy
	    ▪ Nozzle selection
	    ▪ Spray quality
	    ▪ Coverage
	    ▪ Getting the product to the target
	    ▪ Differing requirements of product types
	    ▪ Contact v's systemic herbicides
	    ▪ Insecticides
	    ▪ Fungicides
	• Drift mitigation
	    ▪ Weather conditions
	    ▪ Spray quality
	• Farm safe chemical handling message.
	
	As echoed by GRDC survey data, which indicates that growers' value face-to-face training, the information will be practical and delivered safely on-farm using grower's own machinery. As such, a minimum of two sprayers (standard nozzle sprayer and pulse width modulation) and three batching plant/mixing systems will be made available for the purpose of demonstration during the workshops, with the assistance of local growers/grower groups.
	
	A post workshop survey will be incorporated into this investment in order to measure the grower practice change as a result of attending.

UQ00080 - New uses for existing	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

chemistry° UOQ1507-001RTX (2015-2020)	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. The focus in the southern region will be to find alternative options for controlling winter grass weeds. The northern region will have the objective to find alternative products or combinations of products for optical spray technology application or developing new treatments for more recently discovered glyphosate-resistant species. In the western region, work will finalise new treatments to combat wild radish. The results will be delivered to consultants and growers through the GRDC Farm Advisor Updates and GRDC Farmer Updates in each region, through articles in the farm press and electronic articles.
Spray Drift Inversion Hazard System Program Coordination BET1810-001WCX (2018-2020)	This investment is designed to provide Australian grain growers with an effective tool to determine surface inversion conditions to be able to apply agricultural chemical sprays in compliance with Commonwealth, State and Territory legislative requirements by October 2022.
Development of 'Nowcasting' ability for hazardous and non-hazardous atmospheric conditions for agricultural spraying CER1908-001SAX (2019-2020)	This investment is designed to enable access to world-class spray application decision technology to predict air inversion that is recognised by regulatory authorities.
UQ00072 - Spray application management (DRT modelling, managing surface-temperature invers (2013-2017)	The Australian grains industry is facing economic loss due to regulation of existing pesticides and associated application due to continued adverse spray drift events and lack of current suitable data to support current best practice. There is also potential increased regulation of pesticide products due to current pesticide use practices and stewardship including residue management and spray drift. There is new innovation and tools to reduce spray drift risk that needs further testing and evaluation to support its use and regulatory approval in Australian conditions. To address these gaps, there is a need to develop new knowledge and tools for use by regulators, manufacturers, advisors and growers. This project will generate field and wind tunnel data to strengthen the National Working Party on Pesticide Applications (NWPPAs) drift reducing technologies (DRT) framework. Many adverse drift incidents occur under conditions of surface-temperature inversions. These inversions restrict the timing of spraying operations. This project will also determine what the safe minimum droplet size is that can be used and which nozzles tips don't contain suspended fine droplets under stable atmospheric/surface-temperature inversion conditions. Previous work aligned with the NWPPA has determined the droplet size spectrum and spray quality for a large range of nozzles, pressures and tank mixes. Knowledge is missing on the level of herbicide efficacy that a grain grower will achieve with medium and coarse spray qualities on grass and broadleaf weeds. Adoption of new DRT practices will be slower when uncertainty exists. Efficacy studies will be conducted on grass and broadleaf weeds using medium and coarse spray qualities so growers will be confident that weed control will be maintained with these sprays.
DAW00231 - Management of spray drift through inversion risk awareness (2013-2017)	For many pesticides it is an APVMA mandatory requirement not to spray when inversions exist. To comply with this legal requirement, applicators must anticipate and detect inversion occurrence at the target prior to and during application. Currently, there are no practical or viable risk mitigation systems in place for at the target detection. Applicators currently rely on general forecast advice and basic clues to support a best guess. There is clearly a need for improved inversion risk management systems. A pilot scoping study has been proposed to test the feasibility of robust and economically viable instrumentation and high-resolution modelling to detect and predict surface inversions and to quantify

	conditions (such as drainage wind occurrence) within inversions that affect the transport and dispersion of airborne pesticides for specific locations. It is anticipated that results of the scoping study will lead to: Decreased incidents of spray drift due to a better understanding and awareness by growers and the general community about the micro-climate variables related to inversions. A code of practice to assist grower decisions evolving from the information gathered from the analysis of instrumented towers and from the modelling; a code similar to the harvesting codes where a family of variable conditions determines risk and acceptable practices. Third party providers of spray advice will gain knowledge and data to improve and enhance outputs. Applicators being better placed to make wise decisions when armed with detailed micro-climate information over specific targets: particularly in regard to drainage and blocking wind flows that have critical impact on the destination of airborne pesticides when surface inversions exist. Applicators complying with APVMA regulations. Agronomists and trainers being wiser and better armed to give advice as to the frequency and intensity of inversions, the general conditions that are conducive to inversion conditions and accompanying micro-climate effects .The development and deployment of affordable and robust automatic weather station instrumentation that is best suited to detection inversions and to determine spray drift dispersion characteristics.
CRC00004 - Improving spray fallow techniques for better moisture conservation (2015-2018)	The aim of this investment is to develop an improved herbicide fallow/crop rotation to help low rainfall farmers produce profitable crops in low rainfall zones and reduce the risks of seasonal variability, low rainfall, resistant weeds and growing non profitable crops in low rainfall years. If such a package could be developed, then in one system, we could achieve some solutions for many of the main threats to our low rainfall farmers are facing: Drought proofing crops by effectively and cheaply storing soil water in a fallow. Reducing reliance on Glyphosate for control of winter weeds including resistant rye grass. Reducing the time growers spend on machines in winter controlling multiple weed germination events. Reducing the time growers spend at night in summer controlling summer weeds in warm, dry and sometime hostile spraying conditions. Taking advantage of new technology like new two-gene Clearfield wheat, IMI tolerant barley and new dual tolerant Roundup Ready/Clearfield canola. Improving Cropping options by offering a profitable cereal or oilseed option the year after a spray fallow. Saving growers money and energy on herbicides and numerous passes with sprayers over a paddock. General methodology: This project will run over three seasons and will be run over three sites; two in the Geraldton RCSN zone and one in the Kwinana East RCSN zone. This allows for testing of a range of treatments for winter and summer weed control in the first and second season and testing a range of crop types in the treated soil to assess their tolerance to the residues and their ability to achieve their full potential on a profile of stored winter and summer moisture, in the second and third season. Winter and summer weed control will be assessed in the fallow year. Control of winter weeds will be assessed in the subsequent winter crop. The potential synergy between the long-term soil-applied residual herbicides and the post emergent winter sprays will also be assessed. Grain yield, grain quality, overall profitability and ROI analysis will be assessed, as well as the potential saving on farm logistics, farm labour and reduced reliance on Glyphosate on both winter and summer grasses.

Better adapted cereal varieties i.e. shorter season varieties with a longer flowering period and cereal ideotypes for low rainfall environments

GRDC investments addressing this issue

ULA9175069 - Development of crop management packages for early	This GRDC investment will provide growers and advisers in the low and medium-rainfall zones of the southern region will have access to more agronomic knowledge and supporting data to allow them to take advantage of early sowing opportunities with winter and slow developing spring wheats.

sown, slow developing wheats in the Southern region ULA1703-004RTX (2017-2020)	The investment will provide greater understanding of the optimum time of sowing for new cultivars, risks and impacts of drought during vegetative stages, potential threats from weeds, diseases and pests, opportunities for grazing, and nitrogen management and crop density recommendations.
UA00147 - Genetic analysis of heat tolerance in wheat UOA1406-004RTX (2014-2019)	This investment is designed to identify chromosome regions governing variation in heat tolerance and deliver DNA-based genetic markers that breeders can use to select for the favourable chromosome variants. By reducing the reliance on inconsistent field-based tolerance screening, these markers will allow the breeders to produce heat tolerant varieties more efficiently, thus helping to make the wheat industry less prone to the impacts of a warming climate. The project will be a collaboration between the University of Adelaide (Australian Centre for Plant Functional Genomics and Statistics for the Australian Grains Industry) and the NSW Department of Primary Industries (Wagga Wagga and Tamworth). Chromosome regions governing heat tolerance traits will be identified by following segregation in experimental populations derived from bi-parental crosses, as well as by identifying marker-trait associations across a broad collection of elite and exotic germplasm. The association mapping exercise, and a screen for durums better able to maintain floret fertility under heat, will reveal potentially new sources of tolerance, which will then be investigated genetically by making new populations. Heat tolerance data will be collected using a growth chamber as well as field trials at Wagga Wagga and Leeton. In the field trials, late sowings with irrigation will be used to apply heat stress. Sub-sets of the populations will be trialled more widely to estimate the yield advantage of particular heat tolerance traits in different wheat growing regions of Australia. They will also be grown using a normal sowing time and without irrigation, to check whether there are yield penalties under commercial production conditions. Lines possessing heat tolerance traits identified in greenhouse/chamber experiments (maintenance of chlorophyll and single grain weight) will also be evaluated in the field to establish the relevance of these assays to heat tolerance breeding. Closely related sister lines contrasting for variants of the major grain proteins (glutenins) will be used to test whether these variants can affect the response of dough strength to heat exposure during grain growth. The findings will indicate whether the glutenin alleles are useful as markers to select for quality maintenance under heat. The study will therefore provide the industry with information on the breeding value of the various markers and tolerance traits, as well as the effectiveness of various approaches for identifying useful sources of heat tolerance.
UMU00050-DAW00240 - Manipulating barley phenology to maximise yield potential (UMU1406-002RTX) (2014-2020)	The time of flowering (awn appearance/heading date) is known to be the single most important trait that determines the adaptation and yield of barley, and other cereals, to the variable climates and diverse growing regions of the Australian grain belt. High levels of inter- and intra-seasonal rainfall variability cause large fluctuations in grain yield and quality in large measure associated with flowering time and the consequent pre- and post-flowering water use. Achieving the highest possible yields and the best quality requires that the critical event of flowering and the following period of grain production coincide with optimal seasonal conditions in terms of rainfall and temperature. Barley genotypes vary genetically for the period they require from planting to flowering and maturity; and combining desirable genes that underlie the variations in phase development and flowering behaviour (phenology) always has and will continue to play a core role in breeding better adapted barley varieties for Australian growers. The flowering time is determined by the genotypes photoperiod (PPD), vernalisation (VRN) and earliness per se (EPS) genes and their interactions with environmental factors. Several key genes have been identified and various allelic forms of these genes have been discovered, and next generation sequencing technology and completion of the barley genome sequence now provide more efficient tools to identify new genes and alleles for phenology. Up until now the combining of those desirable genes has been by serendipity rather than design, as the tools to identify and track them have not been available. A second major hurdle is that no field performance/ validation data is available to understand the interaction of environmental factors and the various genes/alleles controlling phenology for achieving the best yield and yield stability in the target environments. The Australian barley breeding programs have made significant progress in development of the new barley varieties in the last few years. Hindmarsh, Latrobe, Compass, Granger and Commander have demonstrated high yield and yield stability in the barley NVT trials. However, no public information is available on their specific phenology gene alleles and allele combinations to understand their success in specific environment groups (clusters) identified in the NVT trials. Thus, breeding programs currently select inefficiently as large numbers of progeny are advanced through early generations, only to be culled later due to incorrect phenology. In addition, pre-breeders need a better understanding of barley phenology so as to provide pre-breeding materials with more repeatable responses to environmental changes.

	Finally, the ability to quantify the value of novel phenology traits in barley by simulating effects of allele combinations and sowing date on barley yield across diverse environment types using the crop simulation framework Agricultural Production Systems Simulator would be of enormous value to breeders and pre-breeders. This project will use innovative approaches to develop germplasm, allele-specific molecular markers and APSIM simulations aimed at breeding specifically adapted barley cultivars with high grain yield and quality through manipulation of phenology genes. The proposed research recognises the importance of a multidisciplinary approach and brings together barley pre-breeders, molecular geneticists, plant physiologists, agronomists, biometricians and barley breeders from the Department of Agriculture and Food Western Australia, University of Tasmania, Murdoch University, Australian Grain Technologies Pty Ltd, InterGrain Pty Ltd and the University of Adelaide barley breeding program.
CSP00175 - Maintaining wheat grain number under reproductive-stage drought conditions. CSP1307-005RTX (2013-2020)	In Australian environments, optimising wheat yields is a careful balancing act between conditions that are either too cold or too hot and dry. Unpredictable weather conditions at the time of flowering cause large yield fluctuations on a regular basis. Stabilising productivity of wheat crops in an unpredictable and changing environment requires wheat varieties that are more tolerant to abiotic stress conditions (terminal drought, heat, chilling and frost). Progress in breeding for wheat varieties with higher resilience to abiotic stresses is difficult in the field and has been hampered by: • Variability of field environments - occurrence, timing and severity of stress conditions are beyond control. • Lack of reliable and reproducible screening methods - what is the right trait to screen for? • Lack of physiological and molecular understanding about the effect of stresses on grain number and size. • Complexity of abiotic stress tolerance. In GRDC projects CSP00089 and CSP00130 we have made important progress in establishing screening methods for drought tolerance under controlled environment conditions. Even relatively mild drought stress affects pollen fertility, while the female part of the flower remains receptive to pollination. Without fertile pollen there is no fertilisation and no grain development. We exploited this high stress sensitivity of pollen to develop a screening method that is based on applying short periods of water stress at the young microspore stage of pollen development. The traits we are screening for are maintenance of pollen fertility and grain number. Using this method we were able to identify wheat germplasm with higher resistance to drought conditions. Abortion of pollen development is a scenario caused by different abiotic stresses (drought, heat, cold, shading/light stress), suggesting that a common regulatory mechanism for pollen fertility is triggered by different abiotic stresses. Our drought-tolerant line Halberd is known to be more tolerant to heat and frost conditions. We found there is a significant overlap in the genetic control of drought stress and another stress that induces pollen sterility, including shading or low-light stress. Shading stress is easier to apply than osmotic stress, and because it targets the same genetic mechanism as drought stress we can use shading as a surrogate screening method. The aim of this project is to: Identify flanking markers for two tolerance loci-of-interest that overlap between drought and shading stress. The main focus will be the tolerance loci of the Cranbrook x Halberd population. Refine the interval between the flanking markers of these tolerance loci in order to identify more closely-linked markers that can be used in marker-assisted breeding. This will be achieved using the multi-parent advanced generation inter-cross (MAGIC) population tool for fine mapping developed at CSIRO Plant Industry. Use flanking markers to identify wheat lines that will be evaluated under field conditions (rainout shelter, Yanco MEF). This material will also be tested for heat and cold/frost tolerance. Make available information of breeding lines and flanking markers to breeders for introgression into elite breeding lines. The flanking markers can be used to identify the presence of the drought-tolerance alleles in existing breeding lines. The approach we are presenting targets an important issue for wheat grain productivity under adverse weather conditions: the ability to maintain pollen fertility and grain yield. The outcome of this project will be tools and a strategy to produce wheat varieties that are better able to maintain grain yield under terminal drought conditions and potentially also other stress conditions (heat, chilling/frost conditions).These new wheat varieties may protect the industry from the effects of climate change and increased frequency of inclement weather conditions during flowering.
ANU00020 - The generation of wheat cultivars	Producing drought tolerant varieties of wheat with negligible impact on yield in good seasons is critical for the success of the Australian farming sector. Avoiding GM will streamline the speed at which new genetic material can be incorporated into breeding programs. There could be improved productivity in dry seasons and regions. In a significant study carried out on the model plant Arabidopsis (a relative of canola), we

with improved drought tolerance ANU1306-001RTX (2013-2019)	discovered earlier that plants lacking a functional copy of SAL1 gene are more drought tolerant. In other words, this genetic variation or mutation, enhances the capacity of plants to survive for up to 50% longer in water deficit conditions. In order to exploit this knowledge to understand the drought response mechanism in the cereal crops, such as rice or wheat, we undertook a project funded by GRDC. The aim of the project was to investigate the role of SAL1 gene in the Australian wheat variety Chara. We discovered seven copies of this gene in wheat and assigned their chromosomal locations. We identified 10 wheat lines lacking two out of the seven SAL1 genes. The proposed project would be the continuation of previous study which aims to analyse the wheat lines with non- functional or reduced level of SAL1 activity. A pairwise crossing program involving 10 identified SAL1 mutants has been initiated to study the effects of these mutants on drought tolerance. This project will employ a breeding program to combine more than one mutation in a single wheat line to improve the chances of achieving significantly enhanced drought tolerance. Drought tolerance and yields of these combinations of mutant lines will be characterized under both water stressed and well-watered conditions in the glasshouse and in Managed Environment Facilities. We hypothesize that the best combination of SAL1 mutant lines may remain green, turgid and photosynthetically active, producing more leaves, flowers and seed during mild to moderate water deficit periods. Additionally, we will measure the molecular and biochemical traits (ABA, SAL1 and metabolites) in a subset of the selected Australian wheat varieties under water stressed and well-watered conditions. This study will enable us to determine the underlying biochemical basis of drought tolerance in elite cultivars and potentially correlate ABA, SAL1 or specific metabolites with drought tolerance in Australian wheat. The expected outcomes of this project are as follows: 1. This study will provide the growers with access to wheat varieties with higher yields than current dominant varieties under moisture-limited conditions. 2. Intermediate Outcome: Breeders deploying SAL1 mutant genes in their breeding programs to increase wheat yield stability under water limited conditions. 3. SAL1 established as a marker of drought in wheat.
CSP00202 - Identification of wheat frost tolerance loci using a combination of genetics, biochemistry and molecular approaches CSP1606-002RTX (2016-2021)	In Australia, spring wheat varieties are sown in autumn to develop during winter and are harvested in spring to avoid summer heat and drought conditions during grain-filling. This exposes wheat crops to damage from unpredictable spring frosts. Climatic studies have demonstrated that in Southern Australia the frequency of spring frosts has increased significantly since 1960 and the length of the frost season has increased by one month, resulting in increased occurrences of frost damage to wheat crops during flowering. Sowing later to avoid the risk of frost damage is not an option, as depletion of soil moisture during the hot and dry summer months will also result in catastrophic yield losses, as both grain-setting and grain-filling are compromised by heat and drought conditions. In contrast, earlier sowings or using varieties that flower earlier in spring provide the best opportunities to convert available soil moisture into higher grain yields. To realise this goal it is essential to improve frost tolerance of wheat varieties. The GRDC has therefore 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 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. The potential of wheat to re-acclimatise to cold and frost during reproductive growth is poorly understood. This project will use controlled environment phenotyping to screen four mapping populations and identify cold-tolerance loci quantitative trait locus (QTL). The tolerant and sensitive tail lines of these mapping populations will be evaluated under field conditions to identify the most promising lines for cold tolerance breeding. Gene expression and metabolite profiling studies will be continued to identify biochemical processes that can be used to quantify cold acclimation potential. Candidate genes and metabolite markers will be evaluated on tolerant and sensitive wheat lines grown under controlled environment and field conditions. This approach will lead to the development of alternative screening methods that will support field-based germplasm screening efforts of the NFI. The project will also continue to provide testing capacity

	of interesting new varieties to validate field observations. The outcome of the project will be phenotyping know-how, DNA and metabolite markers, as well as wheat lines with improved frost tolerance.
Improving frost and heat stress management for SA Durum growers DAS2001-005BLX (2020)	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.
CSP00183 - Pedigree based association genetic analysis of wheat phenology CSP1401-008RTX (2014-2018)	The time when wheat crops flower must coincide with optimal seasonal conditions to achieve the highest possible yields and the best grain quality. For over a century Australian wheat breeders, starting with the pioneering efforts of William Farrer, have selected and channelled natural variation to produce wheats with flowering behaviour (phenology) suited to Australian growing conditions. Together with careful selection of sowing date this has allowed growers to manage the flowering date of crops across diverse Australian growing regions with considerable success. The global trend towards warmer climates is altering the flowering dates of existing varieties in some growing regions, however, and is predicted to cause more widespread changes in the near future. Any future changes in growing practices, such as changing sowing date to accommodate altered rainfall patterns, will also require adjustment of phenology. For these reasons ongoing selection for optimal flowering behaviour will be critical for the Australian grains industry. This project will identify flowering behaviours that are best suited to different Australian growing conditions and develop genetic resources to deliver this variation to Australian wheat breeders. The project will first survey the extent of diversity in the key genes that control flowering behaviour through the Australian wheat breeding pedigree and assess the historical contribution of this variation to successful adaptation to Australian conditions. This approach relies on existing multi-site and multi-year data for heading date collected from large numbers of wheat varieties or breeding lines. Data for heading date are compared to precise genotype information for the same material, obtained by assaying DNA extracted from stored seeds with molecular markers for variation in genes that regulate flowering. The impact of variation in individual genes on heading date and crop performance can then be assessed using statistical analyses. Variation that is associated with optimal performance across multiple sites, or improved performance at specific sites, can be identified. This data mining approach uses existing data from field experiments, collected over an extended period at considerable expense, as a powerful resource for association genetics. New genetic resources will then be developed to harness a wide range of variation in the key genes that control flowering behaviour. These will be used to produce near-isogenic lines which can then be used to test and verify the usefulness of variation in flowering behaviour under different current or future field conditions, and to deploy useful novel variation to Australian wheat breeding programs.
ULA00011 - National Phenology Initiative ULA1806-004RTX (2018-2022)	This project aims to connect genetic and physiological understanding of the drivers of cereal development to mathematical models, and ultimately a user interface for growers to be delivered through the NVT website. It involves: • Advances in crop simulation using molecular markers and genomics – wheat and barley • Improve and modify existing APSIM to predict with accuracy, genetic performance based on genetic phenological triggers modelled on localised climactic data. The project is designed to breakdown the contribution of each gene and allele to setting yield potential in wheat and barley cultivars.

	The project involves a cross-functional team of geneticists, crop physiologists, modellers, field agronomists and software engineers.
CSP00178 - Increasing yield and reducing risk through early sowing in the Southern Grains Region (2013-2018)	Autumn breaks are declining in frequency and magnitude in the southern grains region, whilst farm wheat sowing programs are increasing in size. Contemporary sowing programs often exceed the available sowing opportunities. Extreme weather during spring has made achieving timely flowering of wheat crops increasingly critical to yield and farm profitability. Earlier sowing increases the frequency of planting opportunities, and allows more crop to be sown and flower on time. Early sown wheat crops yield more because less water is lost to evaporation, roots grow deeper, water is converted to dry-matter more efficiently and a longer stem elongation phase increases grain number. However, vegetative growth can be excessive, and early sown crops require specific genotypes and management to maximize reproductive growth, harvest index and grain yield. In some locations, a greater proportion of annual rain is now arriving during summer, and conserved summer fallow rainfall allows crops to be sown early even in the absence of breaking rains. No-till, stubble retained systems and controlled traffic allow crops to be sown dry, established on small rainfall events or stored soil water (moisture seeking). Early sowing has emerged as a necessary next-step to capitalise on the benefits of better summer fallow management demonstrated within the GRDC National WUE Initiative. It is also a practice which can take advantage of the robust grass weed control provided by brown-manures and double-breaks increasingly being adopted following research and extension through the GRDC Crop Sequencing Initiative. This project aims to increase the proportion of total farm wheat area planted to appropriate varieties prior to 1 May, either dry or following early autumn rain at four locations in the southern grains region. This will be measured using sowing time data from the Yield Prophet database, and paddock records for ten growers in each location included in the study. Robust regional guidelines describing seasonal suitability for early sowing and appropriate varieties and management to optimise harvest index and maximise yield of early sown wheat will be developed in conjunction with five grower groups using a collective inquiry model of research. These guidelines will be based on regional experiments, and will be extended via fact-sheets, field days and grower group and GRDC updates. The experiments will examine;- The optimal phenology to allow early sowing at four locations in the southern grains region- The management required in different environments to optimise harvest index of early sown slow maturing wheats- Quantification of any yield penalty associated with slow maturity achieved through vernalisation compared to photoperiod sensitivity.