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

Medium Rainfall Zone Southern RCSN meeting, February 2019

Crop establishment under marginal conditions

GRDC investments addressing this issue

Optimising plant establishment, density and spacings to maximise crop yield and profit in the southern and western regions (UOA1803-009RTX))	The aim of this investment is to understand crop establishment, density and spacings to maximise canola and pulse yield and profit in the southern and western regions. It aims to determine the typical rates of crop establishment achieved by growers and factors influencing these. This proposed three and a half year investment, starting early 2018, will deliver a survey of crop establishment, a number of seeder demonstration and comparison trials, and small plot field experimental data over three seasons exploring the opportunity of improved sowing, in terms of reduced seed rates and costs, and increased crop uniformity, yield and profit. The concept of more precise seeding will be tested in three crops with contrasting seed size, canopy development and growth patterns – canola, lentil and faba bean in the south and canola, wheat and lupin in the west. The project also includes development and implementation of an extension and communication plan. Expected outcome - by June 2022, growers and advisers have access to sound agronomic knowledge and supporting data allowing them to improve crop establishment and decrease seed costs with conventional air-seeders for canola, lentil and faba bean in the southern region, and canola, wheat and lupin in the western region, and consider the costs and benefits of precision planters. The initial target of this project is a 30% improvement in establishment of relevant crops and a 5% yield increase over 200,000 ha across the southern and western regions.
Canola Establishment – survey and literature review (BLG110) [NSW strategic Partnership]	The aims of this one year project were to – (1) Undertake a literature review on canola establishment, with the purpose of identifying research gaps and providing key recommendations for future research. The literature review will include both scientific and grey literature. (2) Conduct a field survey across 90 commercial paddocks in central NSW, with the primary purpose of evaluating current canola establishment rates and uniformity of plant spacings. The secondary purpose of the survey is to evaluate management trends that affect canola establishment, such as stubble management (burnt, retained or cultivated), seeding system (disc, knifepoint/press wheels, scatter bar/prickle chain), fertiliser (rate, source and placement) and seed type/source/size/sowing depth. The combination of the literature review and survey will ensure future research is well informed and targeted. The literature review will enable clear hypothesis development for a potentially larger investment in year 2-5 of the bilateral, whilst the survey will provide a current benchmark of field establishment and uniformity of plant spacing's in current farming systems.
Improving crop emergence through the better use of seeding technologies (WMG1802-001SAX)	Timely emergence of crops is a key driver of grain yield for growers. While this is largely influenced by seasonal conditions and the timing of the break to the season, the selection of seeding equipment can also have a large impact on the establishment of crops. The use of paired row seeding configurations has been adopted by many farmers in WA to as a tool to improve crop competition with weeds, but there is anecdotal evidence that this approach can lead to a reduction in the timely emergence of crops due to inappropriate

	placement of the seed into the soil. In seasons where there is low or variable rainfall, paired row seeding can lead to the seed being placed in the dry sidewall of the crop-row furrow, away from the seed row. Conversely, single row seeding can place the seed in the bottom of the seed-row furrow where the soil can dry rapidly and reduce timely crop emergence, indicating that seeding configurations must be matched to the soil type This project will investigate the impact that seeding configuration has on the timely emergence of crops to grain growers in Western Australia across a number of differing soil types. Demonstration sites will be established across the Northern Agricultural region of WA to test the impact of shallow and deep seeding techniques with single and paired row seeding configurations. The key outcome for this project will be to measure the emergence of crops at 14 days following seeding to indicate the effectiveness of the seeding configuration to improve crop establishment. The outcomes of this project will give greater confidence to grain growers to identify the seeding configuration that is appropriate for their soil type and rainfall environment that will maximise the 14-day emergence of crops, and contribute to an improvement in grain yield.
A Review of Seeding Systems that Provide Improved Crop Establishment for Growers in the Western Region (CMP1802-002SAX)	Germination and establishment of crops play a critical role in the overall success of a cropping program, particularly in dry or marginal soil moisture. Growers believe that in 2017, apart from moisture, seeding systems had the biggest impact on whether or not a crop emerged well. The Kwinana West RCSN has therefore nominated seeding equipment as a priority focus area, particularly investigating which seeding equipment enables good crop establishment in dry conditions, especially for small seeded crops. The end result of the project will be a booklet titled: Seeding Systems. Case Studies of Growers in WA: An Initiative of the Regional Cropping Solutions Network. It will feature at least 25 case study participants (five per zone) who use varying seeding systems. Importantly, Cussons Media will extend the outcomes of the project to relevant stakeholders across the Western Region port zones by working with local grower groups and our broader agricultural network.
Seeding systems to improve cereal crop establishment on heavy textured soils (CFG1802-001SAX)	This project will demonstrate to growers the most profitable tyned seeding system for improved cereal crop establishment on medium to heavy textured soils in the eastern wheatbelt. This will be achieved by establishing a trial site to assess a range of furrow closing options (4) and down force pressures (2). The results will be compared to standard practice of growers within the region. The project aims to highlight the need to select the best furrow closing system on heavy textured soils to improve crop emergence and grain yields. Taking a more than single year approach will account for varying seasonal conditions.
Managing early season canola establishment pests in New South Wales – Development of technical content (CES1810-001SAX) And (FLR1810-001SAX)	This investment is an extension project designed to develop: • Technical content • Workshop materials • Evaluation the investment Key resources developed include: • A Best Management Practice Guide in the form of interactive .pdfs • Webinars targeting pests of interest to north, central and south NSW canola growers • Evaluation materials, which will follow the MAKAT model interrogating grower Motivation, Attitude, Knowledge, Ability and Technology
Validation of the persistence of common residual herbicides being used across the low rainfall zone under current farming systems (which are dominated by stubble retention and no-till crop establishment) and to develop techniques	This project can be divided into 3 main objectives: 1. Provide a summary of the existing literature relating to the persistence of herbicides in sandy soils under low rainfall conditions 2. Identify and monitor paddocks through linking with growers and agronomists that utilize summer weed control practices which may lead to herbicide residues in the soil with the potential to impact subsequent crops 3. Conduct a glasshouse trial using intact cores of sand soils collected from the SA and Victorian Mallee to identify how high rates of glyphosate, 2,4-D and mixtures of the two herbicides affect early growth of wheat, lentils, canola and medic following different simulated rainfall regimes of decile 1, 5 and 9. Herbicide use has increased in the low rainfall zone in recent years due to the adoption of conservation tillage, continuous cropping and an increasing emphasis on weed control in summer fallows to preserve

(DAS00162-B)	stored water. Farmers and consultants are concerned about the persistence of herbicides in soils and the potential negative impacts of these residues on cereal and break crops. High costs and difficulty interpreting results mean that the vast majority of farmers do not conduct herbicide residue testing on a regular basis. The small scale paddock survey of broad acre farming systems across Australia detected residues of glyphosate (and its metabolite AMPA), trifluralin and diflufenican in the majority of paddocks sampled at agronomically significant levels before seeding. However, detections of Group I herbicides were somewhat less frequent. Extrapolating results of this kind, or translating small-scale laboratory dose-response trials to practical recommendations for farmers is extremely difficult
High work rate 'plough and sow' technology for farm-scale sandy soil amelioration (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 24-28 diameter disc blades now being adapted for deep ploughing using 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 RD Centre 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.
Increasing return on investment from canola seed through improved establishment - Program 1 (CSP1907-001RTX)	The canola industry is worth around $2-3 billion to the Australian economy every year. Poor crop establishment (on average 40-50% of germinable seed emerging) is experienced in every growing region and is particularly serious in areas where dry sowing is practised. The true cost of poor crop establishment is difficult to estimate as it leads to a range of incurred costs (e.g. re-seeding in serious cases, more aggressive weed management commonly required) and loss of yield potential quality (e.g. poor canopy development, weed competition, staggered maturity of plants). This research seeks to achieve a 25% improvement in canola establishment by 2030. This will be delivered by providing Australian canola breeders with the genetics (germplasm with an average of 75% crop establishment) and the know-how (diagnostic markers and efficient phenotyping methods) to develop varieties with improved establishment and early growth potential. Growers and advisors will gain a better understanding of how establishment-related traits are influenced by their management decisions (e.g. sowing depth, time of sowing), as well as benefiting from the overall outcome of better canola establishment. The expected outputs of this project are to: (1) Understand factors underlying poor establishment to better target genetic studies; (2) develop robust, high-throughput controlled environment phenotyping methods for screening secondary (that is, acquired) dormancy, the rate of hypocotyl elongation and final hypocotyl length and width, and early seedling vigour, validating these methods and ranking varieties in the field; (3) in controlled environments, screen canola diversity panels to understand genetic architecture of these traits and identify alleles with potential for pyramiding in breeding of canola with improvement establishment-related traits; (4) provide diagnostic molecular markers to enable canola breeders to rapidly improve establishment related traits in their breeding programs; and, (5) benchmark germplasm with enhanced establishment against elite cultivars. By the end of the project, Australian canola breeders will have the know-how and tools to develop new cultivars with improved establishment for Australian growers.

Improving production of grower retained open pollinated canola seed using agronomic management to increase establishment in the MRZ and LRZ. (DAN1906-007RTX)	The investment will characterise and evaluate agronomic management strategies that improve canola seed germination and vigour in addition to grower practices (seed size, speed of sowing, depth, and fertiliser placement) that optimise plant establishment density in medium to low rainfall zones in the GRDC northern region. It will identify optimal management (including but not limited to; growing environment, nutrition, harvest management) of open pollinated canola crops destined for seed production to improve subsequent crop establishment.
Demonstrating the effects of reduced lupin seed integrity on crop establishment (LIE1910-001SAX)	In this investment lupins will be collected from a range of growers with variable environments and harvesting conditions to determine the impact if any of specific factors on germination of harvested seed. This includes 'treatment' factors such as: a. Harvest Conditions – temperature, moisture b. Rotor Speed c. Concave Settings d. Variety e. Manganese application – rate & timing f. Number of Augers seed has passed through. g. Seed cleaning methods (if any) h. Grain moisture. Samples will be Manganese tested, germination tested, and establishment of respective crops recorded and economic analysis conducted from the findings.
Increasing production on sandy soils in low and medium rainfall areas of the South° (CSP1606-008RMX)	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, a 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.
Post-Doctoral Fellowship: Unravelling the relationships between soil mixing uniformity by spading and crop response	Rotary spaders are being widely adopted as a soil amelioration tool across the major grain growing regions of Australia. These machines are increasingly used by grain growers to incorporate surface applied amendments, loosen compacted layers and mix top-soil profile layers in constrained sandy soil environments. As part of the GRDC CSP00203 project, the team at UniSA have used Discrete Element Method (DEM) simulations to model and understand the settings and soil interactions of rotary spaders, which include operating depth, forward speed, soil condition and number of passes. The DEM simulations conducted to date agree very well with field validation results, reproducing the exact physical patterns of amendment mixing/incorporation, defining hot and cold spots, in layers within the spaded profile. Increasing forward speed significantly reduces the mixing uniformity and creates greater hot-spot concentrations in particular layers. This highlights the power of DEM to provide understanding of machinery set-up and operation and also guide improved usage. This increased understanding of the rotary spader common set-up and ability to mix surface applied amendment has led to a new research question, "How does the mixing uniformity of the rotary spader affect crop response", which is not being answered by the current project. Therefore, the aim of this GRDC Fellowship is to investigate the effect of surface applied amendment mixing uniformity on crop response. In addition, refined DEM analysis will be carried out to suit particular

	amendments (i.e. lime) and also to investigate the effect of forward speed on the mixing of deeper soil layers.

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

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

Investment Outcome 1.2.8 – Growers have improved knowledge of the economic value of modifying different in-season management practices to reduce frost-related yield losses.
Sound data on the economic value of different in-season frost management practices will be required in order to support growers manage input costs relative to frost risk.

GRDC investments addressing this issue

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

GRS11000 - Frost temperature dynamics and rapid post event identification of damage to broadacre 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)
Boosting profit and reducing risk on mixed farms in low and medium rainfall areas with newly discovered legume pastures enabled by innovative management methods – southern region. (DAS1805-003RMX)	Over the past three decades livestock numbers in Australia have decreased as farmers concentrate on crops. Continuously cropped paddocks are not sustainable and are high risk, especially in dry areas where wheat dominates. Intensive cropping is prone to herbicide resistant weeds, requires large nitrogen fertiliser inputs, and significant financial shocks occur when yields are restricted by frost or dry conditions. There are also indicators of reduced sustainability under these intensive systems which include increases in areas of saline seeps. A pilot project in the medium rainfall zones of WA and southern NSW has demonstrated how novel pasture legumes improve livestock production through enhanced growth and reproduction, and earlier access to markets, while dramatically reducing fertiliser and herbicide inputs for following crops.
Boosting profit and reducing risk on mixed farms in low and medium rainfall areas with newly discovered legume pastures enabled by innovative management methods – Western region (Dryland pasture legume systems). (UMU1805-001RMX)	Over the past three decades livestock numbers in Australia have decreased as farmers concentrate on crops. Continuously cropped paddocks are not sustainable and are high risk, especially in dry areas where wheat cultivation dominates. Intensive cropping is prone to herbicide resistant weeds, requires large nitrogen fertiliser inputs, and significant financial shocks occur when yields are restricted by frost or dry conditions. There are also indicators of reduced sustainability under these intensive systems which include increases in areas of saline seeps. A pilot project in the medium rainfall zones of WA and southern NSW has demonstrated how novel pasture legumes improve livestock production through enhanced growth and reproduction, and earlier access to markets, while dramatically reducing fertiliser and herbicide inputs for following crops. This project will discover resilient low-cost pasture legumes with appropriate management packages and promote their adoption over 500, 000 hectares in the low and medium rainfall areas of Western Australia. As a result, average farm profit will be boosted by 10% and economic risk will be halved over a range of seasons. The project is supported by GRDC, MLA and AWI and involves Murdoch University, CSIRO and DPIRD, collaborating with SARDI and CSU in a parallel (southern) project, and three WA grower groups. There are five integrated programs: legume selection, cropping systems, livestock systems, economics and farm modelling, and extension and project management.
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	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

(CSP1901-002RTX)	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, that 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,)	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

(BWD1707-003WCX) (LIV1707-002WCX) (FGI1707-003WCX) (DAN1707-001SAX), (DAW1607-003RTX)	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 c. 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	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.

and form on the thermal response of winter pulses. (DAN1703-016BLX)	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 phothermal 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.

Diagnosis, amelioration and management of soil constraints – various issues identified by MRZ RCSN

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

CSP00203 - Increasing production on sandy soils in low and medium rainfall areas of the South (CSP1606-008RMX)	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, a 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.
Understanding the amelioration processes of the sub-soil application of amendments in the Southern Region (DAV00149)	In many cropping areas in Victoria, a significant constraint to profitable crop production is the frequent occurrence of poorly structured clay soils that are inherently compacted, which can lead to water logging under high rainfall conditions. These unfavourable soil conditions inevitably hinder crop growth and consequently reduce economic crop productivity. In addition to this problem of poorly structured surface soils, a further major constraint for crop production related to the nature of the subsoil. The application of amendments (both organic and inorganic) can markedly improve crop growth on a range of soil types that dominate grain production in the medium and high rainfall zones of south east Australia. A comprehensive Scoping Study involving an in-depth analysis of current and previous research (published and 'grey literature'), combined with a workshop involving a diverse range of stakeholders (technical experts from a range of disciplines and organisations, consultants and growers) was published that identified both key knowledge gaps and a detailed research plan to determine the processes underpinning grain yield responses to subsoil ameliorants in south-eastern Australia. A series of glasshouse and field trials have been instigated throughout SA, Vic and Tas, and existing trials established under previous projects have been revisited. These indicate part of the beneficial impact of amendments on crop growth appears to be related to improvements in nutrient supply, as well as improvements in soil structure; this effect however depends on the nature of the particular subsoil. Wheat responses to soil amelioration are strongly associated with improvements in root growth (at least on poorly structure, sodic subsoils). Whereas 'More is better' seems to apply to crop responses to the rate of application of amendment in a controlled environment, this may not be the case in the field where water nearly always limits grain production and that there is a real risk of the crop 'haying off'. A review of machinery needed to apply amendments to subsoils based on both current and previous research (Australian and international), as well as the experiences of commercial machinery companies and individual farmers, is nearing completion. Some of the learnings from this review were used to design and construct a new subsoiler design for research targeting the application of both organic and inorganic amendments and nutrients in field based research experiments. Access to suitable machinery (and favourable seasonal conditions/rainfall, both in the period between amendment application and sowing, and later at grain filling) appears critical if the full yield potential of applying amendments (organic or inorganic) into dense poorly structured subsoils is to be achieved.
Spatial variability of soil acidity and response to liming in cropped lands (DAV00152 - D-BA)	Soil acidity is a major soil limitation in many cropping soils, particularly in higher rainfall areas. Liming the whole paddock with one rate to treat surface acidity, is the main method of overcoming acid soil problems. Growers have seen that this approach is not always economic. Horizontal and vertical variations in soil pH within a paddock may be a factor in this outcome. Growers have little information on spatial (horizontal and vertical) variability in soil pH to manage production limiting soil acidity. This is compounded by regional variations in soil pH that make it difficult for growers to use yield-response information for liming from outside their region. This project will provide information on within-paddock variation in soil pH and related soil properties, in different regions of the Victorian High Rainfall Zone (HRZ). We will map the horizontal and vertical variations in soil pH across 10 cropping paddocks in the HRZ in Victoria, to demonstrate to farmers how soil pH varies spatially and the economic benefits of targeting management of soil acidity to different zones within each paddock. Novel methods, such as geostatistics and field spectropscopy (e.g. Mid InfraRed), will be applied to 10 paddocks to model and map variations in surface soil and subsurface soil pH at the paddock-scale. Soil survey data will be used to relate paddock pH maps to different landscapes across Victoria's HRZ. Mapping will provide data on the distribution of soil acidity in surface and subsurface horizons and identify the risk of acidification. Lime test strips will be applied to low

	and high pH zones within each paddock to demonstrate how liming affects soil pH, other agronomically important soil properties such as exchangeable aluminium, and yield. These responses, together with other data, will be incorporated into a Variable Lime Benefit Demonstrator. The 'Demonstrator' will be used to create spatial outputs for soil acidification risk, lime rates and economic benefits of targeting soil acidity. This will be complemented with two-case studies examining the effectiveness of lime improving crop yield and economic benefits from a whole farm perspective for typical rotations. Project findings will help growers to make more informed decisions on managing variability in soil pH and to supply input data for a GPS controlled lime spreader. The impact of this project will be to reduce the uncertainty currently present in lime decision making in the HRZ and enable farmers to better manage risks, both to farm profitability and to soil health from ongoing acidification.
Innovative approaches to managing subsoil acidity in the southern grain region (DAN00206)	Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500-800 mm) of south-eastern Australia. Approximately 50% of Australia's agriculture zone (49-50 M ha) has a surface soil pH below optimal levels (pH < 5.5 in calcium chloride) and half of this area also has subsoil acidity. Soil acidification is accelerated by nitrate leaching under certain crop rotations, by the use of ammonium-based fertilizers, and by the regular removal of plant products, such as grain or hay. The major constraint to plant production on acid soils is aluminium toxicity which inhibits root growth even at very low concentrations. Smaller root systems limit nutrient and water uptake and increase the vulnerability of plants to periodic droughts. The surface application of lime is a common practice used to combat soil acidity. However, lime movement is very slow and take years to ameliorate subsoil acidity. In fact, at the current commercial recommended rates (2.5 tonne/ha in the high rainfall region in NSW), most of the added alkalinity is consumed in the topsoil with very little remaining to counteract subsoil acidification. Therefore, more aggressive methods are required to ameliorate subsoil acidity. This project led by Dr Guangdi Li will investigate more aggressive ways, such as the deep placement of lime to the subsoil where it is most needed, with or without organic amendments to achieve more rapid changes to pH at depth. Other novel materials, such as calcium nitrate fertiliser, nano-lime and slicate-based materials, either separately or in combination, will be tested in different soils with different crop species in both controlled environments and under field conditions. Detailed studies are essential to increase our understanding of these plant-soil interactions and the mechanisms involved. The aim of the project is to manage subsoil acidity through innovative amelioration methods that will increase productivity, profitability and sustainability on farms. At the completion to this project, it is expected that at least 50% of grain growers at risk of significant yield loss due to subsoil acidity (10% or more of potential water-limited yield) will adopt innovative techniques and methods with novel materials and products as part of the most profitable cropping system for their farms to prevent or ameliorate subsoil acidity.
GRANT: A holistic approach to seep management for preventing land degradation in the landscape (MSF1812-002OPX)	The National Landcare Program aims to protect, conserve and provide for the productive use of Australia's water, soil, plants and animals and the ecosystems in which they live and interact, in partnership with governments, industry and communities. Protecting and restoring our soils, water, vegetation and biodiversity underpins the productivity and profitability of agriculture, fisheries and forestry industries and will assist these industries to become more resilient and able to effectively respond to changing climate, weather and market conditions (such as the need to demonstrate environmental credentials to access markets). Sandy seeps have become a significant issue on the dune-swale landscapes in the dry areas of SA and Victoria, making productive farming soils saturated, untrafficable, and weed infested, eventually becoming saline and prone to erosion. Seeps have become more evident in the last decade, due to farming system changes coupled with high rainfall periods. Farmers identify that poor crop water use on the sand dunes along with effective summer weed control and greater retention of soil moisture has led to the expansion and formation of seeps lower in the landscape. This NLP project led by Mallee Sustainable Farming aims to apply a 'tool box' approach to seep management by: 1. Using new and existing remote sensing tools to identify areas at high risk for seep expansion; 2. Preventing seep formation by demonstrating high water use options for different systems; 3. Categorising seep severity and applying the best treatment options to remediate the seep area.

Improving wheat yields on sodic, magnesic, and dispersive soils (UA00159)	This five-year project is led by the University of Adelaide (Prof. Glenn McDonald) and is a collaboration between research organisations in WA, Victoria, NSW and Queensland. It is a multidisciplinary team that brings together plant breeders, soil scientists, plant physiologists, agronomists and crop geneticists. The purpose of the work is to develop strains of wheat with improved tolerance to a number of stresses associated with sodic soils, which wheat breeders can use to increase wheat yields in the future. It will involve a network of national trials to evaluate performance of different varieties of wheat on sodic soils. A crossing and screening program among the superior lines identified will then be conducted to combine the desirable traits into elite lines. The project will also develop genetic tools to help wheat breeders select for tolerance to sodic soil.
GRANT: Building the resilience and profitability of cropping and grazing farmers in the high rainfall zone of Southern Australia (SFS1812-001OPX)	The National Landcare Program aims to protect, conserve and provide for the productive use of Australia's water, soil, plants and animals and the ecosystems in which they live and interact, in partnership with governments, industry and communities. Protecting and restoring our soils, water, vegetation and biodiversity underpins the productivity and profitability of agriculture, fisheries and forestry industries and will assist these industries to become more resilient and able to effectively respond to changing climate, weather and market conditions (such as the need to demonstrate environmental credentials to access markets). Soil acidity is recognised as a significant regional constraint across the HRZ (previous GRDC report estimated this at $1.4 billion/yr). At a regional scale it is considered a high priority across most of the proposed project area. This NLP project covers the equivalent of the high rainfall RCSN area of the southern region. The information / activity will actively involve all relevant influencers and by involving various groups will be representative of the different farming systems. The CeRDI at Ballarat University (and their links to the High Performance Soils and Food Agility CRCs) will be developing and linking spatial information (local soil maps, soil test data, and climate) with pH and lime results e.g. typical buffering and acidification rates based on soil type.
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.
Bio-solids to overcome sub-soil constraints in the Victorian grain growing soils (FED1806-001AWX)	It is claimed that incorporation of organic amendments to the top 30-40 cm soil layer, a practice that has now been termed subsoil manuring, can markedly improve the soils physical and chemical properties, particularly those which are closely related to enhance root growth and therefore crop productivity. Recent attempts at subsoil manuring have utilised several types of organic and inorganic matter, including chicken manure, gypsum, inorganic based fertilizers, lucerne pellets and crop stubbles. These treatments have been used individually and/or as mixtures. However, notwithstanding the fact that these previous efforts to ameliorate the properties of dense clay subsoils have provided promising results, attempts at

	adoption of the practice of subsoil amelioration has been slow, predominantly due to high upfront costs. Therefore, the key to this project is the investigation of a viable option to overcome the shortage of low-cost organic matter for subsoil manuring. The project (in collaboration with DAV00149) will investigate the possibilities of using biosolids as a subsoil ameliorant. Biosolid material is one of the more freely available manure resources Australia-wide, and numerous studies have been conducted on the possibility of using it as an amended fertilizer in agriculture. Indeed, biosolids have been shown to have numerous benefits as an organic nutrient-rich compound which can be innovatively used in agriculture to improve crop productivity. It is relevant to note that even though biosolids are widely used in worldwide agriculture, only 31% of the total production of biosolids is used in agriculture in Victoria, which is the lowest usage across Australia for agricultural purposes. It appears that there is possible community confusion between the terms sludge and biosolids, and we identify here that these terms simply imply the physical differences in the appearance of this material, with sludge appearing as a slurry and biosolids appearing as a soil like matrix. This clearly implies that sludge is operationally different to handle than biosolids, and the basic steps involved in the production of biosolids are (a) collection of raw sewage, (b) treatment of sewage to the desired health related levels, (c) settling and removal of watery sludge to produce the required biosolids. These biosolids can then be regarded as an established, nutrient-rich product that is ready for convenient, safe and beneficial end use. In the investigations related to this project, biosolids will be further treated in order to improve its physical and chemical characteristics for use as a subsoil ameliorant. In one of the treatments, biosolids will be mixed with sawdust, another cheaply sourced available organic matter which can be used to help improve the soil physical properties of the compact clay soil layer. Trials will be conducted to represent both high and intermediate rainfall zones, with different rates of manuring tested against wheat crop productivity, soil physio-chemical and microbial properties, leaching of heavy metals to the deep soil layers, heavy metal accumulation and remobilization into the wheat crop and grains.
Innovative approaches to managing subsoil acidity in the Western Region (DAW00252)	Soil acidity is one of the few soil constraints to agriculture for which there is a profitable solution. However, treatment and management of subsurface acidity requires a more direct and aggressive approach than surface or topsoil acidity. The surface application of lime to treat soil acidity is becoming more common. For the WA wheatbelt, use of agricultural lime is currently around 60% of the annual application rate estimated to be necessary to treat existing and on-going acidification. Surface application of lime to treat subsurface acidity is a slow process and the delay is exacerbated in low rainfall farming systems dominated by a strong adoption of no or minimum tillage because of the reduced cultivation and mixing of the soil profile. For a number of reasons, strategic tillage has gained favour in recent years to bury herbicide resistant weed seeds, disturb and mix water repellent topsoil and incorporate nutrients that have become stratified. Increased tillage is the ideal opportunity to incorporate agricultural lime (and potentially other neutralising products or products that may assist the movement of conventional lime) to depth. This project will work with a number of grower groups to understand more fully and improve the effectiveness of tillage to incorporate lime to depth and if subsurface amelioration of acidity can be improved through the addition of organic matter or other novel products. The extent to which acidification rates might be able to be reduced through the use of 'alkalising fertilisers, such as calcium nitrate, will also be determined as a possible economically viable adjunct to traditional amelioration. Detailed controlled environment studies will be undertaken to test and develop recommendations for the field trial treatments. Detailed studies are essential to increase our understanding of these plant-soil interactions and the mechanisms involved. The aim of this project is to provide recommendations and information to growers on innovative methodologies to effectively and economically manage subsurface acidity. It is expected that at least 50% of growers at risk of significant yield loss due to subsurface acidity (10% or more of potential water-limited yield) will adopt the recommendations and manage this risk when it is cost-effective to do so, or apply other management options as part of the most profitable cropping system for their farm to increase productivity and/or sustainability on farms.
Tactics for improving rooting depth and crop yield on sodic	Sodicity at depth is a sub soil constraint that restricts rooting depth and the amount of sub soil moisture the root can access. Like many other sub soil constraints, sodic soils restrict plant growth and development and result in lower grower returns from these unproductive sections of their paddocks.

soils - West (MIG1801-001SAX)	The project aim is to evaluate possible strategies for growing more grain on soils that have been identified as sodic at depth, specifically in the medium-low rainfall environments. Success will be achieved if management strategies are identified that increase plant growth, rooting depth, crop yield and profit. Through the establishment of two gypsum rate trials on soils confirmed sodic, the rates of gypsum required to re mediate sodic subsoils will be observed by researchers and growers. They will have the opportunity to observe the changes to rooting depth and crop yield over the three year time period of the trial. Through observation and supporting measurements and evaluations, growers will then have confidence in gypsum rates that have shown to increase plant rooting depth and their ability to access stored soil moisture. Access to soil moisture, soil water levels and crop rooting depth will be assessed through the use of soil pits during the season. The objective of the project is to improve crop rooting depth and access to stored soil moisture so that plant growth and crop yield are increased, providing growers on these soil types with more profitable cropping systems. At the end of the project growers in the Northern Agricultural Region of WA will have an increased understanding of sub-soil acidity and rates of gypsum required for treating this constraint.
Incorporating lime to depth in duplex wheatbelt soils (FGI1801-001SAX)	The aim of this trial is to quantify the value of lime applications by different incorporation methods and compare the economic and agronomic returns of each. This trial will also include an application of a rapidly acidifying Elemental Sulphur to demonstrate how soils and crops will perform in 10 years into the future if no action is taken to maintain pH levels. Growers in the area vary the timing and rate of applications, with some applying a consistent amount annually, some applying a blanket amount on certain paddocks every few years and some applying varying rates as required depending on soil type and pH. Analysis will be conducted reviewing each application of lime rate and the effects between the different incorporation methods. The trial will compare the economic benefits of each treatment; as well as the potential loss of production and decline in pH through the acidifying treatment. It is pertinent for growers to evaluate the most practical and economical methods to manage soil pH in duplex soils. The results from each treatment will assist in building a database across various seasons; to demonstrate how different applications respond and influence soil pH across the profile. The effect on germination and development, plant nutrient uptake and yield on duplex soils will be recorded. This trial will highlight any complacency growers may have around soil pH maintenance, with the application of the acidifying treatment.
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 soil organic matter in soils that have been treated with mechanical soil amelioration. This work, in combination with of research that integrates different spatial scales, and extension. The project includes work on soil N processes and the fate of 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.
Seeding systems to improve cereal crop establishment on heavy textured soils - West (CFG1802-001SAX)	This project will demonstrate to growers the most profitable tyned seeding system for improved cereal crop establishment on medium to heavy textured soils in the eastern wheatbelt. This will be achieved by establishing a trial site to assess a range of furrow closing options (4) and down force pressures (2). The results will be compared to standard practice of growers within the region. The project aims to highlight the need to select the best furrow closing system on heavy textured soils to improve crop emergence and grain yields. Taking a more than single year approach will account for varying seasonal conditions.
Re-engineering soils to improve the access of crop root systems to water and nutrients stored in the subsoil – Western Region. (DAW1902-003RTX)	This investment will address multiple interacting soil constraints within the crop root zone through strategic combinations of soil amelioration techniques or from soil profile re-engineering. Soil profile re-engineering is the fundamental redesign of soil profiles to achieve dramatic improvements in critical measures of cropping performance including water and nutrient use efficiency, grain yield and grower profitability. Multiple interacting soil constraints are reducing Plant Available Water (PAW), grain production and long-term profitability of crops across most of the 12 M ha of sandplain soils in the medium-high rainfall zone (van Gool 2018) of the Western Region. Subsoil compaction, subsoil acidity and soil water repellence each occur over more than 50% of these sandplain soils, which mostly comprise of deep sands and texture contrast soils (sand over distinct clay or gravel horizon; duplex). About one-third have low soil water storage (van Gool 2016). These combined constraints result in shallow crop root systems (<30cm), poor access to subsoil water and up to a 50% gap between actual and potential grain yield (Betti et. al. 2018; Davies et.al. 2018; van Gool 2011). The effective rooting depth for unconstrained grain crops on deeper sandplain soils in WA is 150-250cm (Hamblin and Hamblin 1985; Hamblin and Tennant 1987; Hamblin et. al. 1988). Multiple interacting constraints and low plant available water result in lost yields with an estimated value of $1.2 Billion per year (Peterson, 2016). Current soil amelioration options (liming, deep ripping, spading, mouldboard ploughing) address one or more constraints to a depth up to 40cm. The potential yield benefits of addressing multiple constraints through complete soil profile re-engineering to a depth of 80cm is unknown. Soil re-engineering aims to increase plant available water so crops achieve 95% of rainfall limited yield potential. Soil amelioration has predominantly been adopted on deep sands and sandy earths with more limited adoption on sandy gravels and texture contrast soils. The 4.8M ha of sandy texture contrast soils present particular challenges as they can have a layering of both sandy and heavy-textured soil constraints and depth to the clay B-horizon can be highly variable. Developing diagnostic and targeted amelioration packages for these soils represents a substantial opportunity to dramatically improve grain production and profitability. The project will do this through: 1. Identifying the most profitable and long-lasting soil amelioration and amendment strategies for managing multiple interacting soil constraints. 2. Re-engineering the soil profile through a combination of deep soil loosening; reconstituting profile layers and deep placement of nutrients and soil amendments. If soil re-engineering could overcome the 1.0-1.4 t/ha yield gap (van Gool 2011) on 20% of the 12 M ha this would equate to a further $600-$840 million per year in yield benefits that would flow directly to grain growers. 3. Extension and upgrade of the recently released Ranking Options for Soil Amelioration (ROSA) financial model (Petersen et al. 2018) to incorporate the economics and benefits of re-engineering will be a

	primary output of this project. This tool is essential in helping growers understand the costs and benefits of soil amelioration and re-engineering strategies. Our current agronomy and farming systems research has been limited by often being undertaken on constrained soil or soils where only a single soil constraint has been addressed. Innovative high-risk soil re-engineering will provide a new increased yield potential that will underpin new agronomy and farming systems research in the future.
Increased grower profitability on soils with sodicity and transient salinity in the eastern grain belt of the Western Region. (DAW1902-001RTX)	The purpose of this investment is to explore and develop management options for cropping soils constrained by sodicity and transient salinity across the low rainfall eastern grainbelt of Western Australia. Interacting combinations of sodicity and transient salinity, often associated with high subsoil pH, ion toxicities (mainly boron) and poor subsoil structure, interact to constrain crop yields by reducing water extraction by crop. To improve the reliability and profitability of grain production on these soils growers require viable options to mitigate or ameliorate soil constraints (Kirk 2014; Paterson 2015). To capture missed yield crops need increased plant available water on these soil types. Combined approaches which improve water harvesting onto crop rows, targeted amelioration of the soil rooting zone, together with options that increase soil water in the root zone and reduce evaporative losses can improve crop water supply (Mulvany et al. 2018). Current evidence indicates these approaches could increase yields by 20-30% in high rainfall years and 40-140% in medium to low rainfall years (Mulvany et al. 2018). New applied research will evaluate the benefit of different options to improve water capture and availability, and use economic modelling to determine the profitability and reliability of such approaches. This investment will develop soil mitigation and amelioration options and combinations that increase crop available water supply and will generate data to enable a cost-benefit model to guide soil management decisions. National and international research, networking and potential future collaboration will be explored through several study tours, which, combined with the projects research outcomes, will inform future research opportunities.
Tailoring an integrated solution to effectively address sub-soil constraints by incorporation of chemically-balanced nano-amendments (DAN1806-002AWX)	The nature and impact of subsoil physicochemical constraints on crop productivity and profitability of grain production in Australia have been well established. Subsoil physicochemical constraints include transient salinity, acidity/high alkalinity and impacts associated with sodicity (transient waterlogging, high soil strength). Most soils in the cropping region contain one or more subsoil physicochemical constraints that can limit effective root growth and water and nutrients use by crops. As a result, grain yields are significantly less than water limited potential resulting in major financial penalties for growers. The on-going challenge for the grains industry is how best to manage these constraints. This project will address this issue by looking at innovative chemical and engineering solutions to manage hostile soils in broad acre grain production. The conceptual framework of the project is developed around a novel approach for the effective utilisation of a new generation of amendments products: Investigating the potential of nano-sized amendments to boost the agronomic impacts and economic benefits of incorporated chemically-balanced organic matter into constrained subsoils. In this project, we will harness recent advances in development of new nano- amendments (e.g. nano-gypsum, nano-lime) and iteratively evaluate these using a suit of advanced methods to examine amendment chemistry in soils and to effectively incorporate these amendments at the paddock level.
Economics of ameliorating soil constraints in the northern region: **PROJECT A** Spatial soil constraint diagnoses (UOQ1803-003RTX) **PROJECT B** Soil constraint management and amelioration (USQ1803-002RTX)	Approximately 75% of Australian soils have single or multiple constraints that limit agricultural productivity, and in the Northern Region, these commonly take the form of sodicity, acidity, salinity, and compaction. Project A is part of an integrated body of work that will provide growers with tools to identify a) what constraints are present and where these occur (Project A); b) what management strategies can be used to increase yield (Project B) and profitability (Project C); and c) how strategies can be effectively communicated and demonstrated to growers (Project D). **PROJECT A** Specifically, Project A will use a global archive of Landsat satellite imagery in combination with the methodology developed in the GRDC project UQ00081 to produce paddock scale yield maps. In UQ00081, remote-sensing data was combined with ABS SLA-level yield statistics data to enable prediction of yield for any location and for any year with remote-sensing data. This methodology will be extended to produce yield maps at a paddock scale, which will then be integrated with landscape attributes (DEM) and soil maps (SALI and SALIS) to provide growers with a best-bet prediction of where constraints occur (location and depth), and what constraint is present. This framework will be delivered as a web-based tool

<table>
<tr><td>PROJECT C
Economics of adoption (USQ1803-003RTX)

PROJECT D
Program co-ordination – communication, extension and evaluation
(UOQ1803-006RTX)</td><td>(ConstraintID), and demonstrated to growers and advisors in collaboration with Project D.

Once constrained areas have been identified, proximal soil sensing techniques (EM38, Dual EM38, and the techniques developed by DNR00008 and US00087) and diagnostic soil kits will be developed to identify the type of constraints present. Proximal techniques will be used to provide detailed maps of the spatial variability of soil constraints and where these occur across the experimental sites established by Project B, and help demonstrate these techniques to growers. Simple soil kits will also be developed to allow on-site soil analyses by growers to diagnose what soil constraints are present. It is envisaged that georeferenced soil test information will then be fed back into the web-based yield mapping tool to help growers diagnose soil constraints (type and severity).

PROJECT B
This project will work with grain growers, grower groups and consultants to identify the best management options for the range of constrained soils across the different cropping systems. This project will develop a decision framework that will improve the long-term profitability of grain production on such soils. A range of extension activities will be carried out throughout the project ensuring that the project delivers information to the industry through Project D. Ideally, extension will focus on improving skills of advisors, consultants and growers to identify, diagnose and manage problem soils.

Uniquely, the project intends to build into the decision tool capability for rapid determination of soil stability based on cheaply measured soils factors. This will provide soil-specific and spatial capability to aid management. Working closely with Project C, economic management thresholds will be determined; that is, where to amend constraints, where to adapt to constraints and where to apply a mixture of both at the spatial scale with an associated risk.

PROJECT C
The project anticipates delivering an economic assessment framework and tool for growers and advisors to evaluate the economics of amelioration options against soil constraints at the paddock and farm scale. The tool, based on a digital platform that will emulate similar technologies created by USQ and creates the opportunity for adding further research learnings over time from on-site soil samples. The proposed GRDC soils project will also make use of existing access to APSIM and previously mentioned tools (e.g. HSG and AG Margins), as well as those that have previously received investment from GRDC (e.g. On-line crop production model Yield Prophet). The aim where possible is to integrate existing tools and data from project A & B in supporting the building of the new economic assessment framework.

The project will look at investment cost/hectare separate to normal input costs. This allows for a separate cost evaluation of amelioration to allow it to be classed as a farm investment. This may allow for cost to be depreciated over time. Importantly required timeline for anticipated changes is identified and the outlook of residual benefit (treatment stability). This cost will be compared to returns from current yield vs potential yield over time. The investment in dollars can be divided by the expected yield differential multiplied by the market price over time to show if anticipated returns is greater than cost. Such a bio-economic framework, will look to deliver simple cost benefit scenarios to determine break-even point or payback period for farmers and agronomists in the paddock.</td></tr>
<tr><td>Understanding soils to assess amelioration potential in the Southern Wimmera (FSA1908-001SAX)</td><td>Soil salinity, sodicity, acidity, alkalinity, elemental toxicities such as boron, chloride and aluminium, waterlogging and compaction are significant constraints to grain production and profitability in Australia. Recent research findings showing significant yield benefits to strategic soil tillage including deep ripping practices in sandy soils has sparked a resurgence in amelioration activities in the Southern Wimmera. This was highlighted during the 2018/19 growing seasons with a number of growers commencing deep ripping programs to remove compaction and hard pans and allow crop access to water and nutrients at depth. However, a detailed knowledge of soil characteristics and constraints to root growth is required prior to undertaking any strategic soil management practice to ensure it will adequately address the most limiting constraint(s) and does not have any deleterious effects.

Feedback from the Medium Rainfall Zone (MRZ) RCSN has identified that, some growers do not fully understand their soil characteristics and constraints down the profile, and as such, are unaware of the full impacts of soil amelioration practices, including deep ripping. Many growers are not undertaking a soil testing program to understand their soil constraints, especially to depth, making it difficult to assess the suitability of their soil for amelioration, which will depend upon soil type and the presence of one or more constraints.</td></tr>
</table>

	This investment is designed to aid growers' and advisers' ability to characterise soils, identify constraints to crop growth, and assess suitability of soils for amelioration to remove constraints, including return on investment for potential practices in the Southern Wimmera. The approach includes a series of soil pit demonstrations on growers' properties who have undertaken soil amelioration practices as well as a soil masterclass for advisers, based around identification of key soil constraints and the suitability and the return on investment from soil amelioration.
Post-Doctoral Fellowship – Understanding mechanisms of subsoil amelioration (ULA1806-001RTX)	This research Fellowship will enable Dr Jian Jin to undertake detailed soil and crop measurements at the two new field experiments established by Project DAV00149 in the districts of Kiata, in the median-rainfall zone, and Tatyoon, in the high-rainfall zone in the autumn of 2018. The work will focus on root distribution in soil layers, the functioning of the crop canopy, on water and nutrient uptake by the crop, and changes in soil structure, in response to surface and subsoil amendments. The intensive measurements will complement those already planned in DAV00149. This project will help us to understand how surface and subsoil amendments affect the soil structure and root proliferation in soil layers, crop water and nutrient uptake, and grain yield.
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.
Development and validation of soil amelioration and agronomic practices to realise the genetic potential of grain crops grown under a high yield potential, irrigated environment in the northern and southern regions. FAR1906-003RTX	This investment will develop and evaluate the effectiveness of novel soil management technologies and crop specific agronomic management practices on system profitability. Soil management technologies will focus on improving soil structure, infiltration and moisture retention on: 1. shallow and poorly structured red duplex soils 2. sodic grey clays prone to dispersion and waterlogging Crop specific agronomic practices will focus on maximising system profitability through: • optimising the return on nitrogen through improved use efficiency • improving the understanding of N-form, timing and rate in the context of irrigation timing and inter-related agronomic decisions • understanding how to consistently optimise yield (in the context of water price, input costs and

	commodity price) for the crops where gaps are most apparent: ▪ faba bean (the pulse crop with the most potential for irrigated systems) ▪ chickpea (an emerging high value pulse, important in crop sequence to provide a cereal disease break) ▪ durum (the major option to increase profitability of the cereal phase of rotations). Durum also has stronger straw strength compared to bread wheat ▪ canola (higher yields provide scope for significant increase in profitability) ▪ maize (the summer crop with the greatest scope to improve returns under a double cropping system) • generating data to inform whole farm sensitivity analysis undertaken as part of PROC-9175816 "Optimise farm scale returns from irrigated grains: Maximising $ return per megalitre of water" increasing grower capacity to respond to varying water and commodity price through agronomic practices targeted to the unique constraints of irrigated cropping systems. This investment is aligned to, and will collaborate with and leverage investments in, the following related GRDC investments: • ICF1906-002RTX: Facilitated action learning groups to support profitable irrigated farming systems in the northern and southern regions. • UOT1906-002RTX: Optimising farm scale returns from irrigated grains: maximising dollar return per megalitre of water
Increasing 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).
In field assessment of selected soil properties and plant N contents using IR Spectroscopy	Utilisation of soil and plant testing by growers and agronomists are at very low levels which can be attributed to a wide range of issues. It can be suggested that time and physical demands required for taking soil samples limits soil testing uptake along with the associated costs of getting samples analysed at the laboratory. Soil test interpretation and soil type variability within a paddock can also offer significant challenges to defining appropriate fertiliser decisions based on soil test results. This variability within the paddock can also result in different abilities of the soil to meet crop N demands and therefore a measurement of real time crop N status is vital to precision applications of N in season. The advancement of IR spectroscopy instruments to handheld versions allows for use in the field. In a controlled environment it has been shown that handheld instruments have performed as well as benchtop instruments in the prediction of several soil properties. This project aims to advance the potential of rapid soil assessments beyond research case studies to a commercial service. In this proof of concept, we will limit the soil analysis to those applicable for surface treatments (0-10cm) but increase sampling frequency to that required to produce a paddock map of that soil characteristic. In-field measurements of soil characteristics will focus on those that are known to be well predicted using IR technology (Texture, Organic Carbon, Phosphorus Buffering Index, Cation Exchange Capacity) but also prediction of two important management practices 1) Lime requirements through determination of soil pH and 2) Gypsum requirements through analysis of soil dispersion through prediction of soil sodium levels and Exchangeable Sodium Percentage. Assessment of soil drained upper limits (DUL) and lower limits (LL) on the surface samples will provide a preliminary assessment of the ability to predict these two important soil traits in a field setting using IR technology. Further development of DUL and LL predictions will need to be made on full soil profile samples for the interpretative data to be of use for growers and advisors.
Benchmarking and managing soil herbicide residues for improved crop production (DAN00180)	Australian grain growers have progressively adopted a number of best management practices in order to minimise soil tillage, which is one of the main causes of soil erosion, soil compaction and soil organic matter loss. Because soil tillage was previously the most common form of weed control, farmers are now relying more heavily on herbicides to control weeds. Little is known about how the increased application of herbicides affects soil biota and soil functions that sustain crop growth and ecosystem services such as crop residue turnover, water holding capacity, soil carbon storage and nutrient cycling. A review of scientific literature found that few studies have investigated long-term effects of pesticide application, and even less discuss measured or observed changes to soil processes (Bunemann et al 2006).This project will address current knowledge gaps regarding the impact of herbicides on soil biota in all three growing regions of the Australian grains industry. The project objectives include determining the effects of different herbicides on not only soil biological communities and biodiversity, but also quantifying their effects on soil functions critical to ecosystem health. This will lead to the development of a risk assessment framework that can be used by the grains industry to rank herbicides for maximum efficacy with minimal impact on the soil environment for different growing regions (North, South and West), by incorporating herbicide use patterns by growers under different management practices and climates. In addition, the project will develop and validate a new suite of rapid tests to detect herbicide residues, allowing for faster, cheaper, and better targeted herbicide management. The outcomes of this project will be an increased understanding of the wider impacts of herbicides and herbicide classes on soil fertility and biological functionality. The project will provide specific recommendations on application regimes that remain agronomically and economically effective, whilst minimising any risk to the productive capacity of soils. This will lead to a more resilient and therefore competitive grains industry. The analytical techniques and risk assessment framework developed in this project for monitoring the effects of herbicide residues will also provide a platform from which other agronomic inputs, such as fertilisers, bio-control agents or organic amendments, can be rigorously assessed. This project will enable the grains industry to demonstrate environmental stewardship and best practices to sustain Australia's natural resource base.
Regional soil testing guidelines for the northern grains region (UQ00063)	Soil testing information is one of the key factors needed to identify nutrient limits to productivity and subsequently devise a fertilizer program. However, without calibrated soil test – yield relationships that are robust enough to quantify likely yield response to added fertilizer, farm managers and advisors are not able to make fertilizer decisions that will optimize productivity, nutrient use efficiency or profitability. The national database "Making Better Fertiliser Decisions for Crops" has identified some significant gaps in these relationships. The purpose of this project is to start filling those gaps in our knowledge of plant responses to the supply of nutrients. The project is national in scope. This project describes the work for

	the Northern GRDC region, in partnership with the projects from the West (Brennan et al.) and the South (Conyers et al.). In addition, there are significant gaps in soil testing methodology for all nutrients except N. The greater reliance on stored soil moisture for crop productivity in the clay soils of the northern region, rather than in-season rainfall, places a greater emphasis on subsoil nutrient reserves that can be accessed during periods when topsoils are dry. These levels are being depleted across the region. The 10-30cm layer looks to be the most important for assessing soil P and K status (in addition to the traditional testing of the top 10cm), while for the more mobile S the critical depth is probably extended to 60cm. There is currently no information on the critical soil concentrations of these nutrients in the subsoil for any crop. We therefore have large gaps in our knowledge for many of the crops grown in the northern region, and for most of the nutrients, as well as the appropriate soil testing methodology to assess subsoil P, K and S status. Our aim is to fill these gaps by conducting trials across the region from the Central Highlands in Qld to the southern Liverpool Plains in NSW, with sites also located in western areas of southern Qld and central and northern NSW. We will provide soil test - plant response calibrations covering the above gaps in knowledge, with this project focussing on P, K and S soil test-crop response information for the major crops in the region (sorghum, wheat and chickpea), with the objective of better matching fertilizer inputs to meet crop demand yet minimise nutrient losses.
Overcoming constraints to profitable cropping on forest gravel soils of the Western Region (DAW00258)	Ironstone gravel soils (often referred to as gravel soils in Western Australia (WA)) are widespread throughout the cropping areas of south-western Australia. The term forest gravel is loosely defined, covering a broad range of gravel soils in the medium to high rainfall zones of the western region and the scope of this study. Forest gravels are widespread, locally common and important cropping soils and a better understanding of their properties and management is urgently required. The extent of gravel soils and their agricultural potential will be synthesized from the scientific literature and local evidence such as soil survey reports completed for the western region. The foci of this investment are characteristics related to nutrient retention, plant available water, compaction and soil water repellence and the interaction of these key characteristics and constraints with other abiotic and biotic stresses likely to be encountered in the field. A key aim of this project is to build knowledge on how nutrients and water move through gravelly soils, particularly those with a water repellent surface. Urbanek and Shakesby (2009) suggest that there is a critical stone content for inducing preferential flow; the stone content needs to be high enough to allow stone to stone connections which create voids for rapid, non-equilibrium water flow (preferential flow). A similar threshold in stone content is also relevant to changes total and fine-soil bulk densities may make forest gravels variously susceptible to soil compaction (Poesen and Lavee, 1994; Racknagel et al., 2013; Torri et al., 1994). In addition, stone content is known to non-linearly alter soil moisture levels and soil evaporation rates. Each of these effects of stone content will have implications for modelling water and nutrient availability to crops (van der Heijden et al., 2013). Glasshouse and laboratory experiments will provide a better understanding of the impact of gravel on the dynamic processes of soil nutrient supply and demand by crops, plant water relations and the impact of gravel content on the effectiveness of lime for changes in soil. An analysis of gravel physical attributes, mineralogy and geochemistry and its implications for the nutrition (particularly phosphorus) of crops will complement the glasshouse and laboratory work. The intention is to identify physical, mineralogical and chemical differences between gravels in the western region that provide evidence for tailoring agronomic practices to different gravel types. Soil matrix mineralogy on the inorganic fine earth and gravel components will be performed using X-ray diffraction techniques. Additionally EM scans will allow estimations of element distribution on the surface and near surface of gravels. The aim of this project is provide growers and advisors with knowledge that will improve the management of crops grown on gravel soils. The project will use a sequential approach to develop this knowledge. The hydrology of gravel soils and their mineralogy will also be assessed with an emphasis on nutrient availability to crops. All of this work will be used to guide a programme of glasshouse and field experiments which will address key knowledge gaps and provide an evidence-base for extension.
Delivering value from soil moisture probes on Eyre Peninsula	Soil moisture probes are now located in 37 Eyre Peninsula (EP) paddocks and are currently providing daily information to growers. The initial soil moisture probe network of 20 sites was established by EPARF, in conjunction with SAGIT, AgFarm, LEADA and EPNRM (Figure 1). The network has been in place since 2016 and many of the soil types they are located on have not been fully characterised for physical limitations to enable an accurate estimation of plant available water.

	This short term project will enable the characterisation of ten soils within the soil moisture probe network to be undertaken within the same time period and by the same operator, to increase the sampling accuracy, improve soil test results and allow for better characterisation and understanding of the plant available soil moisture on the sites. This will provide a more rigorous interpretation of soil moisture data which can then be provided to the growers. The network has created a lot of grower and industry interest in how soil moisture is being utilised by plants and different plant types (pastures and legumes). The initial SAGIT funded project has shown the potential uses of the soil moisture probe network, however limited funding has not allowed full soil characterisation of all the soil sites, and new sites have subsequently been added over time. Currently only limited information has been provided to growers on plant available water. The soil characterisation of the additional sites will allow the agricultural industry and growers to reliably use the soil moisture probe network as a reference for in-season nutrient management decisions.
Improving sustainable productivity and profitability of Mallee farming systems with a focus on soil improvements (DAS00169-BA)	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.
Understanding how waterlogging affects water and nutrient uptake. (DAV00151 - D-BA)	Grain yields in the south-east High Rainfall Zone (HRZ) are well below their climate-limited potential due to a combination of agronomic, genetic and resource constraints. Crop nutrition, particularly the efficient use of nitrogen, is one of the major constraints, and this can be exacerbated when other soil conditions are suboptimal. Potential yield increases derived from cultivar or agronomic improvements are likely to be limited by hostile soil conditions, particularly those that cause temporary waterlogging during wetter periods, and those that restrict the availability of water and nutrients to the plant in drier periods. Current research in the HRZ is addressing nutrient management on well drained soils only. However, approximately 70% of soils in the HRZ are susceptible to waterlogging in wet seasons. The relationships between waterlogging events, crop root growth and access to soil water and nitrogen, and the consequences for grain yield and quality are poorly understood. Research is therefore required into how the timing and duration of waterlogging affects root development and water and nitrogen acquisition over the growing season, so that management practices can be developed to alleviate the constraints and lift grain yields. This project will use a combination of field measurements and modelling to enhance understanding of the effects of waterlogging on crop growth and water and nitrogen uptake and the consequences for grain yield and quality and identify management practices that may increase crop production on waterlogging-prone soils. As a result of this project, growers, advisers and scientists will better understand the constraints to efficient water and nitrogen usage by wheat growing in waterlogging-prone soils of the HRZ,

	and potential approaches for improving crop yields and quality through management.
Victorian Grains Investment Partnership 2.2 (sub-soil constraints)	Soil-based constraints significantly limit grain yield and profit throughout large areas of the southern region and nationally. Removing multiple soil constraints can achieve an 80% improvement in productivity (Sale et al 2016). Enabling crops to achieve full water use efficiency in variable soils and seasons will be vital for future grain production systems. Over the last decade there have been few breakthroughs in the management of multiple soil constraints. Current recommendations are based on past research undertaken in "old" farming systems. These practices do not account for advances in farming systems or amelioration practices. At present growers have not widely adopt soil amelioration practices. This is not surprising due to the upfront costs and risk arising from the lack of reliable prediction of where and when different soil amelioration strategies work. There is a need to understand multiple soil constraints and address the right constraint at the right place and amount, at the right time with the right management. If we can reliably diagnose the type of constraint present, we can then predict when and where amelioration strategies will be cost effective, growers' confidence in adoption will increase markedly. This project aims to increase marketable yields by 10% and production efficiency by 20% in the medium and high rainfall regions of Victoria where soil constraints have been identified. Overcoming multiple soil constraints will allow crops to use the full soil water profile and increase yield and stability of income in variable seasons. Increased adoption of soil amelioration practice will improve soil health and the sustainability credentials of the grains sector. The project will use new approaches to develop a fundamental understanding of the nature, extent and severity of multiple soil constraints on crop productivity. Soil process research will occur in controlled environments and at point-scale in the field. New approaches using existing technologies will allow the accurate identification and quantification of multiple constraints for different crops and farming systems and their relative importance in constraining crop growth and yield. Existing spatial approaches will be integrated to develop a new fundamental understanding of multiple constraints on crop productivity down the soil profile. This new understanding of priority soil constraints will underpin increases in efficiency and reliability and profitability of management interventions. New and current and combinations of tolerance, avoidance and amelioration management practices will be designed and tested for farming systems in the medium and high rainfall zones. This will include to potentially applying lime, gypsum and organic matter to reduce costs and increase efficiency, building on previous and current GRDC and other (AVR) funded projects in these areas. The project will develop new economic response functions for different soil constraints by management invention and integrate these into existing economic approach (ROSA) to help growers and advisers determine the most cost-effective soil management options for multiple soil constraints for their production systems. Transformational changes for **growers** from this project include: • FROM single soil constraint management approaches TO managing multiple and priority soil constraints. • FROM unreliable, costly, high-risk, single factor ways to manage soil constraints TO targeted and cost-efficient crop and soil management practices that use right combinations of avoidance, tolerance, and amelioration tactics. • FROM low adoption rates of practices that manage soil constraints TO growers confidently fixing the right constraint, in the right place and amount, at the right time with the right management achieving water use efficiency, increases in yield and improvements in soil health.

Identify and test alternative pasture options, including annual, perennial and hard seeded varieties (compared to vetch) to provide a range of options which will produce feed throughout the whole year across variable environments

GRDC investments addressing this issue

Boosting profit and reducing risk of mixed farms in low and medium rainfall areas with newly discovered legume pastures enabled by innovative	Over the past three decades there has been a shift from integrated crop-livestock production to intensive cropping in dry areas which has significantly reduced the resilience of farms. Intensive cropping is prone to herbicide resistant weeds, large nitrogen fertiliser requirements, and major financial shocks due to frost, drought or low grain prices. A pilot project with MLA and AWI in WA and southern NSW has demonstrated how novel pasture legumes such as serradella, biserulla and bladder clover can improve livestock production while reducing nitrogen requirements, weeds and diseases for following crops.

management methods	This new project will develop recently discovered pasture legumes together with innovative management techniques that benefit animal and crop production and farm logistics, and promote their adoption on mixed farms over one million hectares in the low and medium rainfall areas of WA, SA, Victoria and southern NSW. The project is also aiming to halve financial risk. There are five integrated programs of work: 1. Development of pasture legumes that are: • Well adapted to major soils in dry regions; fix abundant nitrogen; produce quality stockfeed to fill gaps. • Harvestable with conventional machinery to minimise seed costs. • Of suitable seed dormancy to enable summer sowing or natural regeneration after crops. • Tolerate cropping herbicides, legume diseases and pests. 2. Cropping systems research to maximise benefits to crops through: • Cheap pasture sowing/regeneration practices that easily integrates with crops. • Flexibility to change crop/pasture mix according to seasonal conditions and prices. • Enhanced nitrogen fixation and soil fertility; reduced fertilizer inputs. • Decreased weed herbicide resistance, diseases and pests. 3. Animal systems research to deliver: • Increased growth and reproduction by extending the period of quality feed; reduced supplementary feeding. • More meat achieving 'grass fed' premiums; more fibre. • Understanding anti-nutritional factors and 'duty of care' for new species. • Grazing of weeds in preference to legumes. 4. Whole farm economic modelling to quantify the impact on profit by: • Integrating data from above programs into paddock-scale and farm models. • Exploring optimum combinations of enterprises, prices, soil type, and labour requirements over a range of seasons. • Mapping the best fit for each pasture to maximise whole farm profit and/or reduce risk. 5. Extension activities will directly interact with at least 3,500 growers, and increase plantings of new legumes by more than 1,000 growers (average 250 ha each) through: • Participatory on-farm research that ensures technologies meet farmer needs. • Demonstrations to quantify animal production and welfare, and benefits to crops. • Field days, workshops, case studies and other activities with grower groups; providing relevant information for publications, including YouTube videos. • This program will also coordinate project management and evaluation.