Grains

Overview

The grains industry is Western Australia's largest agricultural industry with an annual export value of about $5.3 billion.

Kerry Regan
DIRECTOR, GRAINS DIRECTORATE

THE GRAINS INDUSTRY IS CRITICAL, contributing more than $5 billion per year to the state economy and underpinning jobs, businesses and communities across WA (Figure 2).

With 85 per cent of grain production exported, maintaining our competitive position in world markets is imperative. WA's grain exports go predominantly to South East Asia, North Asia, Europe and the Middle East and opportunities exist to expand our Asian export markets.

To remain internationally competitive, the WA grains industry must achieve a minimum productivity gain of two per cent per year to keep pace with the terms of trade. To achieve this our grain growers must have ongoing access to production technologies evaluated under WA's tough grainbelt conditions.

Despite declining winter rainfall, more frost and high temperature events, acidifying soils and increasing input costs, WA's grain production has continued to increase over the past 30 years (Figure 3). The industry has continued to push the productivity frontier by adopting better crop varieties, better management practices and more reliable farming systems.

On average, there is a 24-year cycle in agriculture between initial research investment and the resultant development and adoption of technological innovations.[2] An ongoing commitment to research and development is therefore critical to maintaining the industry's international competitiveness and economic benefit to WA.

[2]Alston JM, Pardey PG and Rutttan VW (2008) Research Lags Revisited: Concepts and Evidence from U.S. Agriculture, Economic History Association meetings, The Engines of Growth: Innovation, Creative Destruction, and Human Capital Accumulation New Haven CT, September 12-14, 2008

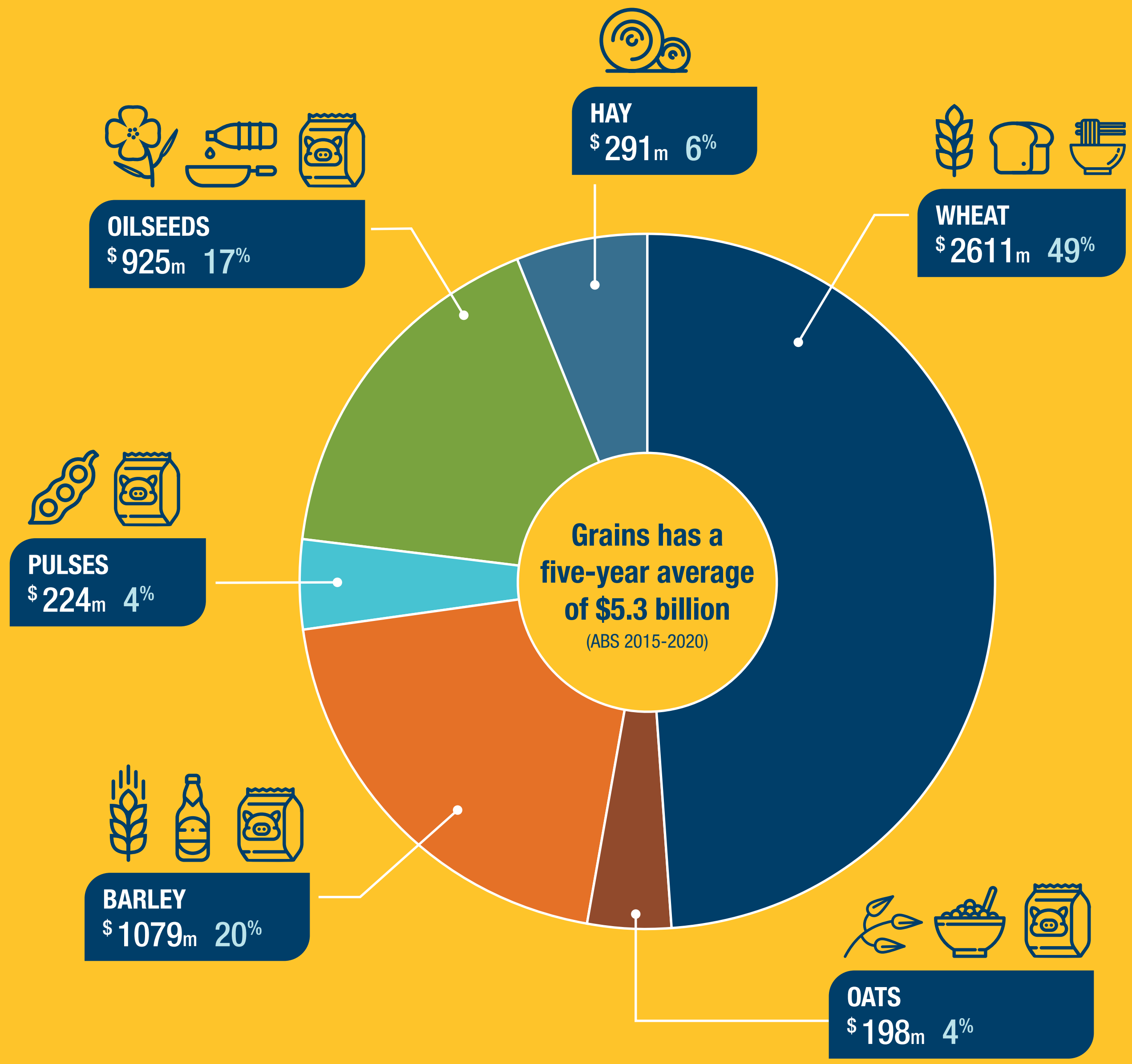

FIGURE 2. Gross value (A$ million) of Western Australian grain production (five-year average of 2015-2019)

Source ABS

Grains

Over the next 30 years, the WA grains industry will adopt farming systems with greater diversity to manage climate and market risk and improve resilience and sustainability.

Increased productivity will be driven by advances in robotics, remote sensing, data analytics and digital platforms, genetic tools such as genomics and gene editing, and farming systems innovation such as re-engineered soils. There will also be a growing focus on specialised characteristics to meet end-user requirements, such as udon noodles, biscuit wheats, and healthy oat and barley products.

WA grain growers have long been drivers of innovation, adopting new science and solutions on-farm, along with business risk strategies to address crop production challenges.

Some of WA's crop production challenges:

- The ongoing drying and warming of the climate that we are experiencing in the grainbelt, along with increasing prevalence of frost events.
- Rapid rise in grain production and exports from the Black Sea area, a very low-cost production area.
- Changing international trade flows associated with global politics and the enduring effects of the COVID-19 pandemic.
- Increasing scrutiny and lowering of minimum residue levels (MRLs) for some chemicals that are currently a key part of production of WA crops.
- Consumer expectations about sustainability, animal welfare, food safety and health.

Grains

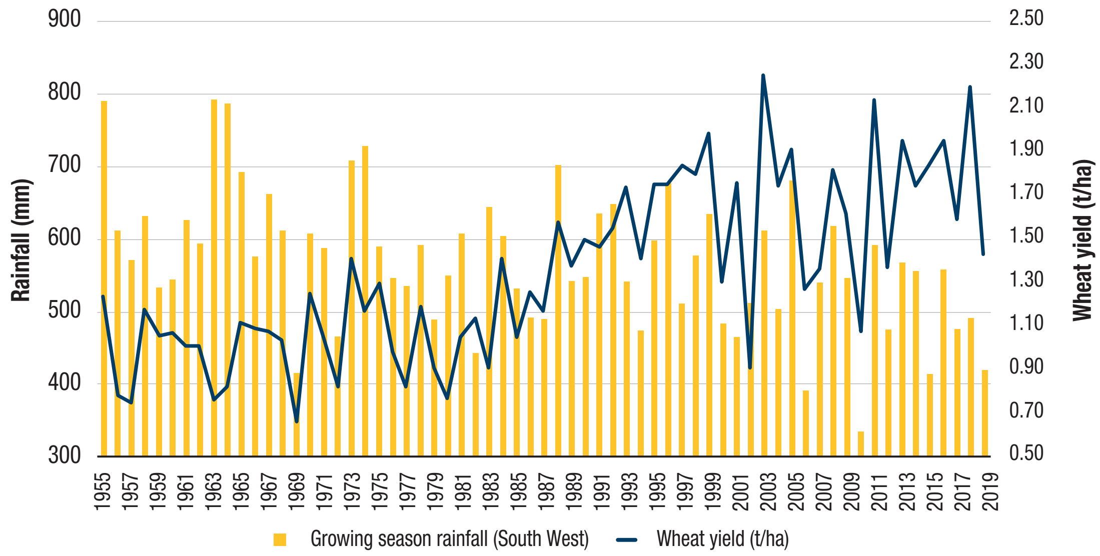

FIGURE 3. Western Australian wheat yields and annual rainfall (1955–2019)

DPIRD has a reputation for scientific expertise, regionally-based technical capability and infrastructure, which are uniquely placed to address WA's specific grain production priorities. The department's research capacity is being rebuilt through an organisational restructure and appointment of new scientists and technical staff along with significant investment in infrastructure (see box).

These investments support the delivery of applied R&D at a local level. To maximise the benefits of our R&D for WA, DPIRD collaborates with independent agronomists, grower groups, specialist scientists at universities, and the CSIRO.

We are also strengthening research linkages nationally and internationally to tackle grain science questions of a more fundamental nature with universities and other WA research providers.

DPIRD already has strong partnerships with the University of Western Australia and Murdoch University through the SoilsWest Alliance and Western Crop Genetics Alliance, which was recently expanded to include lupin and oat pre-breeding.

We value our long-term partnership with the Grains Research and Development Corporation (GRDC), a critical partner and co-investor in a large portfolio of projects prioritised by the Australian grains industry.

New infrastructure developments include:

- **$11.5 million upgrade** of the Northam Grains Research Facilities, featuring new storage, preparation and processing rooms, glasshouses, screen houses and field plots.
- **$2.1 million refurbishment** of ageing research laboratories and office facilities at Merredin.
- **$4 million to support** regional grains R&D infrastructure and equipment, such as plot seeders and tractors, glasshouses and specialist research equipment.

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We also work closely with the Australian Export Grains Innovation Centre (AEGIC), founded by DPIRD and GRDC in 2012 to enhance the international competitiveness and value of Australian export grains through science, technology and innovation. AEGIC combines market intelligence, R&D and customer engagement which are crtitical to WA's export-oriented grains industry.

Our R&D is focused on WA's major crops: wheat, barley, canola, oats, lupins and pulses (field pea, fababean, chickpea and lentil).

Our strategic direction addresses new technologies, export market priorities and the significant challenges faced by WA growers including seasonal rainfall variability in a changing climate, spring temperature extremes and infertile soils.

The research is supported by expert field research services which provide operational management, research facilities and equipment for the delivery of grains research experiments.

We also have a role in industry development by working closely with the Grain Industry Association of Western Australia, other government departments and more broadly with industry. Our grains commodity experts maintain knowledge across the supply chain through their excellent industry networks.

Our R&D contributes strongly to WA government and grains industry priorities, including the recently developed Primary Industries Plan for 2020–2024, which has a vision for a more sophisticated, diverse and globally competitive sector.





DPIRD's grains research and development:

Crop protection:

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Providing effective and economic on-farm management strategies to minimise losses from pests, weeds and diseases.

Genetic improvement:

Page 96

Evaluating and developing new breeding lines and genetic traits under harsh WA environmental conditions and providing information and genetic resources to crop breeding companies, including InterGrain, for the development of better crop varieties.

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Crop science and grain production:

Page 118

Optimising the management of new varieties, crop type and rotations, and seasonal risk decision-making in the farm business context.

Soil science and crop nutrition:

Page 138

Identifying new soil management techniques to improve soil fertility and crop nutrient availability.

> ***"DPIRD's diverse scientific expertise and infrastructure, along with an ability to work closely with growers, commercial groups, other research organisations and universities, contributes to more profitable and reliable farming systems for WA's regionally specific environments.***
>
> KERRY REGAN

CROP PROTECTION

CROP PROTECTION

Purpose: optimise yield, profits and market access for Western Australia's $5.3 billion grains industry.

WEEDS

PESTS

DISEASES

MONITOR

Keep abreast of emerging weeds, pests and diseases by implementing surveillance and early warning systems that enable timely and efficient control.

UNDERSTAND

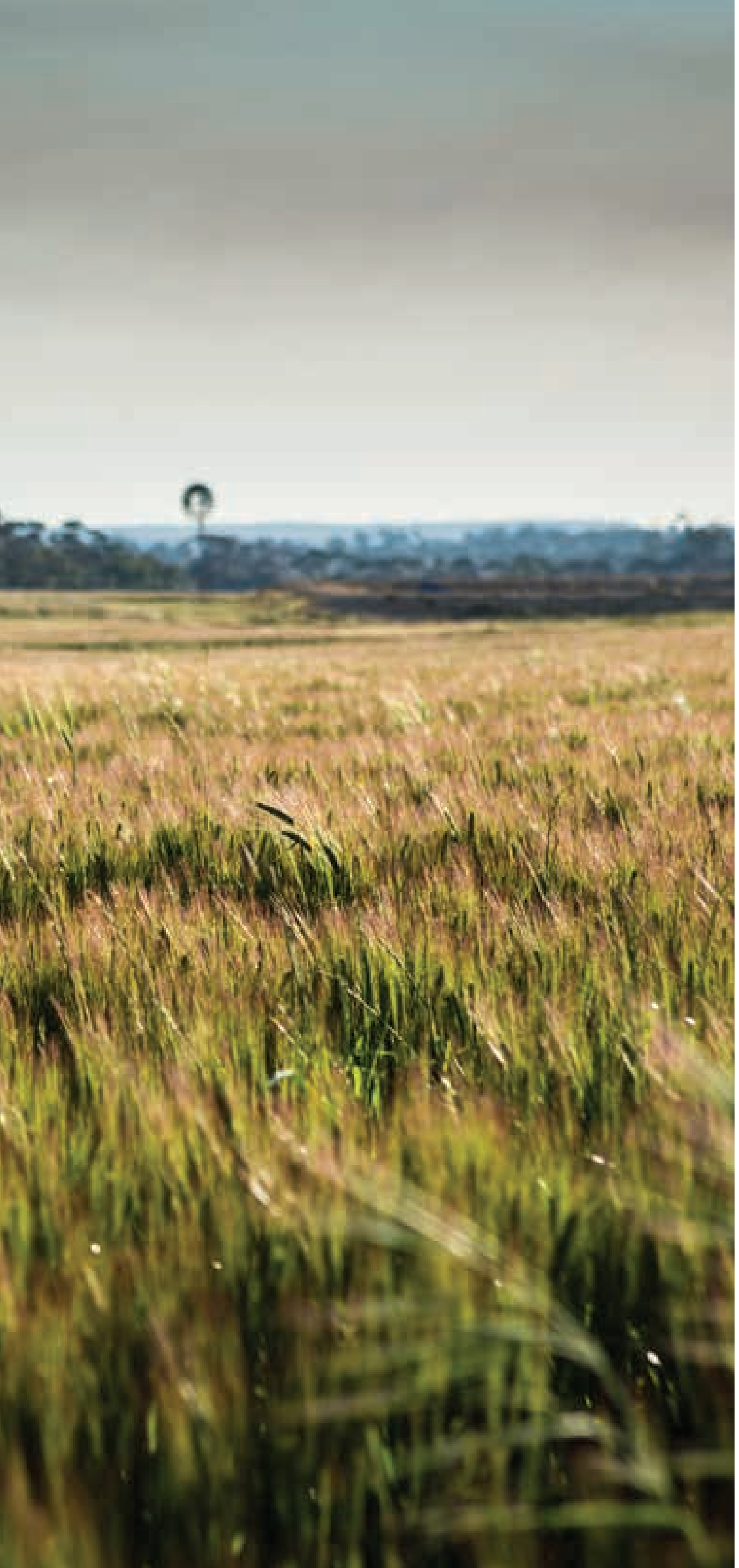
Understand how weeds, pests and diseases reproduce and spread, and develop management systems that exploit their weaknesses.

MANAGE

Develop management systems that fit into the whole farming system and provide easy access to decision-support tools.

CROP PROTECTION

Dr Sally Peltzer
MANAGER, (CROP PROTECTION)



Crop Protection Grains

WEEDS, PESTS AND DISEASES cost Western Australian grain growers more than $1 billion each year due to reduced yields, product downgrades and control costs. Chemical control is the second largest on-farm expense after fertiliser. Many growers spend about $70 per hectare or a fifth of their entire input costs on insecticides, pesticides and herbicides each season.

DPIRD's crop protection team is focused on reducing chemical usage on-farm and identifying non-chemical control methods for integrated pest management systems.

Getting smarter about chemical use not only saves grain growers money but also helps slow the development of chemical resistance – an issue borne of using the same chemical too often and often unnecessarily.

It is estimated that reducing chemical use across the Western Australian grains industry by just 30 per cent could save growers about $240 million each year.

Each time a chemical is applied unnecessarily it provides the weed, pest or disease with another opportunity to master resistance against the specific insecticide, herbicide or pesticide.

Growers are facing an increasingly smaller range of in-crop chemicals for weed, pest or disease control due to insect, weed and pathogen resistance so using chemical groups judiciously is critical.

The WA grains industry is export-oriented, with nearly 90 per cent of annual grain production exported to more than 50 countries worldwide. There is a growing move internationally to restrict chemical use or ban specific chemicals completely.

To maintain and expand market access it is critical that WA growers adopt non-chemical methods where possible and apply pesticides, herbicides and insecticides only when needed using the safest spraying technologies available.

The Crop Protection team is using a three-pronged approach to develop better ways to manage crop pests, weeds and diseases and ensure chemicals are used astutely:

1. Monitor and report on emerging weeds, pests and diseases to enable timely and efficient control.
2. Understand how weeds, pests and diseases reproduce and spread to exploit their weaknesses.
3. Develop management systems that fit into the whole farming system and provide easy access to decision support tools.

Monitor

It is impossible to properly manage something without monitoring, so a key activity of the crop protection program is surveillance for current and exotic pests and diseases. By keeping abreast of pests and diseases as they emerge throughout each season — or enter WA for the first time — growers can implement strategies that quickly overcome the problem before it spreads. In the long run, such surveillance will save considerable money and time.

The Crop Protection team is using the latest mobile applications and drone technologies to survey cropping systems remotely and in real-time and capture information about the status of pests and diseases in grain cropping areas across WA. The information collected via these early warning systems is then delivered directly to growers or fed into DPIRD's modelling programs to predict how the pest or disease is likely to behave throughout the season. This information helps growers fight an outbreak with timely and targeted chemical applications while pest or pathogen numbers are still low.

Surveillance keeps abreast of emerging threats

Proactive surveillance of cereal crops across WA port zones has led to the early detection of a new fungal disease in the state's billion-dollar barley industry.

The surveys were undertaken as part of the broader surveillance work of DPIRD's Crop Protection team who work with growers, agronomists, scientists and grower groups to develop a seasonal snapshot of the pests, diseases and weeds across the Western Australian grainbelt.

Ramularia leaf spot is a fungal leaf disease that affects crops late in the season. Disturbingly, the experience internationally is that Ramularia can rapidly develop resistance to fungicides. Following detection of Ramularia leaf spot in Tasmania in 2016, DPIRD plant pathologists carried out a targeted surveillance program in WA's southern growing regions for the presence of this disease. It was identified in three locations in the Albany and Esperance port zones, the first record of the disease in WA.

Ramularia leaf spot in barley.

As part of a national project led by research scientist Andrea Hills, leaf and seed tests will help determine whether the disease is present in the other mainland states and show the current distribution of Ramularia leaf spot in WA. The surveillance work will also collect fungal isolates for further testing to determine whether sensitivity to the main three fungicide groups used in WA cropping systems has changed.

Understand

Controlling weeds, pests and diseases is all about understanding how and when they reproduce, grow and spread. By unravelling the lifecycle of a weed, pest or disease it is possible to identify when it will be most vulnerable to cultural or chemical control.

The Crop Protection team is investigating the biology and epidemiology of a range of weed, pest and disease species to determine how and when to best control.

The goal is to find weak spots for each species. For example:

- When is an insect most vulnerable to a bait or spray?
- How do seasonal conditions influence aphid–virus populations?
- How long do weed seeds and fungal fruiting bodies last in the soil?
- When do grass weeds shed their seeds?
- How soon do weed seeds become viable after seed-set?
- Can fungal resting bodies such as sclerotes be destroyed at harvest via mechanical crushing?
- How do seasonal conditions affect the lifecycle of fungal diseases?
- When are snails most hungry and therefore most likely to eat baits?
- How does sowing time affect the disease risk in spring?

Doublegee

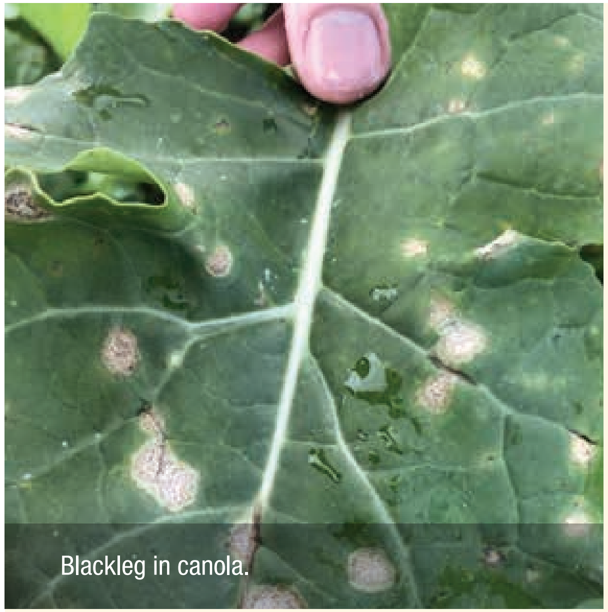
Doublegee (*Rumex hypogaeus*) is the fifth most costly weed in WA agriculture. It is estimated that growers lose $754 000 per year through lost production and control costs. More than 50 per cent of wheat yield can be lost with doublegee densities of 50 to 120 plants/m^2.

Individual plants can produce an impressive 1100 seeds along their branches but, disturbingly, they also produce hidden and subterranean seeds at the base of the plant crown. DPIRD research scientist Dr Catherine Borger investigated when these underground seeds are produced compared to their above-ground counterparts and how fast they mature.

Catherine found that the subterranean seed were produced earlier than above-ground seed. Underground seeds were produced by the time the plant had just four leaves while the above-ground seed was produced later – once the plant had five leaves. The findings have implications for the timing of herbicide applications. The current recommendation on many herbicide labels is to spray doublegee at the two to four-leaf stage but according to Catherine's work this is too late to prevent seed set completely. Late spraying could explain why complete eradication of doublegee has been so difficult. Given the abundance and early development of the subterranean doublegee seeds, the use of a pre-emergent residual herbicide will be necessary to completely prevent seed set. Catherine's work to better understand doublegee growth and development is continuing.

Doublegee (*Rumex hypogaeus*).

Blackspot in field peas.



Blackleg in canola.

Manage

Crop Protection team members integrate their early warning systems and biological knowledge into management systems so that growers are not only aware of emerging pest outbreaks but to manage pests and diseases using a combination of chemical and non-chemical strategies.

Modelling pest and disease populations throughout the season and under a changing climate is a central focus of the Crop Protection program. Using pest and disease monitoring data collected early in the season to predict the likelihood of an outbreak later in the crop's lifecycle allows growers to be prepared for an issue before it gets out of hand.

Localised models predict disease-free sowing dates

Weekly disease forecasts delivered by DPIRD research scientist Jean Galloway and her colleagues are providing canola and field pea growers across Australia with safe sowing windows to avoid fungal pathogens.

Blackspot in field pea and blackleg in canola are major fungal diseases in Australian cropping regions.

The blackspot risk forecast model known as Blackspot Manager predicts the blackspot risk of a specific location up to two weeks in advance. Blackspot alerts are sent to subscribers across Western Australia, South Australia, New South Wales and Victoria through SMS and email, with a risk level for each grower's local area.

With no varietal resistance, and little in the way of chemical control to manage blackspot of field pea, cultural methods are the most effective way to minimise the impact of this disease; these include include delaying sowing until at least 50 per cent of the spores have been released from the previous season's stubble.

The canola blackleg model monitors the maturation of blackleg fruiting bodies on the previous season's stubble and, using local weather data, predicts the risk that spore release will coincide with the susceptible stage of the crop. A risk forecast is produced each week of the canola sowing window for locations across the Western Australian grainbelt and is provided to growers via the DPIRD website and Pestfax. The predicted maturity date of blackleg spores helps growers decide if fungicide application is warranted at the time of sowing. The forecasted risk information can also be entered into the BlacklegCM decision support tool to help with foliar spray decisions at the four to six-leaf stage of the crop.

DPIRD technical officer Amber Balfour-Cunningham examines an insect trap used to send early warnings about pest levels across WA's cropping areas.

Canola flower head infested with green peach aphids.

Smart network assembled for statewide pest and disease control

High resolution multispectral drones, solar-powered remote cameras, 3D printers, automated insect and spore traps and novel DNA tests are being dispatched across the Western Australian grainbelt to monitor the state's grain production zones for seasonal pests and diseases.

DPIRD research scientist Dr Ben Congdon tests the DNA of green peach aphids to determine if they are carrying the costly 'turnip yellows virus', which can cause large losses in canola crops.

THE NEW APPROACH to protecting WA's $5 billion grains industry is saving time and money while delivering management systems fine-tuned for local conditions.

DNA test sparks early warning to manage viral spread

The green peach aphid is one of the world's most destructive pests and WA's billion-dollar canola industry has just one foliar insecticide left to keep it at bay.

The tiny insect is known to suck on the sap of 400 plant species worldwide, from peaches and potatoes through to canola and wild radish. While feeding, the aphid can infect its hosts with hundreds of different types of plant viruses.

In canola, the 'turnip yellows virus' is transmitted via the aphid's sucking mouthparts and can reduce seed yields by 50 per cent and cause costly oil quality downgrades in the remaining yield.

As the virus replicates itself inside the cells of the canola plants, it robs the crop of photosynthetic sugars and effectively starves it of nutrition, leading to less biomass production and lower seed yields. Once a plant is infected, it remains so for life.

Symptoms of the disease only show up in the canola plants once the virus has got out of control, at which point spraying for the aphid is ineffective. Early detection of the virus is therefore key to managing the disease and ensuring that the one remaining insecticide for the aphid's control is used judiciously and at the right time.

Until recently, the virus could only be detected retrospectively using time-consuming laboratory testing on infected plant tissue. But innovative work by DPIRD research scientist Dr Ben Congdon and colleagues is developing an early warning system to alert growers to the presence of the virus before it spreads too far.

The test is cheap, takes just 30 minutes and is sensitive enough to detect the DNA of just one virus-carrying aphid amongst 100 virus-free aphids.

By using a DNA method currently being used to fast track identification of COVID-19 infections, Ben can determine whether green peach aphids trapped on strategically placed sticky traps near canola crops are carrying the destructive 'turnip yellows virus'.

Aphids not carrying the virus do minimal damage to the canola crop but, when left uncontrolled, a virus–aphid combination can infect an entire canola crop within just a month. Ben's early detection system for the virus is therefore an important tool in the battle against the disease. Growers can now proactively spray for aphids before they spread the virus into the crop. Importantly, the early warning system also means that crops without the virus can be left unsprayed, which will delay the development of aphids with resistance to the last remaining in-crop chemical, reduce costs and protect beneficial insects.

A sticky trap captures tiny green peach aphids near a canola research trial being run by DPIRD research scientist Dr Ben Congdon (background and right). Also pictured is DPIRD Crop Protection manager, Dr Sally Peltzer.


Green peach aphid (*Myzus persicae*).

The green peach aphid is not only one of the world's most destructive pests, it has also gained a reputation for overcoming many of the insecticides used against it. Australian populations of green peach aphid are now known to resist four different chemical groups: synthetic pyrethroids, organophosphates, carbamates and neonicotinoids. Just one foliar insecticide remains effective against the aphid, the systemic chemical sulfoxaflor. Disturbingly, the resistance mechanism that some aphid populations have developed against neonicotinoids (currently used as a seed dressing with variable efficacy) has been found in Europe to also confer cross resistance to sulfoxaflor. Should these aphids enter Australia, or resistance to sulfoxaflor evolve independently in Australia, growers would be left with no chemical management options for the green peach aphid.

Preservation of sulfoxaflor's effectiveness is therefore critical to the ongoing control of 'turnip yellows virus' in Australian canola crops. Use of Ben's early warning system means that this last remaining chemical need only be used when required.

Crop Protection

DPIRD research scientist Christiaan Valentine is developing and testing an array of novel insect and disease traps to enable remote monitoring of seasonal pest and diseases across the WA grainbelt.

The goal is to remotely intercept seasonal pests such as native budworm as the moths migrate from the pastoral region to the agricultural region.

The automated traps are 3D printed then laced with pheromones to attract the target species. Each unit contains a camera to record an image of moths inside the trap. When an image is taken, it is automatically uploaded via the mobile network so it can be analysed for moth type and abundance.

The remote trapping system will enable more accurate monitoring of the moth species which, in some seasons, can cause widespread damage to WA's pulse and canola crops and pasture legumes. The monitoring data will be used to provide an early warning system to growers so that they can target their costly monitoring efforts and be better prepared to control the pests before they spread too widely.

In other research, Christiaan, together with Jean Galloway, is developing and testing automated spore collection units which ultimately will be used to quickly diagnose and manage a range of fungal diseases in grain crops. As fungal spores move through the air, the traps collect them onto sticky microscope slides.

DPIRD research scientist Christiaan Valentine about to install an array of solar-powered native budworm traps across the WA grainbelt.

Native budworm (*Helicoverpa punctigera*).

Diamondback moth (*Plutella xylostella*).

The research will provide growers with real-time surveillance information about when and where to apply targeted pesticides and fungicides. The data will also be used by DPIRD crop modellers to predict how a disease might spread throughout a region given specific seasonal conditions.

Fungicide timing fine-tuned with surveillance cameras

Main photo: Remote camera captures the emergence of sclerotinia fruiting bodies (above).

SURVEILLANCE CAMERAS located in Western Australian cropping paddocks are being used to monitor when spores are released by the costly pathogen sclerotinia stem rot, a fungal disease capable of knocking 20 per cent from the annual yield of the state's one-billion-dollar canola industry.

To control sclerotinia effectively and economically, fungicide must be applied at just the right time. Spraying too early with just one spray can leave the window open for a further infection in spring, while spraying too late will be a waste of time and chemical or, even worse, lead to chemical residues in the canola grain.

However, the best time to control the disease is intimately linked to seasonal conditions and, as such, can vary from year to year.

To quantify how the fungal disease responds to seasonal conditions, DPIRD researchers have installed solar-powered cameras across eight WA grainbelt sites to monitor sclerotinia spore release in relation to rainfall, temperature and humidity.

Every three to four hours the cameras automatically send photos of the sclerotinia inoculation sites via the mobile network, allowing DPIRD research scientist Jean Galloway to remotely monitor the fungal lifecycle in real time.

The goal is to use crop modelling to develop localised early warning systems for sclerotinia and to improve spray decisions made using the SclerotiniaCM decision-support tool.

Pest monitoring made easier with eyes in the sky

To overcome monitoring error and to ensure pesticides are used efficiently, DPIRD research scientist Dr Dustin Severtson is using the latest drone video technology to capture a paddock's health status in real time using a system known as live normalised difference vegetation index (NDVI), which effectively measures stress and health in crop plants.

As property sizes in WA continue to increase, so too does the challenge of monitoring them for pests and diseases, which often occur in hot spots rather than uniform outbreaks across paddocks and properties.

Crop monitoring is currently done by walking into a paddock for about 50 metres to look for plants showing signs of insect damage or stress and to capture hidden insects using a sweep net. But with pest infestations often forming in hot spots there will always be a degree of error involved in using human legs and eyes alone to monitor crops across large properties. As a result, disease and pest hot spots that are discovered represent just a tiny proportion of the entire crop which can result in spraying more of the paddock than necessary, while hot spots that are missed can result in a decision not to spray at all.

The new technology is a significant advance on previous drone monitoring systems as it forgoes the need for expensive computer hardware and software to process and piece together multispectral camera images. Instead, the drone live streams the NDVI imagery to allow the operator to quickly identify areas of the paddock showing ill health. These areas can then be targeted for more intensive monitoring and a decision made on the necessity for spraying.

Information gathered via the live stream technology will be used to augment and expand DPIRD's CropScout app. The app, developed by Dr Dustin Severtson and his colleagues, allows growers to make more informed spraying decisions based on pest and disease thresholds in monitored crops.

The overall aim of the project is to make chemical management decisions more effective by ensuring pests and diseases are sprayed only when necessary, thereby reducing the occurrence of unnecessary spraying and the build-up of chemical resistance amongst insect pests and pathogens.

DPIRD research scientist Dr Dustin Severtson is using drone technology to monitor crop health in real time.

Map highlighting patches of crop that are stressed (red/blue) and which require further monitoring.

Disarming the enemy

EACH YEAR, WEEDS SEND the Western Australian cropping industry an invoice for one billion dollars to cover their estimated $100 per hectare impact on grain yields and management costs.

Reducing this enormous invoice is a central research focus of the DPIRD Crop Protection team.

One of the challenges in weed management is keeping abreast of 'new' weeds as they emerge in cropping systems. Many of these weeds have in fact been around for decades but a changing climate, minimum tillage and herbicide resistance have enabled what were once considered minor weeds to take up a more prominent place in cropping and pasture paddocks.

Understanding the behaviour of such weeds — how they grow, reproduce and persist in cropping systems — is the key to their control because it enables researchers to expose and exploit potential weaknesses in the lifecycles of these costly plants.

For example, in the past decade great brome and barley grass have risen in importance in Australian cropping paddocks. Collectively the two weeds cost the nation's grain growers more than $20 million each year in lost production and control costs. In the case of brome grass, herbicide resistance has forced growers to use more expensive herbicides, resulting in their spending an additional $3 million a year on chemical control of this species.

DPIRD research scientist Dr Catherine Borger has spent the past five years investigating how great brome and barley grass succeed so well in cropping systems and whether they have any exploitable weaknesses. Catherine quantified the germination pattern of the two grasses along with their seed production and seed shedding behaviour over time and between seasons. She found that great brome in particular displayed a staggered germination pattern making herbicide control problematic and allowing it to go on to produce more than 1500 seeds/m^2 in-crop.

Mechanical destruction of weed seeds during crop harvest using a specialised seed destructor attached to the header was pioneered in WA in the 1990s. The system captures weed seeds in the chaff fraction of the crop harvest and crushes the seeds, rendering them unviable. The crushing mill can destroy up to 99 per cent of the weed seeds, driving down the weed seedbank in the soil and reducing the need for in-crop chemical control.

Catherine investigated whether the mechanical destruction method could be used to better manage brome and barley grass populations in crops.

While both weed species tended to shed their seed onto the ground before harvest, the proportion of seed held on the weeds at crop harvest each year varied significantly — from 0 per cent to 70 per cent — depending on the season. Despite this large seasonal variation in seed retention, Catherine found that mechanical destruction could still significantly reduce the weed seed population over time.

Using the DPIRD-developed simulation model Weed Seed Wizard, Catherine processed the field research data to demonstrate how a mix of chemical and mechanical control affected the weed seedbanks.

When great brome was controlled by herbicide alone and just one per cent of weed seed was captured with the harvested grain, the total weed seed in the soil seedbank on 1 December each year increased from 319 seeds to 10 954 seeds over the six-year study. However, when 20 per cent of the great brome seed was destroyed at harvest, the number of seeds in the soil seedbank fell to 5925 within six years. When 60 per cent of seed was captured at harvest, total seeds in the soil seedbank were lower than the initial starting seedbank of 100 seeds/m^2.

The research indicated that mechanical destruction at harvest and in-crop herbicides could effectively run down the seedbank of both great brome and barley grass species in just three or four years.

Barley grass management – one size doesn't fit all

A grower-led research program across the Western Australian grainbelt is delivering localised management systems for the problem cropping weed barley grass, for which herbicide resistance is a developing issue.

DPIRD research scientist Dr Catherine Borger is working with six grower groups to test barley grass populations for herbicide resistance and investigate the economics and success of a range of cultural and chemical weed control methods. Thirty-nine different populations of barley grass (suspected of resistance) from cropping properties across WA were delivered to DPIRD Northam in 2019 for herbicide resistance testing. The populations were likely to be different species of barley grass, as they varied significantly in growth habit and flowering time. Without a reliable way to identify them genetically, it is effectively impossible to tell them apart. Developing herbicide resistance to Group A and B herbicides was evident in about 50 per cent of the populations. The wide range in morphology and flowering and seed-set time means each grower group will need to become familiar with its own particular population and implement a specific management system accordingly. Factors such as plant height, timing of seed-set, seed shedding and seed dormancy all contribute to how effectively weed seeds can be captured and destroyed at harvest using harvest weed seed destruction, while morphology and developmental patterns affect herbicide efficacy. Each grower group is running a three-year rotation trial to determine the best management system for the barley grass in their area. Importantly, the economics of the farming systems will be considered when developing the final weed management approaches.

Dr Catherine Borger examining barley grass populations in the glasshouse.

Mobile app guides fungicide timings

A newly released decision-support tool developed by DPIRD is taking the guess work out of managing the costly and difficult-to-control fungal disease sclerotinia stem rot in canola. This is part of a suite of tools for disease management developed by a national team of pathologists led by DPIRD's Jean Galloway.

Development of the decision-support tool was inspired in part by the variable results of nearly 50 sclerotinia research trials run by DPIRD scientists across the WA grainbelt. Out of 47 trials only a third delivered both a canola yield and sclerotinia response to fungicide application. The remaining two-thirds of the trials failed to show a canola yield response to fungicide control, indicating that the fungicide was either unnecessary or poorly timed.

To infect canola crops, production of the many millions of sclerotinia spores must coincide with canola flowering. Diseased canola petals must then fall and become lodged in the canopy under specific weather conditions for the fungus to enter and infect the canola leaves and stems. The decision-support tool known as SclerotiniaCM models paddock disease and rotation history with local weather conditions and canola development to predict whether sclerotinia will develop and whether spraying with fungicide will deliver an economic return to the grower. The decision-support tool has been validated in field trials in 2018–20 and has proven accurate in predicting the economic value of fungicide applications.

Research scientist Ciara Beard using the DPIRD-developed SclerotiniaCM decision support tool to determine whether a canola crop requires spraying for sclerotinia.

Rain, rain go away

There is a common saying among hay producers that 'first you cut, then it rains'. One of the problems with rain after hay cutting is that the extra moisture can aid the growth of saprophytic fungi. These saprophytic organisms feed on the cut hay, compromising visual quality and market value. Exported oaten hay must adhere to strict quality guidelines, and ensuring a consistent supply of high-quality product underpins WA's $130 million export hay industry.

DPIRD research scientist Dr Kylie Chambers is investigating whether fungicides applied in the weeks before hay cutting can provide insurance against wet weather damage by reducing the impact of saprophytic organisms. The project is part of a larger national project on hay agronomy and stems from anecdotal evidence suggesting that spraying strobilurin-based fungicides three weeks before hay cutting can help the crop to retain green leaves for longer (preventing the downgrading of hay visual quality) while also combatting saprophytic organisms post-cutting. Kylie is trialling the use of several fungicides and application timings (within the registered withholding periods) to quantify how they influence green leaf retention and the level of saprophytic damage when rain occurs following hay cutting. Irrigation is being used to supplement post-cutting rainfall and maximise results. The research will also calculate any economic impact of fungicide application on the quality of rain-affected hay.

Combining agronomy and genetics fine-tunes fungicide use

The fungal disease spot-type net blotch (STNB) is the most dominant disease of WA's billion-dollar barley industry. Work by DPIRD research scientist Geoff Thomas is unravelling how a combination of crop agronomy and genetics can be used to thwart disease development and refine the way fungicides are used to control the pathogen.

STNB has grown in prevalence with the growth of the barley industry, which now covers 1.5 million hectares each year in WA. DPIRD surveys indicate that 90 per cent of the state's barley crops carry a certain amount of this fungal disease. STNB is carried over each season in barley stubble so planting barley onto barley stubble results in emerging crops coming into early and close contact with the disease. Most barley varieties are susceptible or very susceptible to STNB and many WA growers sow barley early in their cropping program, which, under favourable conditions, prolongs exposure to the disease. STNB infects and can eventually kill the crop's green leaves, reducing photosynthetic area and, in turn, grain yield. Yield loss is greatest when there is significant rainfall in the second half of the season — when the crop is heading and filling grain.

DPIRD research scientist Geoff Thomas (right) discusses the results of his fungal disease trial with colleagues.

In a recent review by Andrea Hills (DPIRD) of more than 25 DPIRD trials, yield losses from STNB infection in susceptible varieties occurred in more than half (58 per cent) of trials analysed. Successful control of STNB resulted in yield gains ranging from 0.2 to 2.2t/ha, which represented from five to 59 per cent of the untreated yield.

Geoff's research is examining how sowing date, variety resistance and fungicide timing affect disease development throughout the season and final grain yield. Results so far show that early sowing (April 23) can result in significantly higher disease severity at a similar growth stage than when sown four weeks later (May 20) and that growing very susceptible barley varieties (versus moderately susceptible) results in a doubling of leaf death and likely lower yields in crops left untreated for the pathogen (Figure 4). Susceptible varieties in high disease pressure circumstances can require multiple fungicide applications to combat the disease but varieties with even a slight increase in genetic resistance (moderately susceptible to the disease versus very susceptible) can ward off the disease more effectively, reducing the frequency of required fungicide treatment. Sowing early to chase higher yields will result in higher disease levels in years favouring the pathogen and these crops will require fungicide to combat STNB and achieve the yield potential that early sowing provides.

The goal of the research is to model the predicted yield and economic impacts of sowing time and variety choice with and without fungicide applications in seasons likely to favour the STNB pathogen. The project will enable growers to make more informed economic and agronomic decisions about the risks involved with sowing susceptible varieties early and the returns likely from fungicide control of the disease. Ultimately, the research will lead to a more refined use of fungicides in barley crops, saving growers money while increasing yields and slowing the development of fungicide resistance.

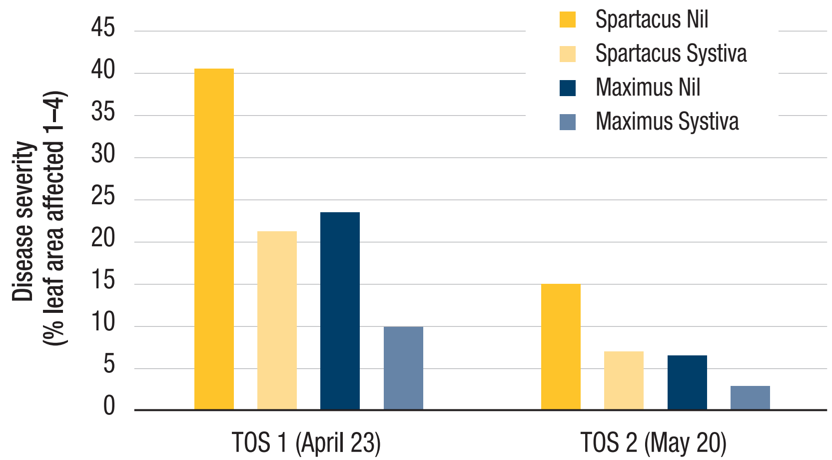


FIGURE 4. Impact of sowing time, barley variety and fungicide on fungal disease severity

Note: Maximus barley has slightly less susceptibility to the fungal disease spot-type net blotch than Spartacus barley. Sowing early (April 23) increases exposure to the fungal disease compared to sowing four weeks later in May. Applying fungicide, sowing later and using a variety with even slightly less susceptibility (Maximus vs Spartacus) generates the least disease severity.

Research is underway to investigate whether mechanical amelioration methods reduce soilborne disease and nematode pests in the topsoil where they can adversely affect crops at establishment.

Tillage buries pest and disease problems

Large areas of the Western Australian grainbelt are susceptible to soil constraints such as subsoil compaction, acidity and water repellence. These soil constraints result in lost grain production worth more than $4 billion each year. They can also exacerbate yield losses in paddocks infested with soilborne disease and nematode pests.

Over the past decade, deep tillage and soil inversion methods have been implemented widely to ameliorate problem soils across more than 250 000 hectares of WA's grainbelt. Results have been impressive with crop yields increasing by as much as 50 per cent on ameliorated soils compared with those left untreated.

Plant parasitic nematodes feed on crop roots and are a natural part of our soil ecosystem. When populations get too high they can significantly reduce crop yield as feeding prunes roots and reduces nutrient uptake.

DPIRD research scientist Dr Sarah Collins examines a soil amelioration trial investigating whether burying soilborne crop pests and diseases at depth can reduce their impact on crop yields.

Amelioration methods range from deep ripping compacted soil layers at depth through to using a mouldboard plough to completely invert the subsoil and bring it to the surface.

The methods aim to create a new soil profile, which could influence the distribution of soil borne diseases, nematode pests and weeds over time.

DPIRD research scientist Dr Sarah Collins has been investigating if mechanical amelioration practices can reduce the influence of soilborne crop diseases and nematode pests in paddocks where they have a history of causing yield losses.

Root lesion nematodes (RLN) are native to WA soils but can multiply rapidly, feeding on and damaging susceptible crop roots. Unfortunately, WA's most commonly grown grain crops, wheat, barley and canola, are all susceptible to RLN. In a bad year these nematodes can cost WA farmers up to $110 million in lost yields.

In WA's grainbelt, major soil borne pathogens and nematode pests are usually concentrated in the topsoil from 0–10 cm of the soil profile. Redistributing topsoil pathogens and pests deeper into the soil profile could reduce their impact on crops, particularly early in the season when crops are becoming established.

Sarah's research team, in collaboration with the Soil Science and Crop Nutrition team, is investigating if mechanical amelioration techniques alter the prevalence and distribution of nematodes and soilborne diseases in the soil profile and if these effects persist over time.

The research is also examining the effect of deep tillage on the distribution of weed seeds throughout the soil profile and whether amelioration results in fewer weeds in the following crop. Soil inversion provides effective weed control by burying weed seeds, mostly in the middle layers of the ploughing depth, whereas deep ripping, and deep mixing in some cases, stimulate weed emergence and seed head production.

In two seasons since the initial amelioration, changes in nematode pests and the soilborne pathogen that causes rhizoctonia bare patch have varied with the type of mechanical amelioration treatment. The magnitude of improvements has increased with tillage intensity in the order: deep ripping < soil mixing < soil inversion. The soil movement created by inversion successfully reduced *Rhizoctonia solani* and nematode pests in topsoil but increased them deeper in the profile. Deep ripping, which has much less effect on the soil profile, did not create enough soil movement to significantly change topsoil populations.

The longevity of changes in *R. solani* and nematode levels over two seasons was dependant on the site and nematode species in the topsoil and soil depth. In the topsoil, *R. solani* and root lesion nematode species were only effectively reduced for the two seasons by soil inversion. Conversely, another nematode, *Pratylenchus neglectus* has moved back into the topsoil in the sandy soils at Yerecoin more rapidly than in the gravelly Darkan soils where soil inversion and soil mixing treatments were used.

The effect of these redistributions will continue to be examined to determine if and how long the nematodes and diseases remain active at depth.

Fertiliser might exacerbate crop disease

Adding the optimum amount of nitrogen and potassium fertiliser to crops suffering from the fungal root disease rhizoctonia bare patch could counter the effects of the disease, which can halve wheat yields in some seasons.

DPIRD research scientist Dr Daniel Hüberli.

The soilborne fungus grows on crop residues and soil organic matter and is adapted to dry conditions and lower fertility soils. It causes damage by pruning newly emerged crop roots, which results in water and nutrient stress to the plant and reduced grain yields.

DPIRD research scientist Dr Daniel Hüberli is investigating the relationship between nitrogen and potassium fertiliser rates and disease incidence.

A field trial at Muresk found that nitrogen alone, in a site low in potassium, increased the level of root infection in barley, but also increased grain yield especially with the addition of potassium.

At a sister trial in South Australia with more disease, nitrogen applied to infected barley generated additional dry matter and yield potential in winter, which could not be supported by the diseased roots during spring. As a result, the barley crop suffered a combination of head loss, lodging and reduced grain quality.

Further work is needed to define the optimum amount of nitrogen and potassium required to avoid exacerbating disease and potential yield losses.

Rhizoctonia solani, the cause of rhizoctonia bare patch, prunes newly emerged crop roots, which results in water and nutrient stress to crops and reduced grain yields.

DPIRD research is investigating the relationship between fertiliser rates and disease incidence to determine the optimum amount of nitrogen and potassium required to counter the root disease rhizoctonia.

GENETIC IMPROVEMENT

GENETIC IMPROVEMENT

Purpose: contribute to the continual genetic improvement of Western Australia's $5.3 billion grains industry

CEREALS

PULSES

LUPIN

EVALUATE

Evaluate wild and domesticated crop lines for yield, quality, disease resistance and tolerance to soil and climatic constraints.

DISCOVER & DEVELOP

Identify genes responsible for specific traits and develop plant breeding tools.

SHARE

Package genes into prebreeding lines and deliver to breeders along with breeding tools.

GENETIC IMPROVEMENT

Dr Darshan Sharma
MANAGER, GENETIC IMPROVEMENT PORTFOLIO

DPIRD research scientist Sharon Westcott uses marker assisted selection to identify breeding lines with promising production traits.

IF WESTERN AUSTRALIAN FARMERS were using the same wheat varieties and cropping technology as they were 50 years ago, the state's average wheat yield would be about half of today's at just 0.75t/ha (Figure 5).

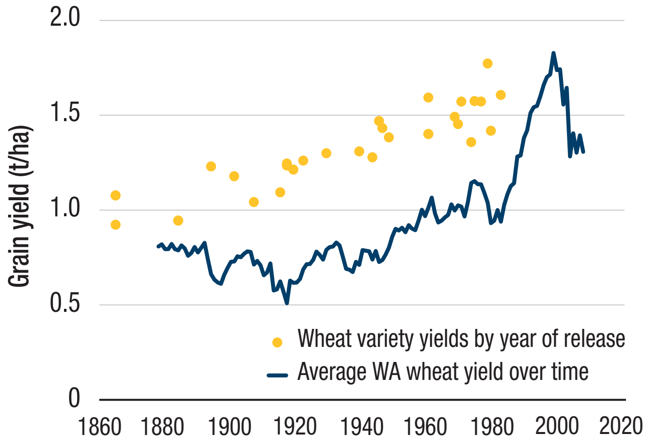


FIGURE 5. Change in Western Australian wheat yields over time (1880–2010) and the yield of new wheat varieties in the year they were released

Source: Re-drawn from Angus (2011). Variety yield data from Perry and D'Antuono (1989).

Note: New wheat genetics and agronomic packages have resulted in a steady increase in WA wheat yields over time. The significant increase in yields after 1980 was the result of semidwarf wheat varieties and lupins being added to the rotation along with the release of new grass selective herbicides.

Australian plant breeders release dozens of new crop varieties every year. Each new variety is the product of decades of research and development and contains a combination of genes proven to deliver a productivity advantage in yield, quality, disease resistance and tolerance to other factors such as salinity, soil acidity, drought, heat and frost.

DPIRD's genetic improvement team plays a critical role in these plant breeding endeavours.

The researchers identify promising genes in wild and commercial crop plants from across the world and combine them into breeding lines and user-friendly genetic tools that Australian breeders can use to develop new and improved crop varieties.

The work is time consuming and painstaking. It relies on complex laboratory techniques and hundreds of annual glasshouse and field trials across WA's cropping zones to assess the plants for disease resistance, yield and quality improvements and their capacity to withstand the challenges of WA's distinctive climate and soil conditions.

Genetic Improvement

Once crop lines are identified as having traits of interest (e.g. yield improvements, disease resistance, acid soil tolerance, reduced frost susceptibility) the researchers use molecular science methods to delve into the crop genomes and identify the genes conferring the trait. The genes are then stacked together in crop breeding lines adapted to WA cropping zones. Molecular markers for the identified genes are also developed so that plant breeders can ensure the genes of interest can be tracked within their breeding populations using laboratory tests.

Using this process, DPIRD research scientist Dr Manisha Shankar and her team have recently completed a decade-long project to gather resistance genes from places as far flung as Mexico and Syria for the wheat disease yellow spot, a fungal pathogen that costs WA farmers as much as $100 million each year. The genes and their markers are now making their way through commercial breeding programs and wheat varieties with resistance to yellow spot are due for release in the next few years.

Genetics rises to production challenges

Crops sown in WA face harsh conditions and a range of root and foliar diseases along with several soil constraints. Over the past 50 years, annual rainfall has dropped by 20 per cent across the south-west of WA and the cropping season now finishes weeks earlier than it did in the 1970s.

Identifying promising genes is a bit like finding needles in a haystack. For example, the barley genome contains about 40 000 genes, and the wheat genome contains around 100 000 genes. It is therefore no surprise that identifying and then locating specific genes associated with yield or stress tolerance takes considerable detective work. To make matters even more difficult, many traits — such as those controlling flowering time and grain yield — are controlled by hundreds of different genes and researchers must determine which of the many genes hold the most potential so that the genetic information can be stacked together and delivered to plant breeding companies in a user-friendly form.

Despite all these challenges the yield of WA crops has continued to rise — buoyed by stronger genetics and advanced agronomy systems (Figure 5).

DPIRD's Genetic Improvement Group gathers genes from across the world and incorporates them into crop breeding lines that commercial breeders use to develop new and improved crop varieties for Australian farmers.

Molecular eyes reveal whole genome

Sifting through tens of thousands of genes requires complex molecular and computational tools. Major advances in both these areas have greatly improved the speed and accuracy of DPIRD's genetic investigations. For example, working as part of an international team, DPIRD research scientist Professor Chengdao Li sequenced the barley pan genome (the entire gene set of all strains of a species) in just three years using advanced molecular and data analytics methods.

The speed with which the sequencing task was achieved is extraordinary given that the barley genome contains five billion individual components, each of which needed to be identified, then sequenced together to form the entire barley genetic story. The information gathered through the pan genome project has revealed valuable genetic variation across the world's barley lines, which can now be mined for traits that will improve barley performance in Australian cropping systems for many years to come.

New genes, new crops

DPIRD's genetic improvement work spans a range of crops, from wheat, barley and oats through to lupin, pulses and quinoa (Table 1). The wheat, barley and lupin research operate at the pre-breeding end of the crop breeding process, i.e. identifying and collecting genes for delivery to commercial plant breeders. The oat, pulse and quinoa work is done in collaboration with government agencies to breed new varieties.

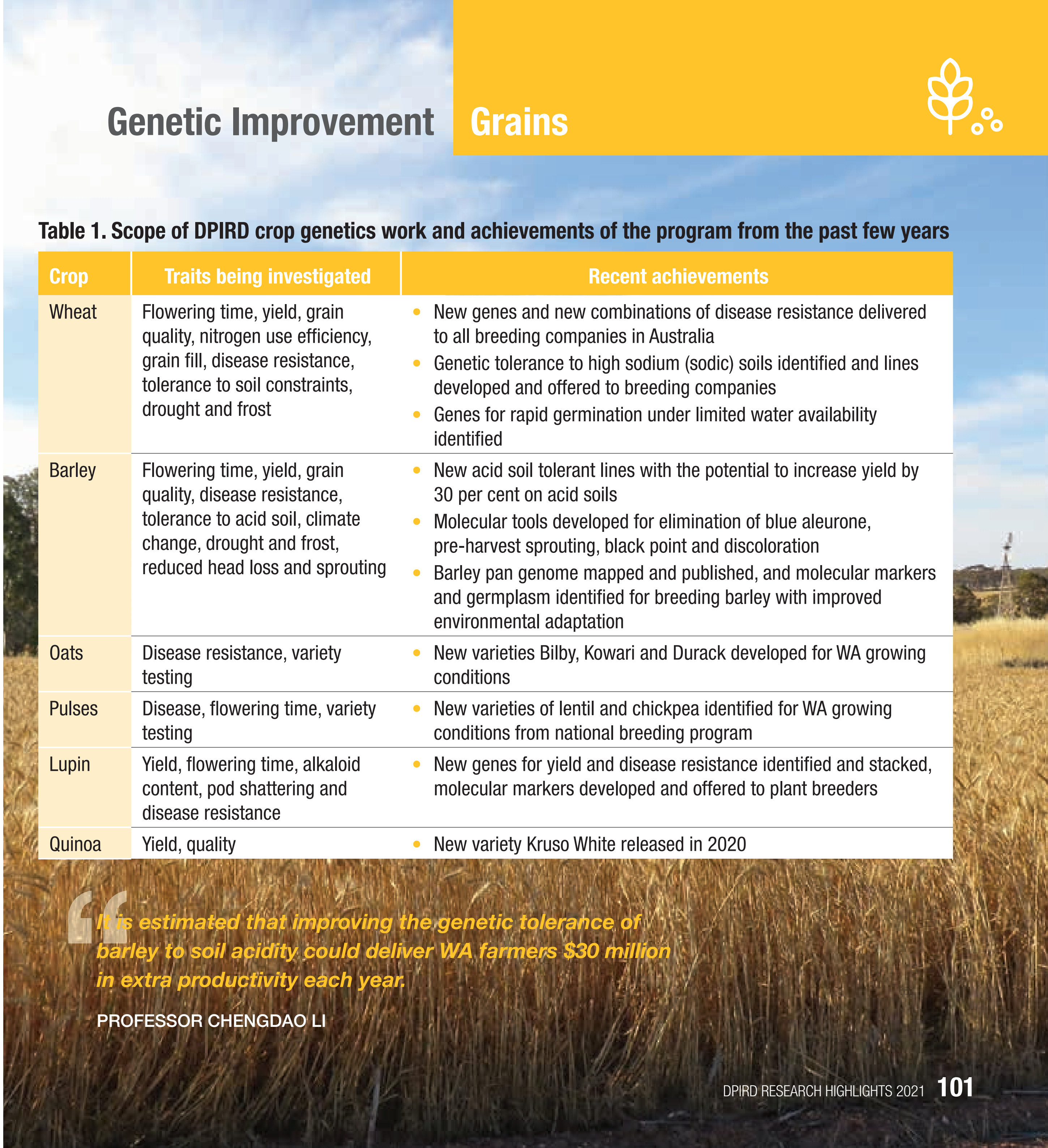


Table 1. Scope of DPIRD crop genetics work and achievements of the program from the past few years

Crop	Traits being investigated	Recent achievements
Wheat	Flowering time, yield, grain quality, nitrogen use efficiency, grain fill, disease resistance, tolerance to soil constraints, drought and frost	• New genes and new combinations of disease resistance delivered to all breeding companies in Australia • Genetic tolerance to high sodium (sodic) soils identified and lines developed and offered to breeding companies • Genes for rapid germination under limited water availability identified
Barley	Flowering time, yield, grain quality, disease resistance, tolerance to acid soil, climate change, drought and frost, reduced head loss and sprouting	• New acid soil tolerant lines with the potential to increase yield by 30 per cent on acid soils • Molecular tools developed for elimination of blue aleurone, pre-harvest sprouting, black point and discoloration • Barley pan genome mapped and published, and molecular markers and germplasm identified for breeding barley with improved environmental adaptation
Oats	Disease resistance, variety testing	• New varieties Bilby, Kowari and Durack developed for WA growing conditions
Pulses	Disease, flowering time, variety testing	• New varieties of lentil and chickpea identified for WA growing conditions from national breeding program
Lupin	Yield, flowering time, alkaloid content, pod shattering and disease resistance	• New genes for yield and disease resistance identified and stacked, molecular markers developed and offered to plant breeders
Quinoa	Yield, quality	• New variety Kruso White released in 2020

"It is estimated that improving the genetic tolerance of barley to soil acidity could deliver WA farmers $30 million in extra productivity each year.

PROFESSOR CHENGDAO LI

Ancient grain resurrected on modern farms

Behind the recently announced quinoa variety, Kruso White, lies years of dedicated research by DPIRD staff in Kununurra, South Perth and Northam.

Trials started at the department's Kununurra Research Station in 2012, with just three grams of seed to determine whether the crop would perform well in the north.

It did, and the following years of research led to the development of Kruso White, a medium standing, robust variety that can be grown successfully from the Kimberley right through the WA grainbelt under rain-fed and irrigated systems, in winter, spring or autumn. The new variety has also generated interstate interest.

Kruso White is being promoted as the key to transitioning quinoa from a niche, cottage crop to wider adoption across Australian broadacre farming.

Production of quinoa has risen globally, from 23 000 tonnes in 1990 to almost 200 000 tonnes in 2019.

DPIRD research scientist Dr Harmohinder Dhammu and his team assessed Kruso White across WA's cropping zones. Average yield of the new quinoa variety across 15 national trials was 1.5 tonnes/ha, with a yield range of 0.5–3.1 tonnes/ha. Gross margins of Kruso White production were found to be double that of wheat and canola under rain-fed conditions at Geraldton, WA, assuming a quinoa yield of just 1 tonne/ha.

DPIRD research scientist Dr Harmohinder Dhammu in a quinoa variety trial at Geraldton, WA, where Kruso White yielded the highest (3.1 tonnes/ha) among the national trials.

In 2019 Plant Breeders Rights were granted for the new variety and seed was sent to the USA and China for analysis of seed characteristics (protein, weight and amino acid package).

DPIRD has developed an agronomy management package for Kruso White, which will now be available to growers.

Research into quinoa continues in conjunction with global research partners.

To increase the genetic material available for commercial quinoa production, DPIRD is collaborating with King Abdullah University of Science and Technology in Saudi Arabia and the Northern Australia Crop Research Alliance, which is based in the Ord River irrigation area, to investigate more than 1000 lines as part of a global research project.

International genes offer disease resistance promise

New wheat varieties with improved resistance to the fungal disease Septoria nodorum blotch (SNB) are a step closer, with the discovery of suitable wheat germplasm and several resistance genes.

SNB costs WA growers about $108 million each year due to early leaf death and reduced grain fill, particularly in high rainfall areas and in wet years.

DPIRD research scientist Dr Mike Francki and his team assessed wheat lines from Australia, Mexico and Syria in six different environments across the WA grainbelt and found a total of 19 local and international lines with good and consistent SNB resistance.

The best performers against SNB included varieties and advanced breeding lines sourced from the International Maize and Wheat Improvement Centre (CIMMYT) in Mexico and the International Centre for Agricultural Research in the Dry Areas (ICARDA) based in Lebanon.

Four lines from CIMMYT and ICARDA showed consistently low SNB response across all environments against 42 different SNB fungal isolates, when evaluated in field trials at DPIRD's Northam, Katanning and Manjimup research facilities.

The team used genetic marker technologies to localise some of the genes responsible for SNB resistance to specific regions of the wheat genome.

Each of the 234 wheat lines was screened using more than 23 000 genetic molecular markers, spanning the entire wheat genome. Associations with disease response were then made for each marker.

Several individual genes appear closely linked on the same chromosome, with evidence that each gene responds independently to different fungal isolates and environments. The discovery has enabled scientists to refine their understanding of the genetic and environmental interactions that influence SNB disease response, which will help to make breeding for SNB resistance more efficient.

Wheat lines with consistent SNB resistance across WA environments were used to combine genes into WA-adapted wheat breeding material. The research will ultimately help wheat breeding companies develop more tailored and robust varieties with improved SNB resistance that perform well throughout the WA grainbelt.

DPIRD research scientist Dr Michael Francki and project scientists Dr Dora Li (Murdoch University) and Esther Walker (DPIRD) have identified genes conferring resistance to the costly fungal disease Septoria nodorum blotch.

Wheat genes sought for problem soils

DPIRD research scientists Rosemary Smith (right), Dr Darshan Sharma (second from right) and Dr Bob French (third from left) along with Australian Grain Technologies wheat breeders Dr Usman Ijaz (left), Dr Russell Eastwood (second from left), and Dr Dion Bennett (fourth from left) inspecting elite lines of wheat developed by DPIRD for tolerance to sodic, magnesic and dispersive soils.

Sodicity is the result of high levels of sodium being retained in the subsoil. This high sodium level causes clays to disperse, which reduces drainage and renders the subsoil hostile to plant roots. As a result, crop and pasture yields decline.

Sodicity affects nearly a third of all soils in Australia and costs the agricultural industry as much as $2 billion each year in lost production.

Soil surveys indicate that sodic soils cover about 1.5 million hectares or 8–10 per cent of the Western Australian grainbelt and cost WA growers about $0.5 billion in lost production each year.

DPIRD research scientists Dr Darshan Sharma and Rosemary Smith have been part of a six-year national research program aimed at identifying wheat breeding lines with genetic tolerance to sodic soils.

Wheat lines originating from crosses made in a previous Australian Centre for International Agricultural Research (ACIAR) project were grown across the WA grainbelt and assessed for growth and yield.

Several elite lines with improved yield and tolerance to sodic and dispersive soil have been selected and are currently being assessed across Australia as part of a national sodic soils project.

The lines are on offer to wheat breeders so that genetics conferring tolerance to sodicity can make their way into Australian wheat breeding programs.

Pulses bred for WA conditions

DPIRD research scientist Mark Seymour (pictured) and technical officers Pam Burgess and Chris Matthews contribute to pulse breeding programs in WA. The trials provide Australian lentil, field pea and chickpea breeders with flowering times and maturity dates of plant breeding lines under WA conditions. Due to the abundance of high sodium (sodic) soils in the Esperance region, the DPIRD team also measures soil conductivity (EM38) in mid-winter on all trial plots to ensure future crop varieties are adapted to the sodic soil constraints. Flowering time, maturity dates and EM38 readings are collated and sent to breeders to combine with pulse datasets collected in other Australian states. The combined analysis is then used to determine which lines are released as new varieties to growers.

DPIRD research scientist Mark Seymour.

Bacteria breakthrough shines light on frost damage

A major breakthrough in frost research has been achieved, with the discovery that a type of bacteria found on some stubbles could elevate the risk of frost damage in cereal crops, particularly after rainfall.

The research is part of a two-year DPIRD project funded by the Council of Grain Growers Organisations (COGGO) and led by DPIRD research scientist Dr Ben Biddulph.

Field trials over the past two seasons at the department's Dale frost nursery show wheat grown on stubbles with ice nucleation active (INA) bacteria froze from the ground up at temperatures four to five degrees warmer than without stubble.

INA bacteria produce a protein that increases the freezing point of water, heightening the risk of frost damage to wet crops after slow moving cold fronts.

DPIRD frost research scientist Dr Ben Biddulph is leading a research project investigating the contribution of stubble-borne bacteria to frost damage in wheat. The research has found that wheat grown on stubbles with ice nucleation active bacteria froze from the ground up at temperatures four to five degrees warmer than without stubble.

While the phenomenon has been observed in horticulture crops, this is the first time it has been confirmed in Western Australian cereal crops.

Pure water alone did not cause frost damage, indicating it was the bacterial ice nucleating proteins that contributed to the frost damage.

The preliminary findings indicate that the increased frost damage associated with crops growing in stubble is linked to bacteria living on the decaying crop residues and the ice nucleating proteins they produce.

The research findings are not a ‘silver bullet’ to frost mitigation but do open the door to management options, treatments and plant breeding strategies to be investigated further to protect crops from the risk of frost damage.

In horticultural systems globally, bactericides and management practices are used to manage INA bacteria and the bacterial blight they cause, while in other crops genetic variation for bacterial blight is used in breeding programs.

International frost collaboration

DPIRD research scientist Dr Ben Biddulph has developed a rating system for frost damage in the field that enables wheat to be quantified for susceptibility to frost-induced sterility at flowering time. The system has since made its way to Argentina via PhD student Diana Martino, who was supervised by Ben when she visited Australia in 2013 to complete part of her research studies.

Diana was given access to the wheat germplasm she worked on in Australia and has now assessed those wheats along with Argentinian wheat lines for reproductive frost tolerance in Argentina. The Australian–Argentinian research collaboration has helped confirm genotype variations in frost susceptibility across the southern hemisphere. The results will stimulate international research into identifying improved sources of frost tolerance.

Argentinian PhD student Diana Martino is collaborating with DPIRD to investigate frost tolerance in wheat.

Wheat disease resisted with multi-gene armour

DPIRD RESEARCH SCIENTIST Dr Manisha Shankar has spent the past decade sifting through the 100 000 genes of the wheat genome to find the handful of genes conferring resistance to one of Australia's most significant wheat diseases, yellow spot.

Armed with a suite of genomic tools and breeding techniques, it took Manisha and her team about a decade to identify the 20 genes across various chromosomes that protect wheat from the effects of the yellow spot fungus.

DPIRD research scientist Dr Manisha Shankar (front right) and her team have discovered 20 genes conferring resistance to one of Australia's most significant wheat diseases, yellow spot.

The most promising genes are now making their way through commercial wheat breeding programs with the hope that new wheat varieties with resistance to yellow spot will be developed within the next few years.

Nationally, yellow spot is rated as the second most damaging wheat disease behind stripe rust. It costs growers up to $30 per hectare in lost production and fungicide costs in hard-hit areas. At a state level, the disease is estimated to cause yield losses of more than $100 million each year.

Controlling the disease with fungicides is problematic because yellow spot spores remain on stubble throughout the year. Leaf infections in the lower canopy can re-infect upper leaves later in the season — which effectively means the disease is never actually killed.

Genetic resistance is the only sure way of curbing the disease.

Manisha leads the national pre-breeding project for yellow spot, which started in 2010 with just one resistance gene available to Australian wheat-breeding programs. While this gene conferred good yellow spot resistance, it did not explain the full spectrum of resistance evident in breeding trials, prompting the research team to look for other resistance genes they could stack together to generate a robust resistance package for plant breeders.

DPIRD research scientist Sue Broughton specialises in a genetic method known as doubled haploid, which is used to speed the breeding of new crop varieties.

To search for new resistance genes, Manisha and her team scoured through 3000 individual wheat lines from Syria, Turkey and Mexico as well as a range of Australian wheat lines.

Each of the many thousands of lines was grown in glasshouse trials and sprayed with yellow spot spores to assess for resistance to the disease. Over the course of several trials and seasons a group of wheat lines showing field resistance to the disease was identified. These lines were then grown in field trials across Australia over several seasons to confirm their resistance capacity.

Lines established as resistant were then crossed with suitable Australian wheat varieties to develop research populations using a specialised genetics technique known as doubled haploid technology.

The populations were assessed for disease resistance at various growth stages and across a range of environments nationally, and analysed at the molecular level to identify the genetic basis of their resistance. The 20 new genes were identified from this process.

Several resistance genes were then purposely stacked together into lines adapted to a range of Australian cropping regions to create robust resistance packages for commercial wheat breeders.

Exciting find delivers triple the resistance

Wheat lines with combined resistance to three significant fungal diseases have been discovered within thousands of international breeding lines brought to WA for yellow spot resistance screening.

Research scientist Dr Manisha Shankar and her team are now developing doubled haploid populations using the triple resistant lines, which could one day provide sources of resistance for commercial breeding programs. Out of an original 2445 screened lines from Mexico, Turkey and Syria, just seven wheat lines were found to contain moderate to high levels of disease resistance genes for all three diseases. Collectively, the diseases (yellow spot, nodorum blotch and powdery mildew), cost the WA wheat industry more than $200 million each season in lost production and control costs.

Yellow spot.

Septoria nodorum blotch.

Powdery mildew.

Like all pathogens, yellow spot has the capacity to mutate and overcome a plant's genetic resistance.

While this has not yet happened with yellow spot in Australia, stacking several resistance genes together in the one breeding line makes it more difficult for the pathogen to break down the wheat crop's defences.

Each of the stacked genes has a corresponding marker developed through the Australian Wheat and Barley Molecular Marker Program, based at the University of Adelaide. The markers act as gene 'flags' that enable breeders to keep track of multiple genes during variety development and determine if new crosses contain the valuable resistance genetics.

The 'Germplasm enhancement for yellow spot resistance in wheat' project is a collaborative project between DPIRD, the University of Adelaide, the Victorian Department of Environment and Primary Industries, the Queensland Department of Agriculture, Fisheries and Forestry, and Curtin University.

DPIRD oat breeding scientist Dr Mirza Dowla (left) along with DPIRD plant pathologists Dr Manisha Shankar, Ryan Varischetti, Geoff Thomas, Dr Hossein Golzar and Dr Sanjiv Gupta (Murdoch University) assessing oat breeding material for resistance to foliar diseases at Manjimup, WA.

National effort breeding resistant oats

DPIRD is a partner in the National Oat Breeding Program, which is responsible for breeding and developing new oat grain and hay varieties with superior quality.

The Western Australian oat industry generates about $200 million for the state economy each year through the production of milled (rolled) oats for human consumption and feed oats and oaten hay for livestock production.

Incorporating disease resistance into new oat varieties is a key focus of the national breeding program.

In Australia, a range of fungal, bacterial and viral pathogens infect oats and reduce yield and quality of grain and hay crops.

DPIRD's genetic and plant pathology scientists contribute to the national oat breeding efforts by assessing breeding material for disease resistance each season and delivering results of the research to oat breeders for analysis.

Barley genes rise to climate change challenge

ANALYSIS BY DPIRD research scientist Professor Chengdao Li and his team has revealed that Australian barleys contain enough genetic resilience to achieve yield increases for the next 30 years, even in the face of predicted climate change.

The recently published research found barley yields had increased by 50 per cent in the past 30 years and that more than 70 per cent of this increase was due to the genetics of new varieties (Figure 6).

Chengdao and his colleagues then dug deeper into the production data to determine how the barley yields had continued to increase through time. They found that by selecting for yield the plant breeders had inadvertently been selecting for earlier flowering time; the most recently released barley varieties have been flowering up to a week earlier than their historical counterparts. By flowering earlier, the barley varieties have been better able to escape the end-of-season heat and drought brought about through a changing climate, and have had more time to fill their grain.

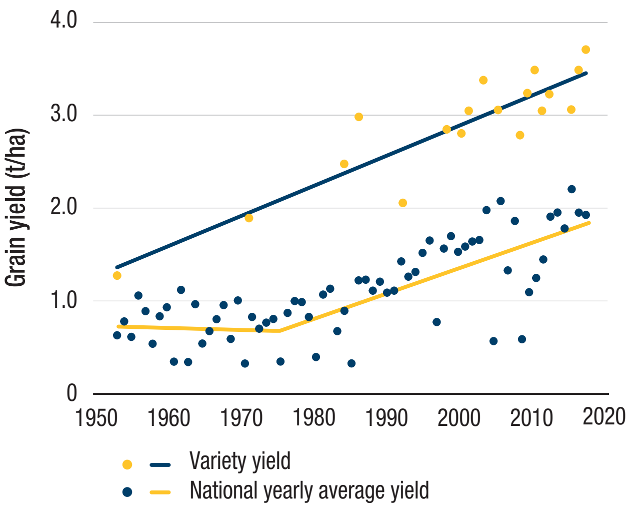


FIGURE 6. Annual increase in average Australian barley yields between 1950 and 2020 compared to the potential yield of new barley varieties

Note: About 70 per cent of the annual yield increase can be attributed to genetic improvements in new varieties.

The next task was to determine how much genetic flexibility remained within the Australian barley genome to enable breeders to develop varieties that would continue to thrive over the next 30 years of climate change.

The research team identified more than 100 genes in the barley genome that controll flowering time and/or yield. By focusing on a proportion of genes that control both flowering time and yield, Chengdao and his colleagues developed three breeding lines that contain genes holding the most promise for yield increases into the future. Specialised digital markers for the genes have also been developed which will enable plant breeders to use a digital scanner to identify which genes have been brought across into barley crossing programs.

The breeding lines and digital markers have recently been delivered to Australian breeding companies along with information about the yield and flowering time traits.

By unravelling the genes that confer yield success in barley, Chengdao says future barley varieties can now be designed to overcome the challenges presented by climate change.

Australian barley yields have increased by 50 per cent in the past 30 years and more than 70 per cent of this increase is due to the genetics of new varieties.

Barley now an open gene book that all breeders can read

DPIRD RESEARCH SCIENTIST Professor Chengdao Li and his team have played a central role in an international collaboration to decode the collective genome of all the world's barley populations, otherwise known as the barley pan genome.

The research, which was recently published in the prestigious scientific journal *Nature*, has effectively decoded barley's global genetic library, giving plant breeders the ability to 'read' the barley genome and better focus their efforts to develop varieties with improved yield, quality, disease resistance and environmental adaptation.

The enormous genetic task took just three years and involved scientists across seven countries and a suite of advanced molecular and computational tools.

Containing 40 000 genes, the barley genome is constructed from an astonishing five billion individual components (bases) spread across seven chromosomes. Chengdao and his colleagues decoded each of the five billion bases within the 40 000 genes of 20 individual barley genomes, including a key Australian variety RGT Planet, which collectively were shown to span the genetic diversity of all the world's barleys.

Once decoded, the barley genome presented to the research scientists as an enormous jigsaw puzzle of billions upon billions of individual base pieces. Each base is represented by one of the four letters (G, C, A, T) that make up the base-pair units in DNA.

The challenge then became how to piece the letter-bases back into genes and determine what each of the genes contributed to the barley plant.

> ***"The pan genome effectively paves the way for us to answer fundamental questions about increasing barley yield, quality, disease resistance and beer-making capacity.***
>
> **PROFESSOR CHENGDAO LI**

DPIRD research scientist Professor Chengdao Li and Minister for Agriculture and Food Alannah MacTiernan celebrate the decoding of the entire barley genome.

Genetic Improvement

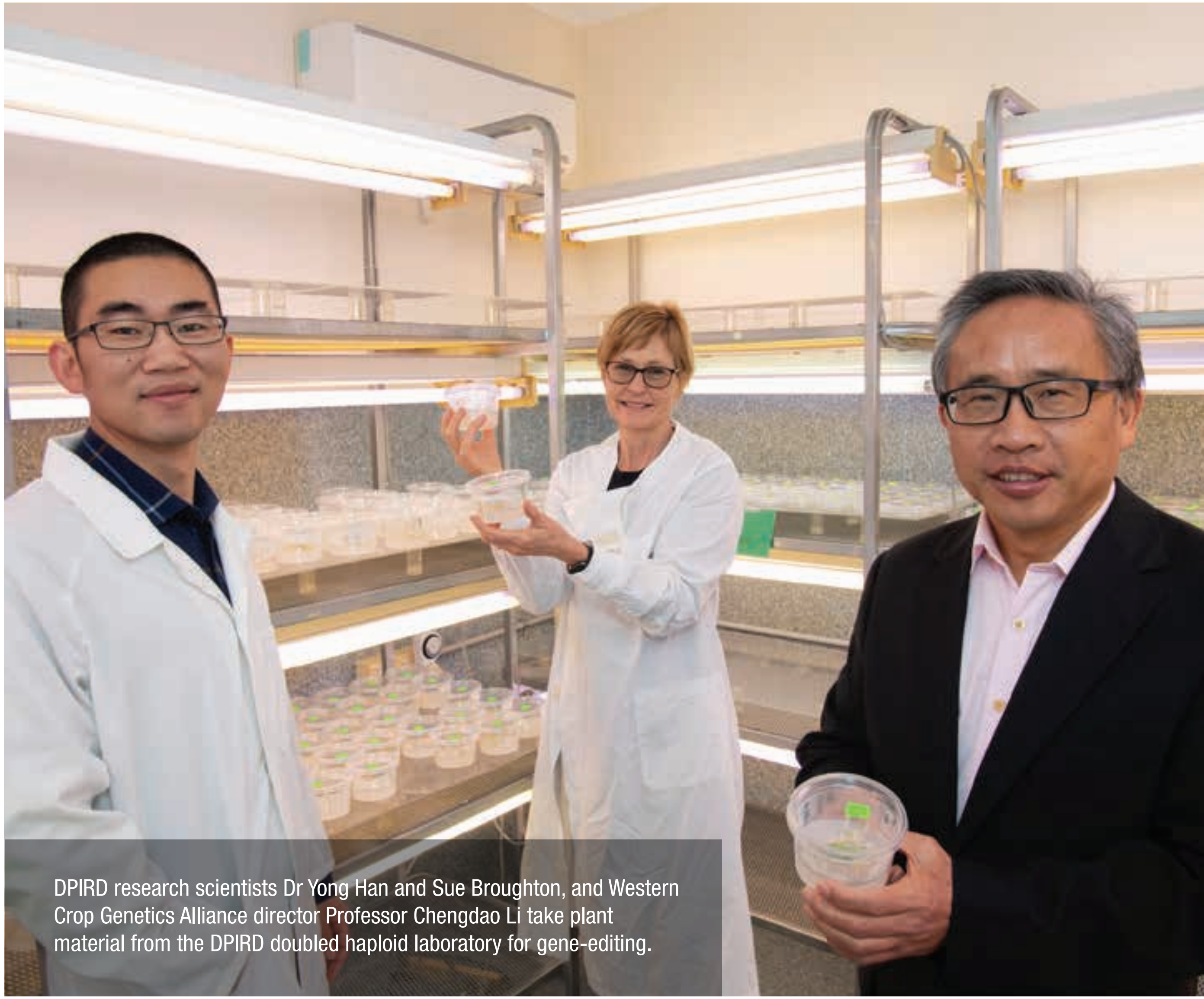
Chengdao and the international team used a specialised computer model coupled with information about the genetic makeup of every single piece of a barley plant from its roots to its shoots, flowers and grain to predict the function of each re-constructed barley gene.

Five per cent of the genes in the pan genome were found to be unique to a specific barley population while 30 per cent of genes were found to have huge variation in function. A further 15 per cent of genes were present as multiple copies in some populations, with some populations containing as many as 100 copies of the same gene. These variations form the foundation for yield, quality, disease resistance and environmental adaptation.

Curiously, in some populations certain barley gene sequences were structured in reverse, which worked to potentially alter many gene functions. One of WA's most popular current malting barley varieties, RGT Planet, was also found to have the gene sequence reversals, which may confer a yield advantage on this variety.

After some detective work Chengdao and his colleagues traced the gene sequence reversal in RGT Planet back through global plant breeding programs to discover that it had originated in the 1960s when radiation was used to deliberately mutate the genetic makeup of a distant RGT Planet relative.

Information about the barley pan genome is now being collated into a user-friendly database for plant breeders. The goal is to develop a digital gene library so that breeders can easily locate genes along the barley genome and introduce specific traits into their breeding programs.



DPIRD research scientists Dr Yong Han and Sue Broughton, and Western Crop Genetics Alliance director Professor Chengdao Li take plant material from the DPIRD doubled haploid laboratory for gene-editing.

Gene editing breakthrough to improve barley crops

A recent breakthrough in gene editing technology will pave the way for more tailored barley varieties, with improved yield, quality and nitrogen use efficiency characteristics.

The Western Crop Genetics Alliance, a partnership between DPIRD and Murdoch University, is behind the innovation.

Director of the Western Crop Genetics Alliance, Professor Chengdao Li, said the new technique enables barley genes to be accurately turned on and off to create a superior trait, something that could not be achieved in Australian varieties with existing technology. The new technique, called doubled haploid CRISPR, provides scientists with a tool to precisely modify existing barley lines and craft higher-yielding varieties suited to localised conditions.

Wild genes offer leap in lupin yield

Combining advanced gene editing tools and new knowledge about the genetic makeup of the world's lupin populations could lift lupin yields by more than 30 per cent while also introducing disease resistance and drought tolerance into future varieties.

The lupin genomics work by DPIRD research scientists Professor Chengdao Li, Dr Gaofeng Zhou and their colleagues shows a significant amount of genetic variation remains to be tapped from wild lupin populations across the world.

Each of the important lupin production traits has now been anchored with its genes along the lupin genome and Chengdao, Gaofeng and their team have developed tools to enable breeders to locate and track important genes through their breeding programs. The next step in the research is to use gene editing technology developed only in the last few years to burrow into the wild lupin genomes and switch off traits such as alkaloid production (which causes seed to be bitter) and pod shattering, which makes seed difficult to harvest.

Grains

CROP SCIENCE AND GRAIN PRODUCTION

CROP SCIENCE AND GRAIN PRODUCTION

Purpose: help WA grain growers to maximise profitability and minimise risk in the WA cropping environment.

WHEAT

- WHEAT

OTHER CEREALS

- BARLEY
- OATS

BROADLEAF CROPS

- CANOLA
- PULSES AND LUPINS

LIAISE

Liaise across the supply chain – grain growers, agribusiness, marketers, processors – to gather and communicate production, market and end-user intelligence.

ANALYSE

Use market, environmental and technical information to identify, and respond appropriately to, risks and opportunities for the WA grains industry.

RESEARCH

Carry out applied and fundamental research to determine crop yield and quality drivers under WA conditions, and develop tools to exploit this information.

ENGAGE

Deliver research findings in a suitably packaged form to the grains industry, investment partners and policy makers.

CROP SCIENCE AND GRAIN PRODUCTION

Dr Bob French
MANAGER, CROP SCIENCE AND GRAIN PRODUCTION PORTFOLIO

DPIRD research scientist Dr Bob French leads the Crop Production and Grain Science portfolio.

OVER THE PAST 100 YEARS, broadacre crop production in Western Australia has increased from about two million tonnes to more than 10 million tonnes each year. For much of the state's farming history this crop production has been driven by an expanding cropping area, but since about 1980 increasing crop yield has been the main driver (Figure 7). This increase in average yield is remarkable given that rainfall across the south west of Western Australia has dropped by about 20 per cent since the mid-1970s.

A range of factors is responsible for the crop yield increase over the past century, including better crop varieties, better farm machinery, better rotations, more efficient fertiliser use, more effective weed, disease and pest control, and a better scientific understanding of how crops grow and interact with their environment.

Improvements in agronomy, or crop management, are commonly thought to account for about 70 per cent of crop yield increases while improved varieties, through plant breeding, are thought to account for the remaining 30 per cent.

Crop Science and Grain Production

DPIRD research scientist Dr Rebecca Swift.

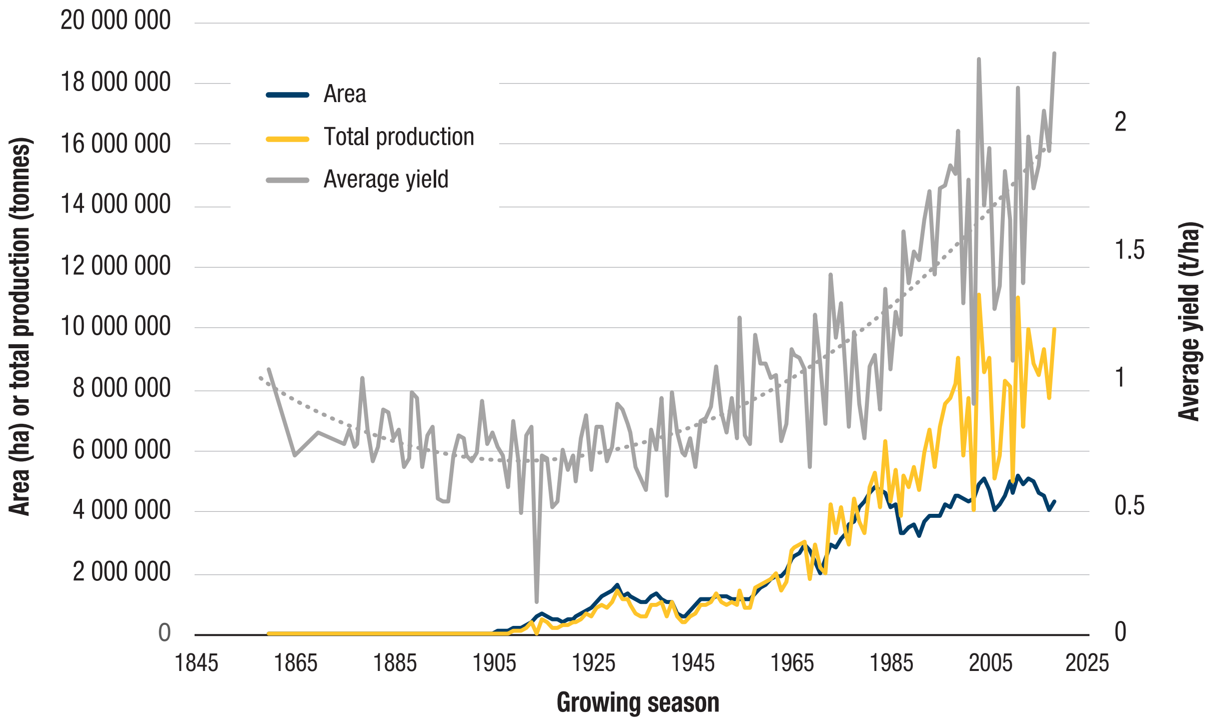


FIGURE 7. Change in average (grey line) and total (yellow line) crop yield vs total area of production (blue line) in Western Australia from 1865 to present day

Note: 2018 was the highest wheat yield on record despite a 20 per cent decline in rainfall since the 1970s.

However, this ratio oversimplifies a more complicated reality in which crop varieties respond to management and environment in different ways. It is therefore critical that crop management systems are developed in tandem with new crop varieties to ensure that each variety can reach its potential within the environment it is grown. This is the first of the important functions of DPIRD's Crop Science and Grain Production portfolio.

The Crop Science and Grain Production team undertakes applied research and development on the major grain crops grown in WA. The portfolio is organised along commodity lines and consists of three streams (see page 119). The first focuses on wheat, the second on barley and oats, and the third on broadleaf crops, which includes canola, lupins and pulses. The research and development team draws on a range of plant and environmental science disciplines to optimise the yield and quality of the major grain crops grown in southern WA under the various economic and environmental constraints our farmers face. Findings from the research and development activities are then extended to growers. A second, and equally important, function of the Crop Science and Grain Production team is industry liaison with peak industry groups and other industry stakeholders to ensure the critical issues facing growers are addressed, either by our team or by others where different skill sets are required.

Using science to tailor agronomy to specific industry needs

A major focus of the Crop Science and Grain Production team is investigating how growers can adjust their crop management and variety choices to optimise grain yield and quality to maximise profitability.

Different grain commodities end up in different markets with different quality requirements, and because each of the different commodity industries is at a different stage of maturity, each stream in the Crop Science and Grain Production portfolio has a different emphasis. For example, the barley stream pays more attention to specific grain quality attributes like small grain screenings, grain colour and grain brightness than the wheat stream. This is because malting, which has quite stringent quality criteria, is by far the largest high-value end-use for barley whereas there are multiple end-uses for wheat, including various types of noodles, breads, biscuits and cakes, each having different quality requirements. The pulse stream has an emphasis on the herbicide tolerance of varieties and fungicide regimes for disease management, because weed and disease control are major impediments to further expansion of these industries.

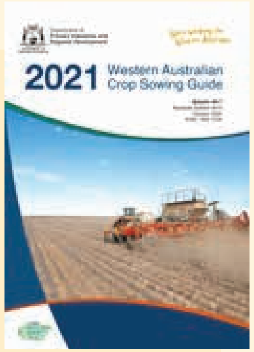
DPIRD research scientists Dr Dean Diepeveen, Georgie Troup and Dr Bob French.

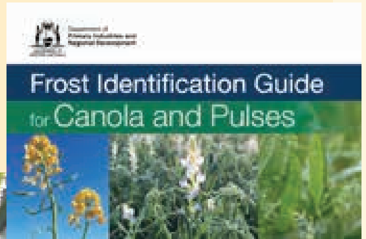
Defining the types of crop varieties that WA growers need, knowing what yield and quality objectives are realistic for our grains industries, and recognising new opportunities to improve crop management all require a fundamental understanding of how crops interact with WA soils, climate and management at a physiological level. We achieve this in part by maintaining linkages with scientists in other parts of DPIRD and other research institutions in WA, interstate, and internationally, including the CSIRO, universities, and other state departments of primary industries. We are also currently building our fundamental crop science research capacity by appointing new staff with these skills, and funding some more speculative research internally to allow existing staff to develop new skills and ideas.

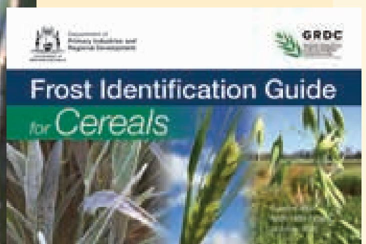
Recent Crop Science and Grain Production achievements

Across streams

- First comprehensive ***Crop Sowing Guide*** since 2005 covering all main commodities. Released in 2019 (Bulletin 4910) and updated in 2020 (Bulletin 4917).
- ***Frost Identification Guide*** for canola and pulses released in 2019.
- New ***Frost Identification Guide*** for cereals released in 2020.







Wheat

- Re-evaluation of nitrogen application timing which indicates that conducive environmental conditions for uptake is more important than development stage, and that applying the same amount of nitrogen later can raise grain protein without compromising yield.
- Characterisation of the interaction between variety maturity type and early sowing on grain yield and quality, and identification of the need for new variety types for early April sowing opportunities.

Barley

- Guidelines for nitrogen management practices to improve grain protein concentration.
- Demonstration of the importance of timely harvesting for grain quality, and how this differs between varieties.

Canola

- ***Canola Agronomy Research in Western Australia*** (Bulletin 4986) which summarises the results of over 100 canola research trials conducted between 2010 and 2017. Released in 2018.
- Identification and validation of optimal sowing windows for canola varieties for different WA grainbelt locations using a combination of simulation modelling and field trials.

Oats

- ***Plant diseases impacting oaten hay production in Australia – a review*** (Bulletin 4916) released in 2020.
- Evaluation of environmental and genetic control of phenology in 360 oat varieties from around the world as a prelude to developing better adapted oat varieties for WA.

Pulses

- Research and extension support to the lentil industry during its expansion phase in the Esperance port zone.
- Demonstration of best-practice disease management and weed control in chickpeas.

Crop Science and Grain Production

Industry liaison

To remain abreast of industry issues, DPIRD has six dedicated industry leads for each of the state's grains commodities – wheat, barley, canola, oats, lupins and pulses. Five of these are in the Crop Science and Grain Production portfolio and the sixth, Greg Shea who leads lupins, is in the Farming Systems Innovation directorate. The industry leads facilitate a two-way information exchange between DPIRD and industry bodies such as the Grains Industry Association of Western Australia (GIWA), specific commodity councils, prominent growers, marketers and processors along commodity supply chains. These conversations ensure our priority setting is consistent with industry needs.

Barley industry lead: Blakely Paynter

New malt varieties are often released faster than the phasing out of old malt varieties and this turnover can create issues for end-users who require sufficient notice of a change in order to adapt their brewing processes to the peculiarities of the new barley. Bulk handlers also require forward notice of new malt varieties as each new malt variety must be segregated, which adds to the cost of storage and handling.

Blakely uses agronomic information collected via DPIRD's annual trial series to demonstrate the production and end-user benefits of new malt varieties. He also works with malt traders to determine how the proposed phasing out of a variety will affect their customers. The resultant discussion leads to a barley variety rationalisation plan that enables everyone along the supply chain to have their say about the proposed changes and prepare for the turnover in varieties.

Barley industry lead and DPIRD research scientist Blakely Paynter.

Wheat industry lead and DPIRD research scientist Dr Dion Nicol.

Wheat industry lead: Dr Dion Nicol

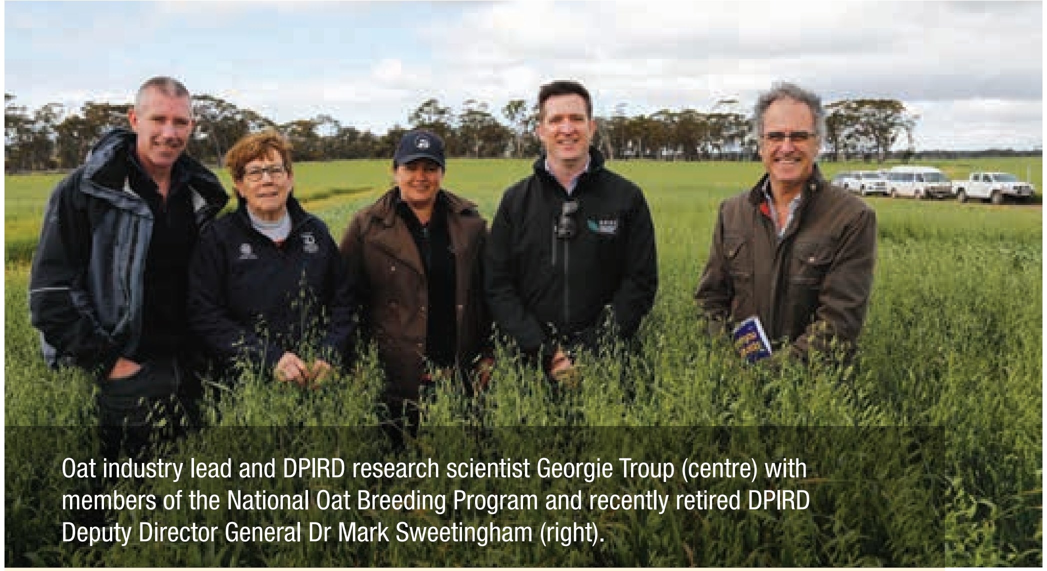
Trade in the wheat industry is complex because seasonal conditions drive not only production but also quality profiles. As a result, there is often limited dialogue throughout the supply chain about customer satisfaction or preferences. Demand for lower quality wheat grades has increased in recent years, particularly from developing Southeast Asian feed wheat markets. This has narrowed the price incentives for higher quality grades, however competition can increase quickly in the lower quality segments and WA wheat needs to ensure it is adaptable in changing markets to maximise value where advantageous. Through the increasing role of the Australian Export Grains Innovation Centre (AEGIC), in partnership with DPIRD and the GIWA wheat council, Dion hopes to improve the strategic goals of DPIRD wheat research to ensure that regional strengths in quality and logistics are captured through on-farm variety choice and management to deliver greater value to the industry.

Canola industry lead: Jackie Bucat

Jackie liaises with canola breeders, seed companies and GRDC National Variety Trial staff to prepare the DPIRD canola variety guide. She has an active research role as well as managing DPIRD canola agronomy research, which is currently focused on exploring the value of early sowing and interacting with growers and grower groups to extend research results and discuss future research needs. In 2020 Jackie instigated and organised the inaugural WA canola research forum, which enabled WA researchers to gather and ensure research is relevant and valuable to industry. Participants included DPIRD, the CSIRO, UWA, AHRI, CCDM as well as industry stakeholders.

Most of WA's canola industry issues are addressed through the national industry organisation, the Australian Oilseed Federation (AOF), where Jackie is the DPIRD representative. She also maintains a canola watching brief across other industry organisations important for the WA canola export industry, for example the National Working Party on Grain Protection (NWPGP) and Grain Trade Australia (GTA). Jackie recently wrote the documentation used by CBH to gain an exemption from the International Sustainability & Carbon Certification (ISCC) for the use of omethoate in WA so that occasional omethoate use, where necessary, will not impede exports to Europe.

Canola industry lead and DPIRD research scientist Jackie Bucat.



Oat industry lead and DPIRD research scientist Georgie Troup (centre) with members of the National Oat Breeding Program and recently retired DPIRD Deputy Director General Dr Mark Sweetingham (right).

Oats industry lead: Georgie Troup

The oat industry in Australia has had a major shift in recent years away from a domestic feed focus, towards a high-quality export focus for both the milling oat and fodder industries. To support this change, and the adoption of new varieties, growers require agronomic knowledge. Georgie has acquired this knowledge through DPIRD's agronomy research program, where she has been evaluating new varieties, and the agronomy required to achieve yield and quality potential.

Georgie works closely with the milling oat and export fodder industry, including local and international processors, and plant breeders to ensure WA growers are best positioned to meet changing market requirements, and to seize new opportunities as they arise through quality reviews and variety rationalisation. In recent years, Georgie has worked closely with AEGIC to evaluate beta glucan, and its opportunities, both agronomically and genetically, to optimise the nutritional quality of WA milling oats.

Crop Science and Grain Production

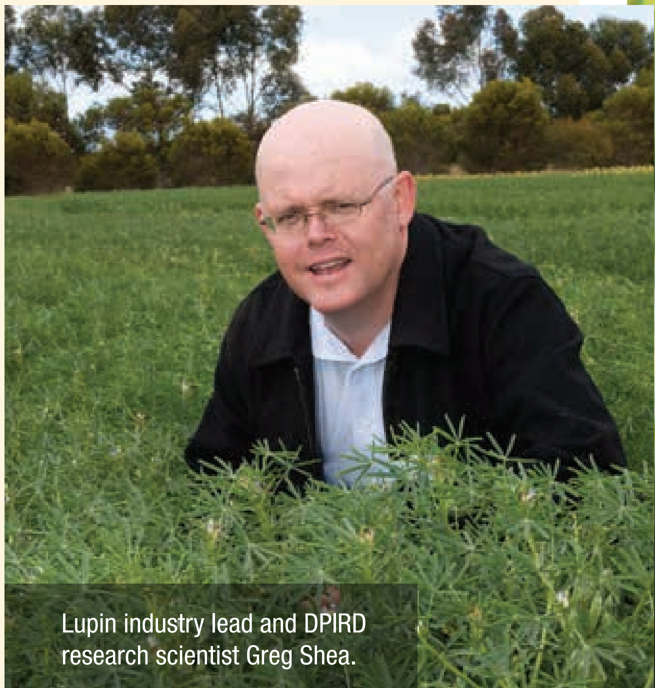
Pulse industry lead: Mark Seymour

The WA pulse industry includes the production and export of field peas, lentils, vetch, faba beans and chickpeas. It is a relatively small, diverse and fluid industry. Mark is directly involved in the research and development of pulses and provides background information on the pulse industry to the DPIRD leadership team and other interested parties based on his diverse contacts with growers and grower groups, pulse experts in eastern Australia, agribusiness and marketers.

Pulse industry lead and DPIRD research scientist Mark Seymour.

Lupin industry lead: Greg Shea

WA produces about 85 per cent of the world's lupin. Lupins were traditionally used for animal feed but in Australia they have been a human food ingredient since 1987. Their use in human diets means they must adhere to tight food quality specifications. Greg liaises between DPIRD specialists and the plant breeding company Australian Grain Technologies (AGT) to ensure that new variety releases have anti-nutritional factors (such as alkaloids) below the acceptable level. The Grains and Legumes Nutrition Council (GLNC) is the independent authority on the nutrition and health benefits of grains and legumes. The GLNC has a mandate to promote the health benefits of lupins Australia-wide and Greg is responsible, in conjunction with other DPIRD staff, for ensuring scientifically justifiable messages on the attributes of lupins are included in communications campaigns.



Lupin industry lead and DPIRD research scientist Greg Shea.

Early sowing can reap yield rewards

DPIRD research scientist Dr Dion Nicol (left) shows visiting scientists a wheat trial at Merredin.

IT HAS BEEN KNOWN FOR MORE THAN 30 YEARS that earlier sown crops tend to produce higher yields, but farmers in Western Australia have traditionally delayed the start of sowing until there is sufficient soil moisture to ensure crop germination, usually sometime in May.

Recent technological innovations such as no-till and better selective herbicides mean farmers can now establish crops on lower rainfall, and many now start sowing into dry soil before the first rains of the season. Simulation modelling by the CSIRO shows that adopting dry sowing can increase average yield across a cropping program by making the average sowing/emergence date earlier. However, there are also risks associated with early sowing such as heat stress and water deficit in emerging crops and frost at flowering.

Historically, the rule of thumb was that sowing did not begin before ANZAC Day (25 April) but with climate change bringing more frequent March and April rainfall events, and fewer in May, farmers now have a strong incentive to exploit sowing opportunities whenever they occur. To be successful with early sowing, farmers need to know which crops are best suited to early sowing, how early they can be sown and what conditions will minimise the risks associated with sowing early.

To date, there has been limited research in WA on how crops respond when sown in March or early April. Crop Production and Grain Science researchers have been addressing these questions over the past few years.

The research has shown there can be significant production advantages from sowing earlier – particularly with canola. For example, work in the northern agricultural region by research scientists Martin Harries and Mark Seymour found that sowing canola in mid, rather than late, April into soil moist from summer rain lifted yields by 20 per cent because the early-sown crops could fill their grain before late-season heat set in.

Such a yield increase translates to an extra $100–200 more per hectare in canola grain sales.

Research seeder sowing barley as part of a DPIRD agronomy trial.

Grainbelt trials

DPIRD research scientists Jackie Bucat, Stacey Power and their team have further investigated early sowing canola to determine how profitable the practice is across WA's cropping areas. The research assessed how early canola can be sown and the canola varieties most suited to an early seeding system. The research also investigated the use of the crop simulation model APSIM-Canola to extrapolate the results from a few trial locations to many locations in the grainbelt.

The team conducted trials across the grainbelt from Mullewa in the north-west through to Esperance in the south-east. In 2019, eight canola varieties were sown at five starting dates over the 12 weeks from 18 March through to 11 June, using irrigation systems to simulate an early break to the season and ensure germination and good establishment (Figure 8).

Major findings from the research included:

- Sowing in March produced similar yields to sowing in April, extending the range of sowing opportunities available for growers.
- Risk factors associated with March sowing included poor establishment due to high soil temperature, crop mortality from drought, frost at the end of flowering, increased levels of predation and disease, and poorer weed control.
- Sowing in early April was profitable and establishment was more reliable across all sites due to cooler temperatures.

Ongoing research will quantify the effects of high soil temperature on canola establishment.

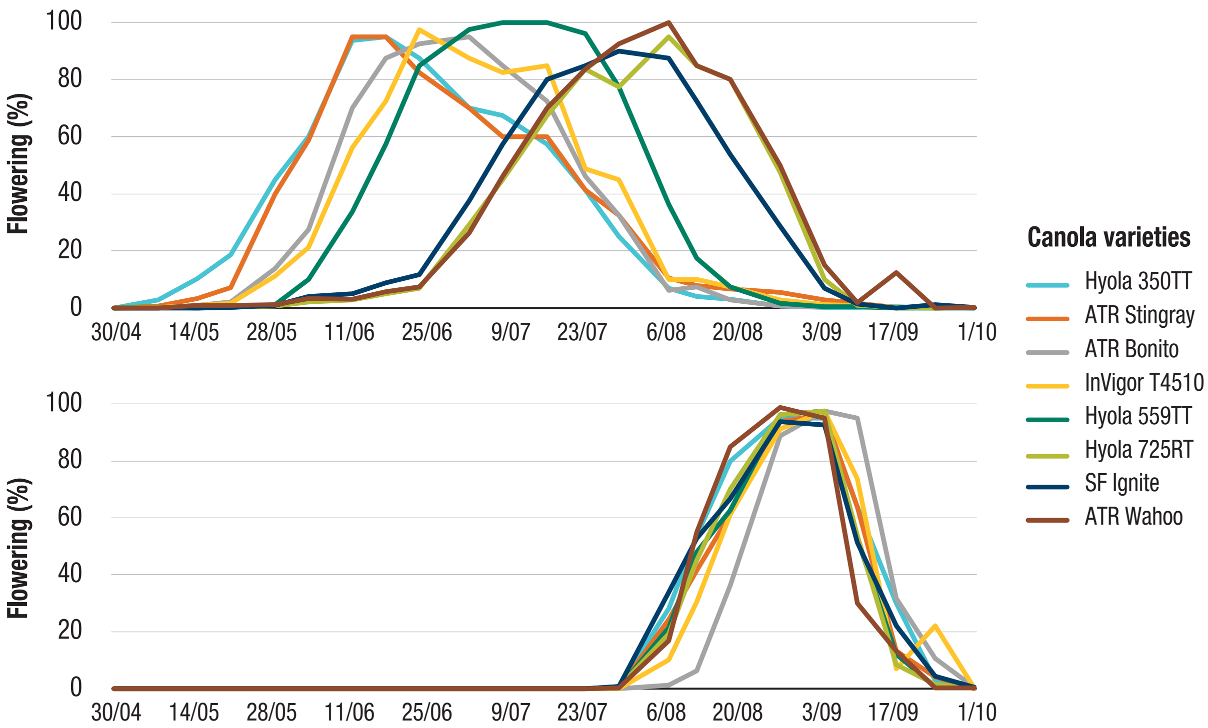


FIGURE 8. Canola at Wongan Hills in 2019 flowered for 75 days when sown on 19 March (top), which was nearly twice as long as the 44 days duration when sown on 21 May (bottom)

Benefits and risks of sowing early

DPIRD research scientists Jackie Bucat and Dr Imma Farre are investigating the yield benefits of sowing canola early.

Sowing canola early effectively extends the growing season, which is particularly valuable in WA's northern and eastern cropping zones where the season is relatively short and often ends suddenly due to heat and lack of soil moisture. By getting seed into the ground in early April the canola crop can take immediate advantage of the first autumn rains or be up and growing by the time these rains arrive.

Early sowing also allows farmers to capture seeding opportunities brought about through summer rain. Sowing early into soils with stored summer rain means crops can germinate and start to grow well before the official autumn break — the timing of which is becoming more unpredictable with climate change.

The main risk associated with early sowing in northern areas is not having adequate follow-up rain. Crops can fail if they germinate on minimal moisture and do not receive enough subsequent rain to keep growing. Weed control can also become difficult due to ryegrass germinating well after the crop.

Frost risk is also heightened with early sowing because flowering occurs earlier, when frosts are more prevalent. Sowing too early, when autumn temperatures are still warm, can cause crop development to speed up, which results in less leaf growth to fill developing grain, and in turn lowers grain yields.

Barley best for early sowing

Wheat has traditionally been sown in mid-May but with the trend towards earlier sowing on larger farms farmers are now seeking information on the effect of sowing early on wheat yields.

Research by DPIRD research scientist Raj Malik and his team examined how early sowing affected yield and profits in wheat, barley and oat crops.

The researchers compared an April sowing with an early and late-May sowing time to determine:

- the best cereal option for April sowing
- the best variety for each cereal type for April sowing.

In 2017 they found that, in most instances, barley was higher yielding and the more profitable cereal option to grow than wheat or oats at all sowing dates provided barley met malt specifications (Figure 9). For the mid-April sowing, depending on the location, barley yielded about 1.0 to 1.7t/ha more than wheat and 0.5 to 1.1t/ha more than oats and produced net returns of $215 to $250/ha higher than wheat and $115 to $375/ha higher than oats.

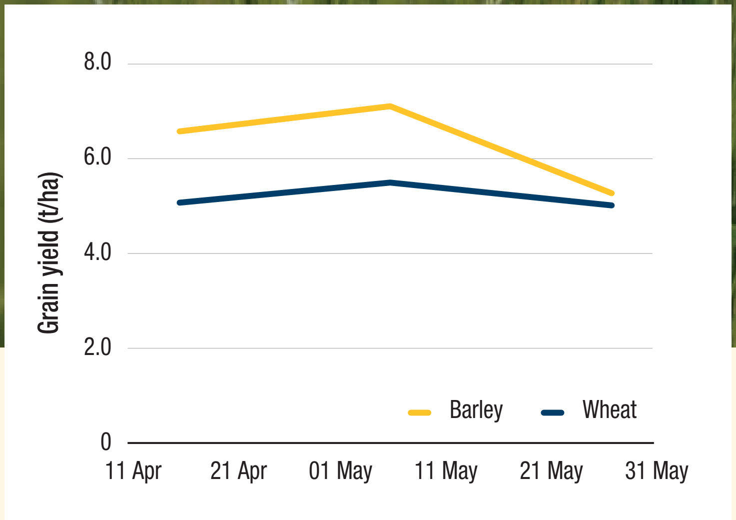


FIGURE 9. Effect of sowing time on yield of barley and wheat. Barley was higher yielding and more profitable than wheat with early sowing

DPIRD research scientist Brenda Shackley delivers results of an early sowing trial to field day participants.

Maturity rating drives early sowing response

How wheat responds to early sowing depends on the variety type. DPIRD research scientists Brenda Shackley, Dr Dion Nicol and Jeremy Curry have shown that varieties with short to mid maturity (measured as the time from sowing to flowering) can yield much less when sown in early April than in May. Scepter, currently the most widely grown wheat variety in WA, fits into this category.

Varieties with mid-long maturity, such as Rockstar and Catapult, are a better choice for early sowing. Winter wheats such as DS Bennett and Illabo, which require a spell of cold weather before they will flower, have the most suitable response pattern for sowing in March, but the development pattern of winter wheat varieties still needs to be optimised for WA conditions.

Differences in flowering time explain most of the yield differences with early sowing (Figure 10). In later flowering crops, grain filling occurs under increasing heat and drought stress. Flowering too early can mean the crop has produced insufficient biomass to support a good yield while also making the crop more susceptible to frost damage. The DPIRD research team is continuing to investigate how sowing time and flowering time affect wheat grain quality.

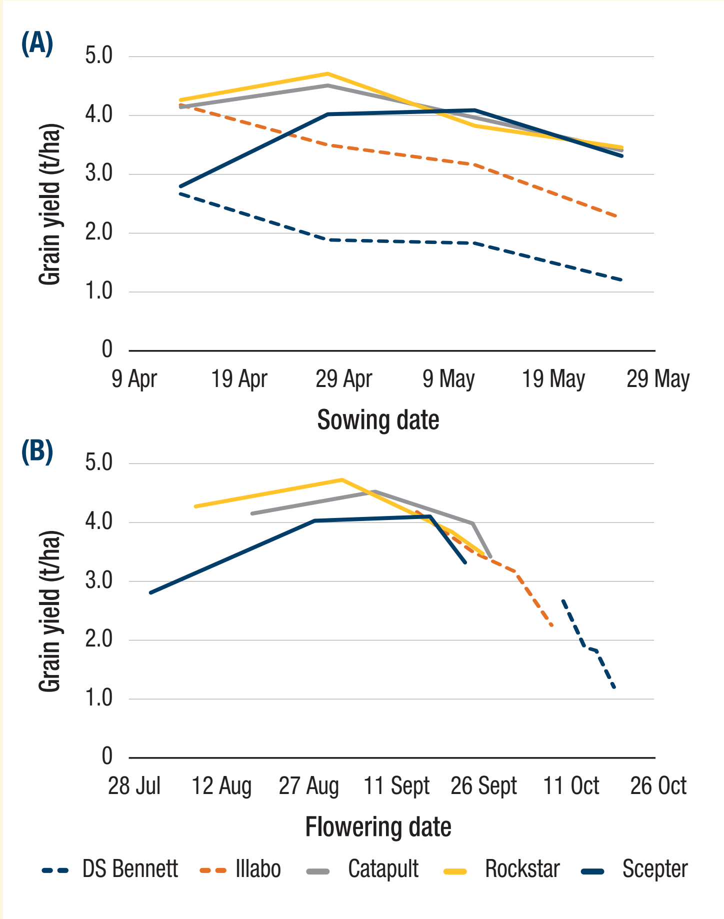


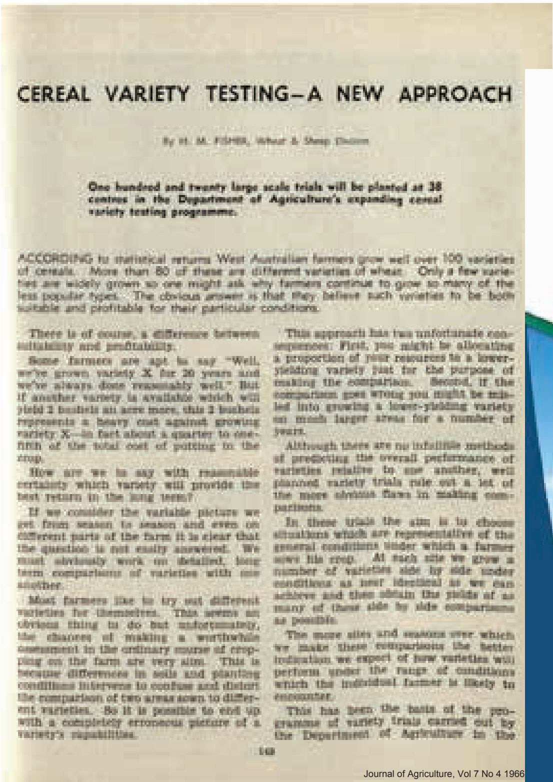
FIGURE 10. Mid-long and winter wheat varieties yield better than short to mid varieties when sown in early April (A) as a result of flowering closer to the optimum date (B)

New Crop Sowing Guides continue long tradition

IN A 1966 ARTICLE ABOUT a new approach to cereal variety testing in the *Journal of Agriculture*, department researcher Harry Fisher wrote that WA farmers grew:

> "*…well over 100 varieties of cereals. More than 80 of these are different varieties of wheat. Only a few varieties are widely grown so one might ask why farmers continue to grow so many of the less popular types…*"

The implication of this statement was that farmers did not have the information they needed to make good variety choices. Harry went on to describe a series of field trials to compare different wheat, barley and oat varieties across the range of agricultural environments in WA, and how the results would help farmers choose the best varieties for their farms.



CEREAL VARIETY TESTING—A NEW APPROACH

By H. M. FISHER, Wheat & Sheep Division

One hundred and twenty large scale trials will be planted at 38 centres in the Department of Agriculture's expanding cereal variety testing programme.

ACCORDING to statistical returns West Australian farmers grow well over 100 varieties of cereals. More than 80 of these are different varieties of wheat. Only a few varieties are widely grown so one might ask why farmers continue to grow so many of the less popular types. The obvious answer is that they believe such varieties to be both suitable and profitable for their particular conditions.

There is of course, a difference between suitability and profitability.

Some farmers are apt to say "Well, we've grown variety X for 20 years and we've always done reasonably well." But if another variety is available which will yield 2 bushels an acre more, this 2 bushels represents a heavy cost against growing variety X—in fact about a quarter to one-fifth of the total cost of putting in the crop.

How are we to say with reasonable certainty which variety will provide the best return in the long term?

If we consider the variable picture we get from season to season and even on different parts of the farm it is clear that the question is not easily answered. We must obviously work on detailed, long term comparisons of varieties with one another.

Most farmers like to try out different varieties for themselves. This seems an obvious thing to do but unfortunately, the chances of making a worthwhile assessment in the ordinary course of cropping on the farm are very slim. This is because differences in soils and planting conditions intervene to confuse and distort the comparison of two areas sown to different varieties. So it is possible to end up with a completely erroneous picture of a variety's capabilities.

This approach has two unfortunate consequences. First, you might be allocating a proportion of your resources to a lower-yielding variety just for the purpose of making the comparison. Second, if the comparison goes wrong you might be misled into growing a lower-yielding variety on much larger areas for a number of years.

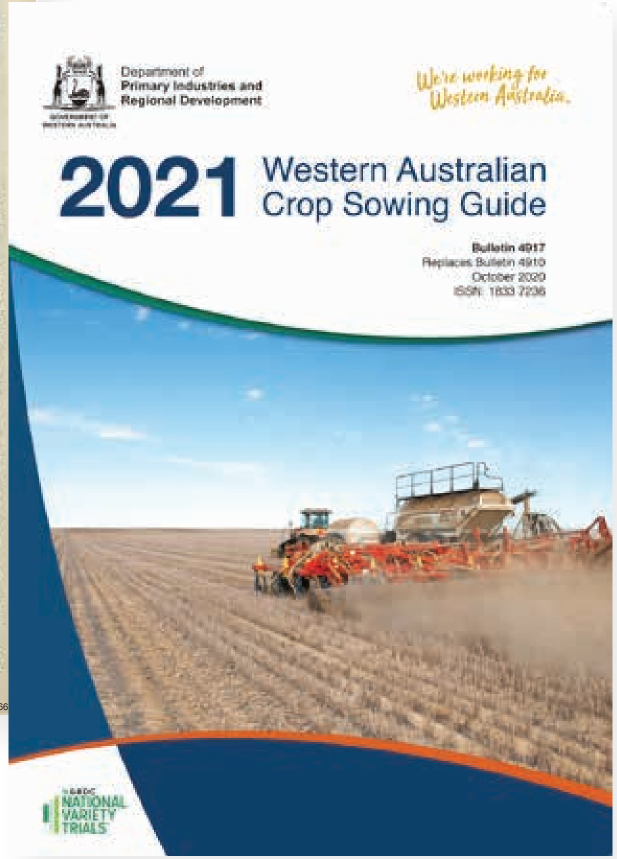
Although there are no infallible methods of predicting the overall performance of varieties relative to one another, well planned variety trials rule out a lot of the more obvious flaws in making comparisons.

In these trials the aim is to choose situations which are representative of the general conditions under which a farmer sows his crop. At each site we grow a number of varieties side by side under conditions as near identical as we can achieve and then obtain the yields of as many of these side by side comparisons as possible.

The more sites and seasons over which we make these comparisons the better indication we expect of how varieties will perform under the range of conditions which the individual farmer is likely to encounter.

This has been the basis of the programme of variety trials carried out by the Department of Agriculture in the

Journal of Agriculture, Vol 7 No 4 1966



Since these early crop variety trials more than half a century ago, DPIRD has continued to provide farmers with objective crop variety advice. The recently revamped, annual Western Australian Crop Sowing Guide, compiled by Crop Science and Grain Production staff and coordinated by research scientist Brenda Shackley, forms an important part of the portfolio's activities.

The Crop Sowing Guide covers all common grain crops grown in WA and provides an independent reference for growers and their advisors and a trusted source of technical agronomic insights for the WA grains industry.

In Harry Fisher's time, crop variety recommendations were published in the *Journal of Agriculture* and took up only a few pages. But as more crops than just wheat and barley were grown, growers requested more information on which to base their decisions. To address this, in the 1980s information on crop varieties was made available via *Farmnotes*, which were produced for each crop and spanned rainfall and latitude zones (known as region/zone cells) across WA.

By about 1990, DPIRD was producing a separate Crop Variety Sowing Guide for wheat, barley, oats, lupins, field peas, canola, and other pulses in bulletin form. The region/zone cells were replaced by the current Agzones in 2002 and the standalone Crop Variety Sowing Guide continued until 2005, after which variety recommendations returned to being provided in separate publications for each crop. At about the same time, DPIRD wound down its Crop Variety Testing program, which had produced the Crop Variety Sowing Guide, and responsibility for crop variety testing passed to the independent National Variety Trials (NVT) program funded by the GRDC. Other state government departments of agriculture and primary industries relinquished their crop variety testing programs at about the same time.

The separate guides for each crop were delivered by separate agronomy projects for these crops, each with co-investment from the GRDC. This meant the wheat variety guide was produced by staff of the wheat agronomy project, the barley variety guide was produced by the barley agronomy project, the canola sowing guide by the break crops project, and so on. As a result, the type of information provided in each guide varied, and there was no consistent style across all crops. For some crops, like lupins, where new varieties did not appear every year, variety guides became rather infrequent.

DPIRD commissioned an external review of the crop guides in April 2019. Interviews and workshops were used to determine what growers and industry advisors valued about the guides and how they thought they could be improved. The main recommendation from the review was to combine the guides and publish a single WA Crop Sowing Guide as hardcopy and digital versions each year. The review also recommended a consistent structure and arrangement of information across all crops and improvements to the presentation of some information. Most data presented in the updated Crop Sowing Guide is sourced from the NVT program, which conducted 672 variety trials in WA in 2020. The NVT information is complemented with data on varietal disease responses and quality characteristics derived from the NVT and other sources, which is set in a local cropping system context based on expert interpretation by staff in the Crop Science and other DPIRD portfolios. This contextualisation includes market information, highlighting how special characteristics of some varieties might be exploited in certain farming system situations, and agronomy guides where new management methods are being developed, or the crop is unfamiliar to many growers.

As well as compiling the guide, Crop Science staff also carry out a range of trials each year to contribute data not readily available from the NVT but necessary to properly contextualise crop variety management in WA. An example of this is the series of wheat sowing time trials, which demonstrates how different classes of wheat varieties, characterised by maturity type, respond to sowing time in terms of yield, quality, frost and heat risk. The data collected allows growers to make best use of sowing opportunities when they occur and also provides the information necessary to update DPIRD's FlowerPower app, a tool developed to help growers make best use of different sowing opportunities. A new updated version of this was released in February 2021.

The new WA crop sowing guides continue a long tradition of DPIRD providing WA growers with comprehensive and contextualised crop variety advice. The recent changes to the guide are serving the industry well, and DPIRD will continue to explore ways to provide more crop variety advice online.

> ***The WA Crop Guides are viewed within DPIRD and the broader grains industry as being a critical resource across the WA grains industry.***
>
> **DR BOB FRENCH**

SOIL SCIENCE AND CROP NUTRITION

SOIL SCIENCE AND CROP NUTRITION

Purpose: manage the chemical, physical and biological components of soil to increase broadacre crop productivity.

DIAGNOSE

Diagnose the chemical (acidity/water repellence/nutrition), physical (compaction/sodicity) and biological (nutritional/pests and diseases) constraints holding back crop production.

RESEARCH

Investigate how and where the constraint occurs and research ways to overcome the constraint to increase the efficiency of water and nutrient use to lift crop productivity.

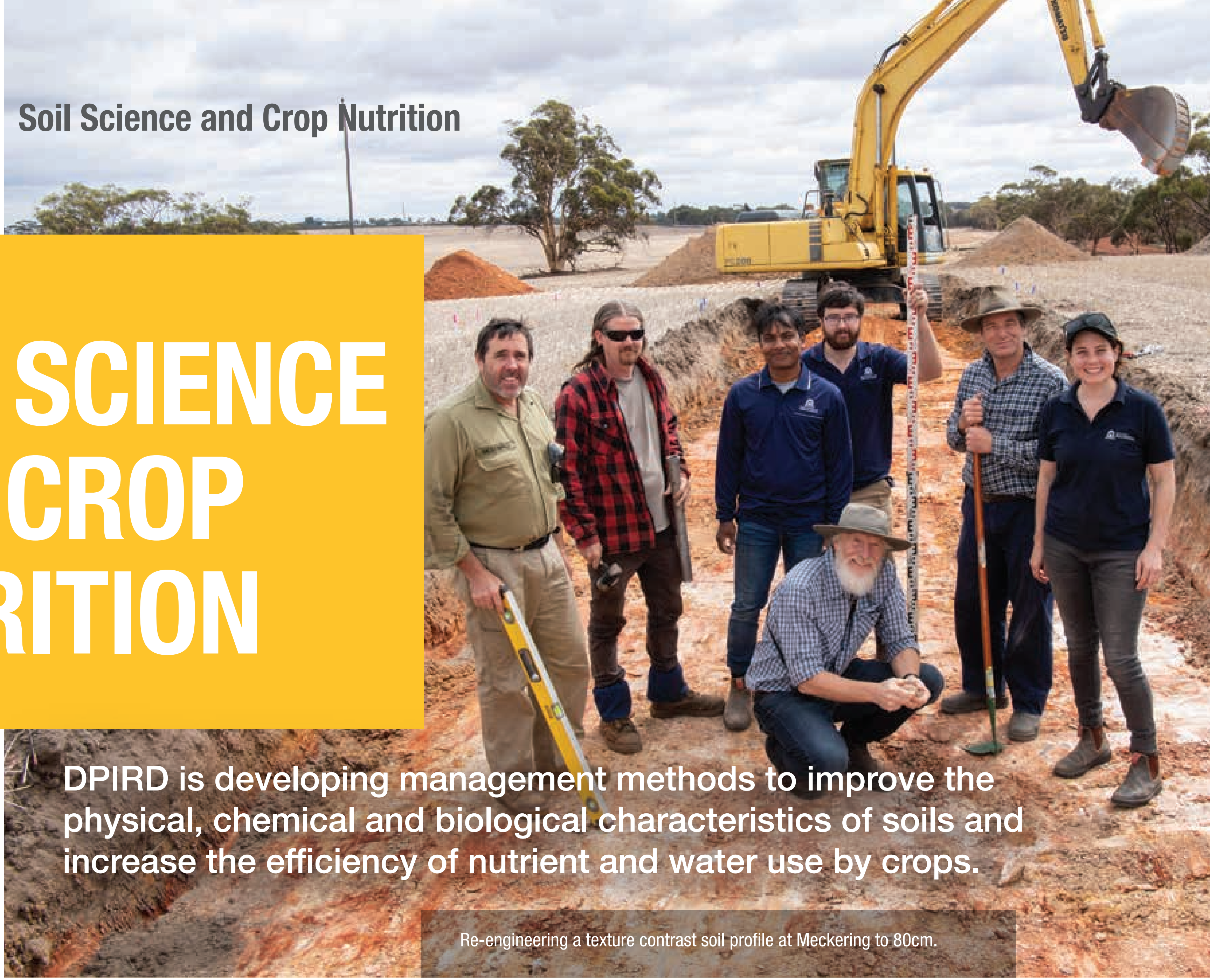
INTERVENE

Develop and extend new practices and tools to manage multiple soil constraints and lift crop productivity to the next level.

SOIL SCIENCE AND CROP NUTRITION

Chris Gazey

MANAGER, SOIL SCIENCE AND CROP NUTRITION PORTFOLIO



DPIRD is developing management methods to improve the physical, chemical and biological characteristics of soils and increase the efficiency of nutrient and water use by crops.

Re-engineering a texture contrast soil profile at Meckering to 80cm.

WESTERN AUSTRALIA'S GRAIN PRODUCTION is constrained by soil conditions that prevent crops from reaching their full productive capacity. DPIRD's Soil Science and Crop Nutrition team investigates the effects of these soil constraints and works with farmers to find ways to ameliorate them and lift productivity.

"Over the past decade, productivity has been increased on more than five million hectares of previously constrained soils across WA's agricultural region thanks to the implementation of research work by DPIRD and our partners.

DR STEPHEN DAVIES, DPIRD RESEARCH SCIENTIST

It is estimated that continued adoption of the soil amelioration techniques and strategies developed by DPIRD could add an extra $1.4 billion in grain revenue to the WA economy over the next five years.

This estimate does not take past successes into account; it represents new adoption in the next five years only. In calculating this benefit, the team has accounted for soil type (including area), crop response, amelioration method and likely adoption, and the scale and extent to which yield responses diminish over time. The benefits do not include the multiple secondary benefits generated by economic activity that arises from this additional revenue coming into the WA economy.

RIGHT: The purpose-built cone seeder, which precisely places seed and fertilisers in ameliorated soil, will provide a considerable boost to the Soil Science and Crop Nutrition team's research capability in 2021.

Economic cost of soil constraints

Constrained soils in WA's cropping zone currently deprive the state of about $4.3 billion each year in lost productivity (Table 2). On average, this amounts to $330/ha on a statewide basis.

Ameliorating these soil constraints costs an estimated $41/ha/year and returns an annual gross benefit of about $124/ha/year. This results in a net average benefit of $84/ha/year and a benefit-to-cost ratio of three. Across all grain-growing regions in WA, this leads to a net benefit in the order of $1 billion per year.

It is estimated that for every dollar a grower spends on soil amelioration, $3 is returned in increased productivity.

Soils for the future

One of the most important aspects of DPIRD's soil research is the adoption of amelioration strategies by farmers. To be fully successful, the research needs to be understood, adopted and implemented across farms. In February 2020, the Soil Science and Crop Nutrition team carried out a telephone survey of 214 growers distributed across the agricultural zones.

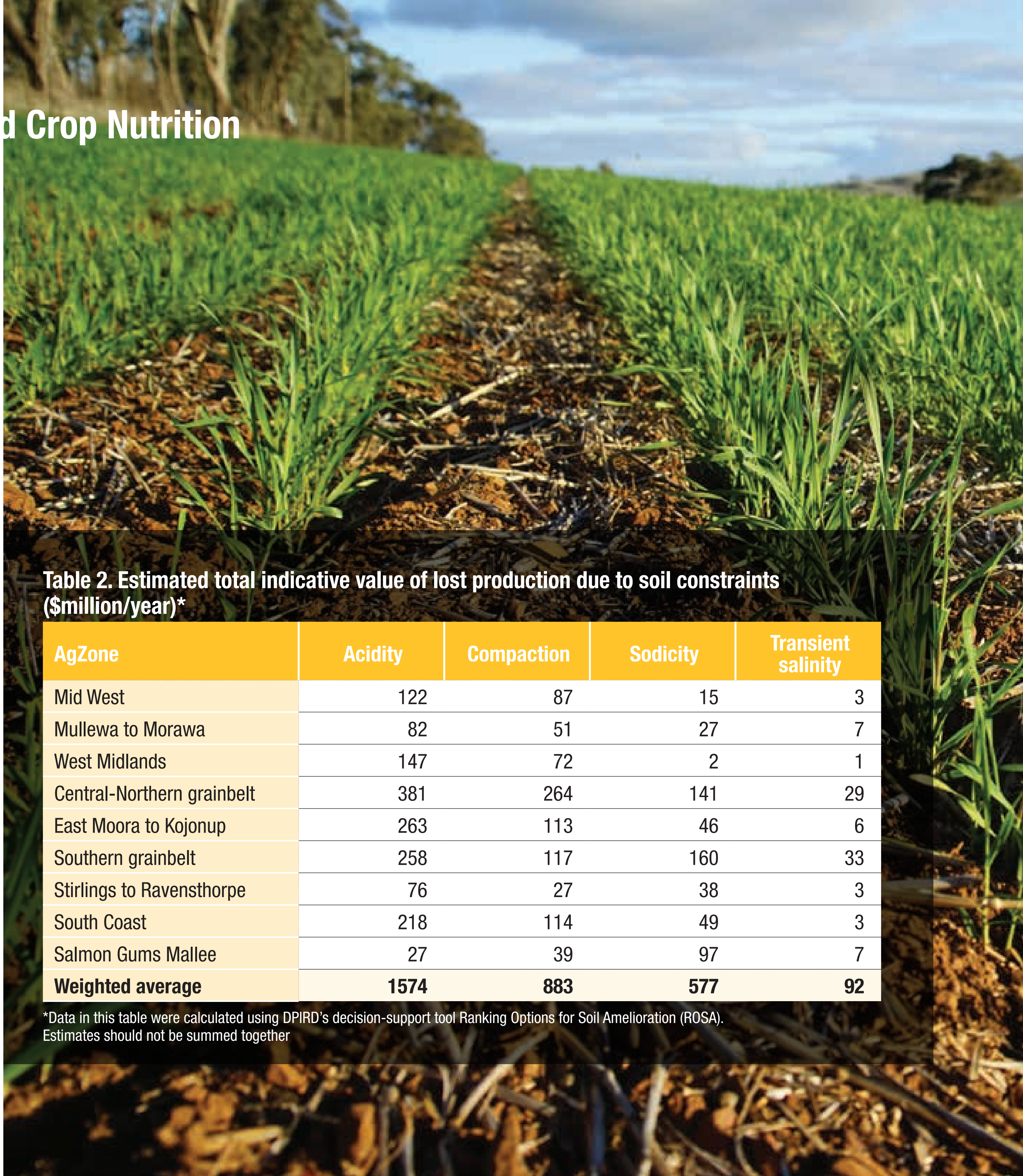


Table 2. Estimated total indicative value of lost production due to soil constraints ($million/year)*

AgZone	Acidity	Compaction	Sodicity	Transient salinity
Mid West	122	87	15	3
Mullewa to Morawa	82	51	27	7
West Midlands	147	72	2	1
Central-Northern grainbelt	381	264	141	29
East Moora to Kojonup	263	113	46	6
Southern grainbelt	258	117	160	33
Stirlings to Ravensthorpe	76	27	38	3
South Coast	218	114	49	3
Salmon Gums Mallee	27	39	97	7
Weighted average	**1574**	**883**	**577**	**92**

*Data in this table were calculated using DPIRD's decision-support tool Ranking Options for Soil Amelioration (ROSA). Estimates should not be summed together

DPIRD's Soil Science and Crop Nutrition team comprises about 35 staff (including these 19) spread across seven locations – Geraldton, Northam, Esperance, Merredin, Albany, Katanning and East Perth.

More than half (52 per cent) of growers had undertaken some form of mechanical soil amelioration. A further 23 per cent had undertaken amelioration by non-mechanical approaches, such as spreading lime, gypsum or clay-rich subsoil.

Adoption of mechanical soil amelioration was highest in the Geraldton port zone with 68 per cent of respondents using mechanical amelioration, followed by Esperance (59 per cent), Kwinana (57 per cent) and Albany (29 per cent).

Growers who were mechanically ameliorating their soil, on average, cropped about 2000 hectares more than growers who were not ameliorating their soil or using non-mechanical amelioration approaches only.

Ninety-seven per cent of growers who used mechanical amelioration applied lime as part of their normal farming strategy and more than half (60 per cent) applied extra lime when undertaking mechanical amelioration. This demonstrates a good understanding of the need to incorporate lime to manage subsoil acidity and the need to manage multiple constraints at once.

The DPIRD Soil Science and Crop Nutrition team is making inroads into the huge challenge presented by constrained soils across WA's highly profitable agricultural lands. Farmers are readily adopting the soil amelioration techniques being developed, with positive results for individual farms and for the state's grain harvest. The next phase of the research will be finding ways to re-engineer difficult soils, making them fit-for-purpose to capture, hold and efficiently supply water and nutrients to crops.

Mapping the problem

THE MAIN SOIL CONSTRAINTS across the WA agricultural region are acidity, sodicity, water repellence, salinity and compaction (Table 3). Understanding the extent of these constraints, and knowing which constraints occur where, improves management. Mapping soil constraints is important for defining their economic impact and directing research efforts and resources to where they can be most effectively used.

DPIRD research scientist David Hall and others from the Soil Science and Crop Nutrition team worked with members of DPIRD's Agriculture Resource Management and Assessment team to map soil constraints across WA's south-western agricultural region. The team used the DPIRD soils database to map key constraints at a shire scale and also where multiple constraints co-exist (Figure 11).

More recently, soil maps approaching paddock scale have been developed based on soil profile texture classes. Knowing the texture of the soil profile can provide insights into the associated constraints, given that many soils have multiple constraints. For instance, deep sands are more likely to be affected by acidity, water repellence and compaction. On the other hand, clay soils in low rainfall environments are more likely to be affected by sodicity, transient salinity and boron toxicity.

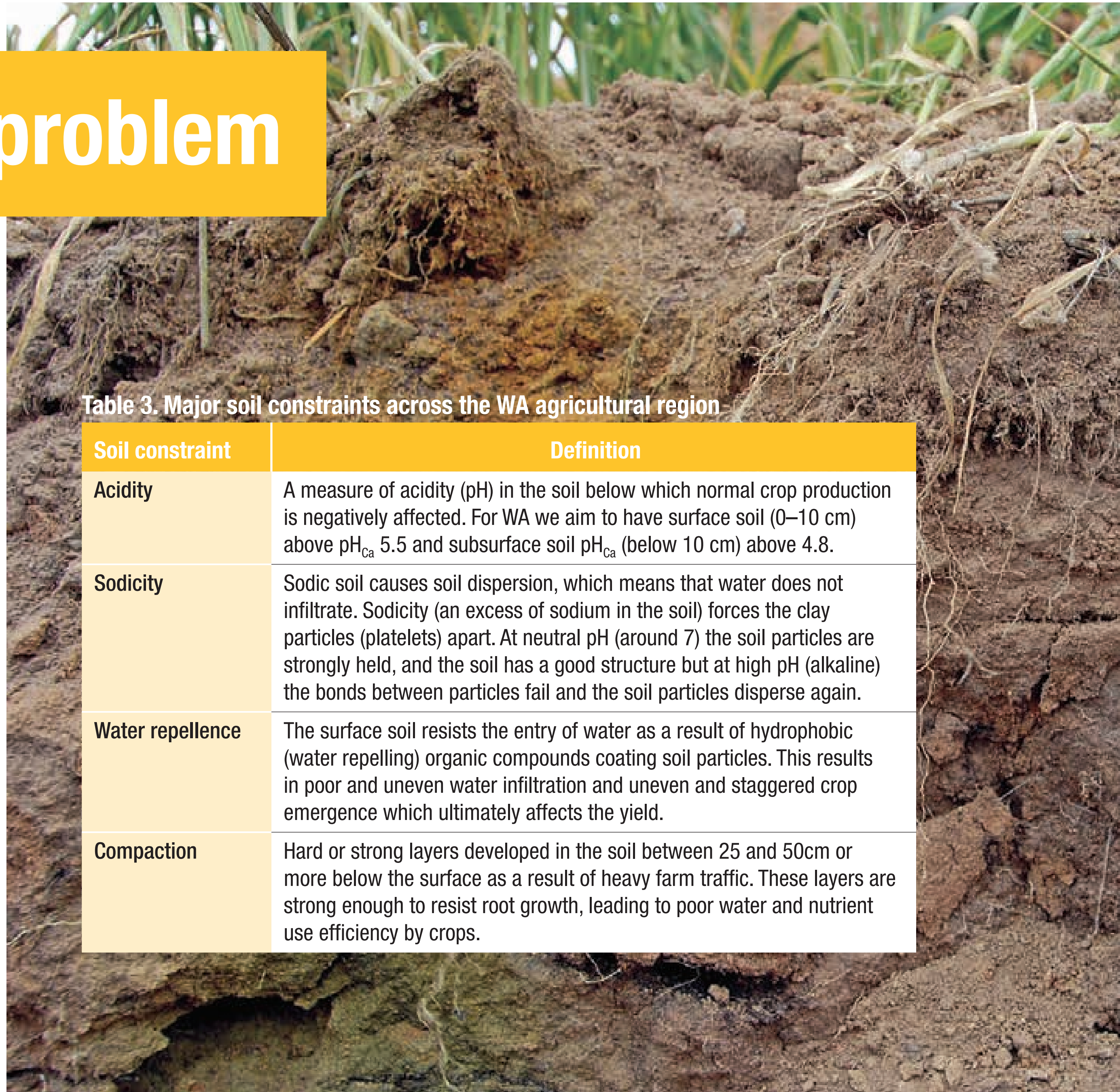


Table 3. Major soil constraints across the WA agricultural region

Soil constraint	Definition
Acidity	A measure of acidity (pH) in the soil below which normal crop production is negatively affected. For WA we aim to have surface soil (0–10 cm) above pH_{Ca} 5.5 and subsurface soil pH_{Ca} (below 10 cm) above 4.8.
Sodicity	Sodic soil causes soil dispersion, which means that water does not infiltrate. Sodicity (an excess of sodium in the soil) forces the clay particles (platelets) apart. At neutral pH (around 7) the soil particles are strongly held, and the soil has a good structure but at high pH (alkaline) the bonds between particles fail and the soil particles disperse again.
Water repellence	The surface soil resists the entry of water as a result of hydrophobic (water repelling) organic compounds coating soil particles. This results in poor and uneven water infiltration and uneven and staggered crop emergence which ultimately affects the yield.
Compaction	Hard or strong layers developed in the soil between 25 and 50cm or more below the surface as a result of heavy farm traffic. These layers are strong enough to resist root growth, leading to poor water and nutrient use efficiency by crops.

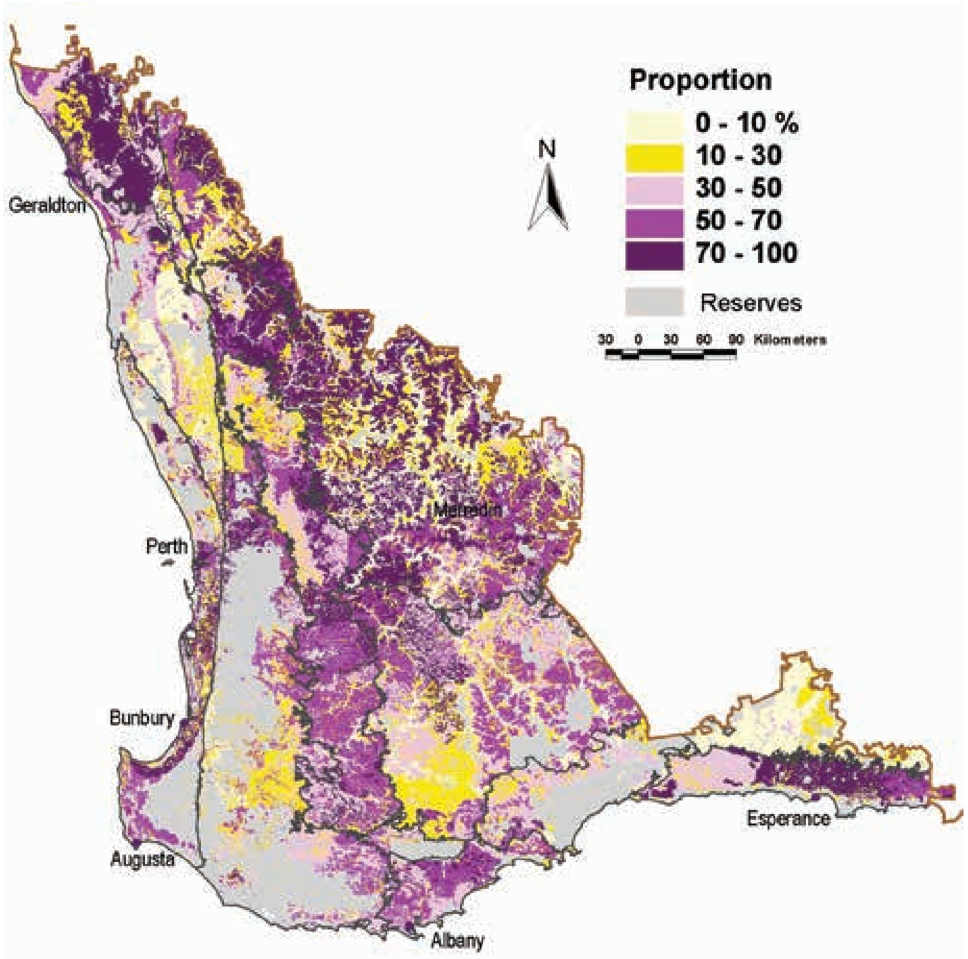


FIGURE 11. Proportion of soil in the Western Australian grainbelt where subsoil acidity occurs alongside other yield-limiting subsoil constraints

Source: van Gool 2016

Tillage offers long-term fix for water repellent soils

WITH VAST AREAS OF sandy surface soils, the WA grainbelt stands out as a global hot spot for the occurrence of topsoil water repellence. Water repellent (hydrophobic) organic residues from plants and microbial sources are slow to degrade in WA's relatively dry environment and can readily cover the surface of topsoil sand particles. The organic residues render soils resistant to water entry and, as a result, soils wet up unevenly and crop germination is poor, patchy and staggered over time. An increasing trend towards dry seeding and and less frequent and lower break-of-season rainfall have made matters worse.

With support from the GRDC, DPIRD Soil Science and Crop Nutrition researchers have been working with research partners from the CSIRO, Murdoch University, the University of Western Australia and the University of South Australia to develop ways to overcome soil water repellence in cropping systems. The research has shown there is no one-size-fits-all approach to managing the problem.

Some strategies mitigate the effects of soil water repellence. These options, which include specialised sowing methods and applying soil wetting agents, provide cheap management options. However, because they do not actually fix the water repellence, they must be implemented every year and need to be targeted at responsive soils and situations. Paired and near-row sowing typically increase early emergence by 50 per cent but have smaller and more variable effects on grain yield.

On a forest gravel near Kojonup, applying a banded soil wetting agent (plot on right) improved barley establishment compared to the untreated control plot (left). In this experiment, banded soil wetters increased barley yields by 0.6–0.9t/ha over the untreated controls, which yielded 3.7t/ha

Lupin establishment and growth in 2020 with (left) and without (right) strategic deep tillage (rotary spading) applied in 2016. Deep tillage increased lupin grain yield by 0.45t/ha over the untreated control, which yielded 1.75t/ha

Banded soil wetters are liquid surfactants that, when applied to the sown furrow on repellent soils, help rain to infiltrate the crop row. The benefits of banded wetters are greater in seasons with low and sporadic germinating rains in autumn. They are most beneficial for dry-sown cereals on the repellent forest gravels of the south-west, with an average yield increase of 0.6t/ha (image top left). On deep sands, the benefits of banded wetters are variable for dry-sown crops, with average yield benefits of less than 0.15t/ha.

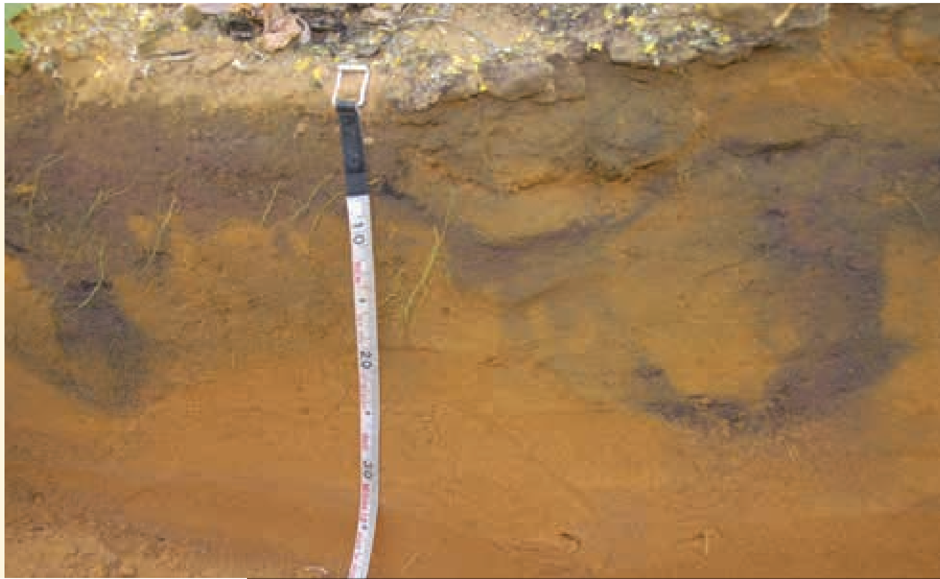
Strategic deep tillage using spading or inversion ploughing provides long-term and reliable benefits across most repellent soils and locations (Table 4). Such tillage effectively 'fixes' the water repellence problem, rather than just managing it for a season with a one-off operation (image top right).

Cereal grain yields have been shown to respond by more than 0.5t/ha to strategic deep tillage, with these yields usually sustained for five years or more.

Table 4. Summary of options for managing water repellent cropping soils in Western Australia showing estimated typical net financial return in responsive situations as defined by soil type, seeding and seasonal factors

Soil water repellence management method	Typical net financial return ($/ha/year)	Longevity of response (years)	Responsive soil types	Responsive factors
Paired-row sowing	51	1	• All repellent soil	–
Near-row sowing	51	1	• All repellent soil	• Dry seeding • Dry autumn
Banded soil wetters	92	1	• Forest gravel	• Dry seeding • Dry autumn
Blanket soil wetters	62	1–2	• Forest gravel	• Dry seeding
Deep soil mixing (e.g. Rotary spader)	107	4–10+	• Deep sand • Deep sandy duplex	• Average to good autumn and spring rainfall
Deep soil inversion (e.g. Mouldboard or one-way/ Plozza)	138	10+	• Deep sand • Deep sandy duplex • Sandy gravel • Forest gravel	• Average to good autumn rainfall; deeper ripping below plough depth
Clay delving and incorporation	125	20+	• Deep sandy duplex	• Average to good autumn and spring rainfall
Clay spreading and incorporation	82	20+	• All repellent soil	• Higher rainfall areas

Repellent soils are usually prone to compaction and subsoil acidification. Ameliorating these constraints as well as topsoil water repellence will increase and sustain yield benefits. For example, deep ripping following soil inversion can increase average grain yields by a further 10 per cent (340 kg/ha), over inversion on its own.



LEFT: Rotary spader ameliorating soil water repellence.
ABOVE: Topsoil incorporated to 30cm.

Crop nutrition and water repellence

When water repellence is ameliorated, the important crop nutrient potassium becomes more available. Severe soil water repellence is more likely when soil clay content falls below five per cent but at these low levels, the soil's ability to retain potassium is also low. Rotary spading has proven effective in treating water repellent soils as it buries the non-wetting soil below the surface enabling water to penetrate into the soil where plant roots can access it. Research conducted by DPIRD has shown that crops grown on soil treated with rotary spading typically have higher potassium uptake than crops grown on untreated, severely water-repellent soil (Figure 12).

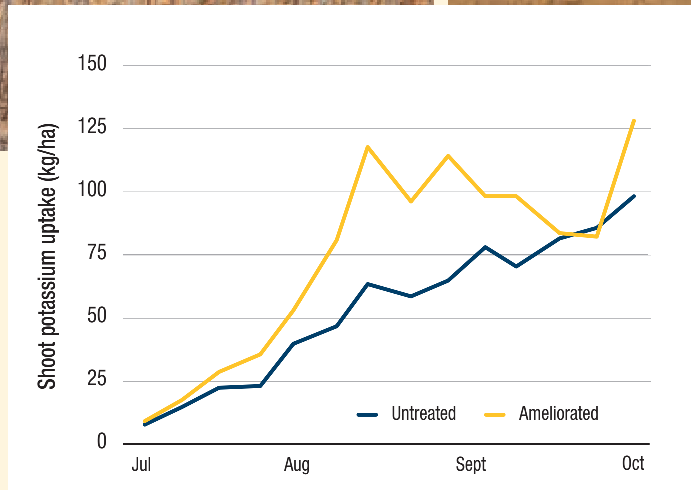


FIGURE 12. Ameliorating soil water repellence with a rotary spader increased the uptake of potassium by wheat shoots in August to September

Research stimulates practice change

SUBSOIL COMPACTION REDUCES the productivity and profitability of cropping soils by restricting root growth and increasing the risk of waterlogging and acidification. Compacted soils can also restrict the healthy activity of soil biology. In WA, 14 million hectares of agricultural land have moderate to high risk of soil compaction. Conservative estimates suggest that compaction costs the WA grains industry $883 million annually. Management options include deep cultivation to break up subsoil compaction, controlled traffic farming (CTF), repeated deep cultivation, and careful management of cropping inputs to protect profitability.

In 2015 DPIRD researchers established seven demonstration sites on a range of soil types across the WA grainbelt (at Binnu, Moora, Broomehill, Ongerup, Esperance and Beacon) to evaluate the economic viability of new methods of deep ripping. In seasons with a cool finish, deep ripping can increase grain yield by 20–30 per cent.

Complementing the research, an extension program delivered demonstration trials, field days, articles, workshops and conference presentations in collaboration with grower groups and industry organisations. The aim was that by the end of June 2019, at least 1500 growers and 250 advisors would have the knowledge (technical and tools) to minimise the impact of soil compaction on farm profitability. It was also intended that a further 200 growers would change their practices to minimise the effect of soil compaction on farm profitability by the end of the project.

DPIRD project officers Bindi Isbister and Wayne Parker conducted a benchmarking survey of growers in 2016 and an evaluation in 2019.

Adoption of deep ripping increased from 34 per cent in 2016 to 49 per cent in 2019 while controlled traffic farming increased from 21 per cent to 25 per cent.

Research plot deep ripper with modifications to incorporate fertiliser and soil amendments.

Increased adoption of deep ripping and controlled traffic is supported by industry with 89 per cent of agronomists recommending CTF to their clients in 2019 compared to 78 per cent in 2016. Research indicates that when CTF is used after deep ripping there is an additional yield benefit of 10 per cent ($60/ha for a 2t/ha yield and $300/t price) and better grain quality.

Sixty-seven per cent of agricultural machinery dealers and manufacturers surveyed have seen a small to moderate increase in demand for deep ripping equipment and 78 per cent for CTF machinery over the past five years. Of the 23 machinery manufacturers and businesses surveyed, 80 per cent have introduced new machinery or suppliers to give their clients more options for managing soil compaction.

These survey results highlight the success of the joint DPIRD and GRDC project to increase the adoption of soil compaction management in WA.

Surveys show that half of growers intend to have a form of CTF in the future, where currently only about a quarter use CTF. This indicates that awareness of the benefits of the practice is growing in the industry.

Calculator keeps wheels on track

Controlled traffic farming (CTF) is a simple concept that is surprisingly difficult to achieve in practice. The simple concept is to not drive machinery where grain is grown because machinery compacts soil. The average Australian no-till system (without CTF) drives over 40 to 60 per cent of the paddock in one season, but a fully-matched CTF system has a trafficking percentage of just nine to 12 per cent. The practicality is that CTF requires the wheel tracks of every machine that traverses the paddock to line up exactly. This is easier said than done, especially given that different machines come in different widths and they are not always simply twice as wide or half as wide as each other. To help farmers and consultants make CTF work in practice, DPIRD research scientist Bindi Isbister worked with industry partners to develop the CTF Calculator, a web-based decision-support tool to help make CTF machinery investment decisions.

The CTF Calculator analyses different machinery set ups to calculate paddock trafficking percentages and also shows the expected dollar gains from various CTF systems. For example, a fully matched CTF system on a three metre wheel track that covers 13 per cent of the paddock area could have an estimated benefit of $47/ha in sandy soils (assuming a grain price of $220/t and a yield of 2t/ha) compared to a system with no CTF where 48.6 per cent of the paddock area is wheeled.

CTF also offers other benefits including improved in-crop access via firm wheel tracks, better soil aeration and drainage of heavier textured soils (loam or clay) in wet conditions and lower greenhouse gas emissions.

LEFT: DPIRD research scientist Bindi Isbister is encouraging WA growers and consultants to use the CTF Calculator to guide machinery investments to overcome soil compaction.

Deep ripping makes crops hungrier

Healthy soil and crop growth from deep ripping between permanent tramlines.

Deep ripping is used to remedy compacted soil. An implement is used to 'rip' deep into the soil – usually more than 30cm – to break up soil compaction and enable plant roots to penetrate deep into the soil. DPIRD conducted a two-year trial to determine if deep ripping also affected the availability of nitrogen to crops. In the first year, the deep ripping caused an increase in soil mineralisation, which increased the supply of soil nitrogen, so adding extra nitrogen provided no benefit. However, in the second year, the crop responded to added nitrogen (Figure 13). Economic analysis showed that applying nitrogen in the deep ripped treatments was profitable, but that it was not profitable in the untreated, compacted soil.

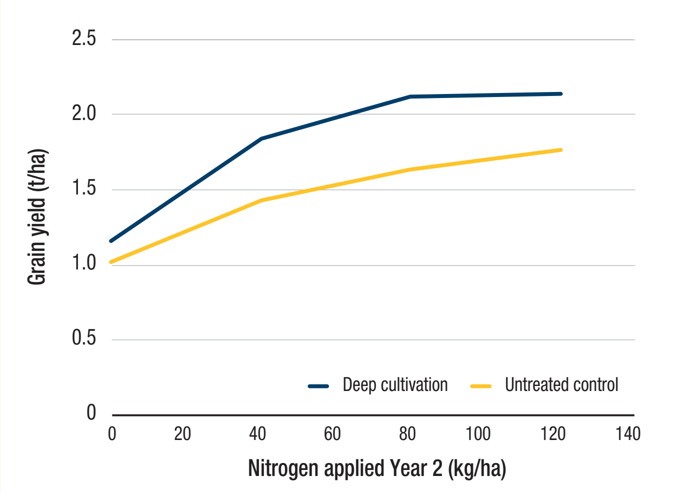


FIGURE 13. Deep cultivation in 2018 increased grain yield per kilogram of nitrogen applied

Grower Bob Nixon from Kalannie (left) and Dr Gaus Azam inspecting limed topsoil incorporated into the acidic subsurface soil after deep ripping with inclusion plates.

Managing the whole acidic soil profile with lime

BASIC CHEMISTRY SHOWS that adding lime (calcium carbonate) neutralises acidity. But to understand the long-term effects of adding lime on acidity deep within the soil profile takes much more than basic chemistry. DPIRD has conducted several long-term (6–23 years) soil acidity management experiments in the WA grainbelt using a wide range of lime rates (cumulative total 0–8.5t/ha).

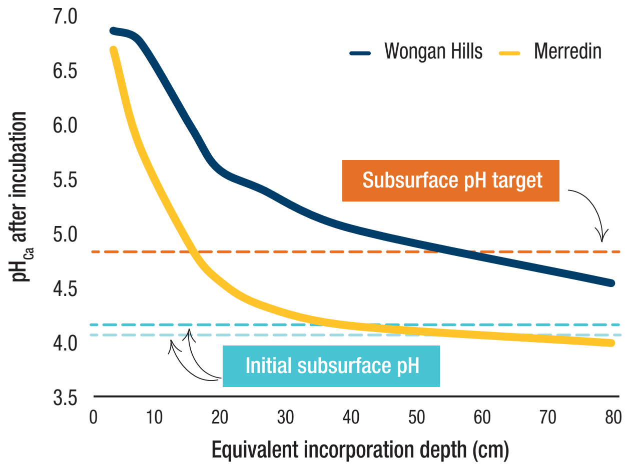


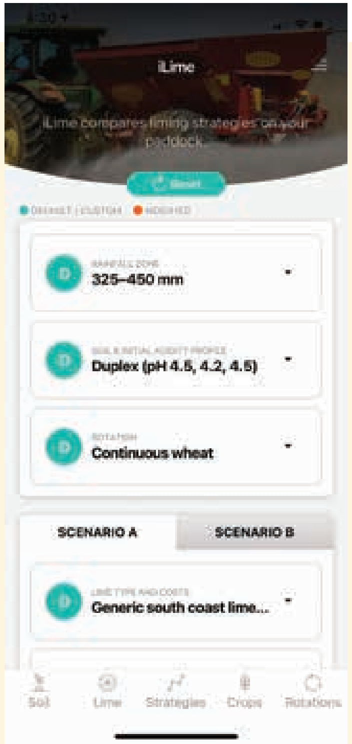
FIGURE 14. Incorporating surface residual lime into the soil profile increases soil pH at depth

When lime is added to soil, some remains undissolved in the soil profile. Soil scientists refer to this as residual lime. DPIRD research scientist Dr Gaus Azam investigated the potential for using residual lime for managing subsoil acidity. He found that a large proportion of surface-applied lime remained undissolved in the top 4cm of the soil profile. When this top 4cm of soil was incorporated, the pH of the subsurface soil increased (that is, acidity decreased), as the residual lime reacted (Figure 14).

Locating the best lime source

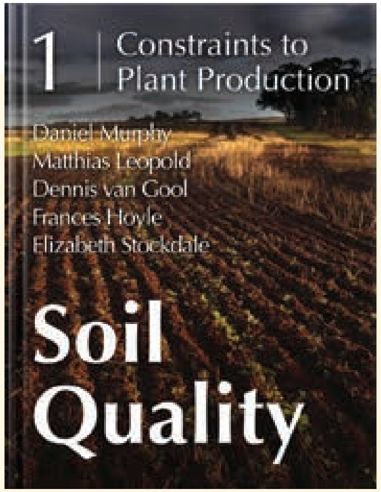
Adding lime to soil neutralises acidity. But each lime source has a different capacity to neutralise acidity and different soil types respond differently to lime. This means a one-size-fits-all approach simply does not work when recommending lime application rates to overcome soil acidity.

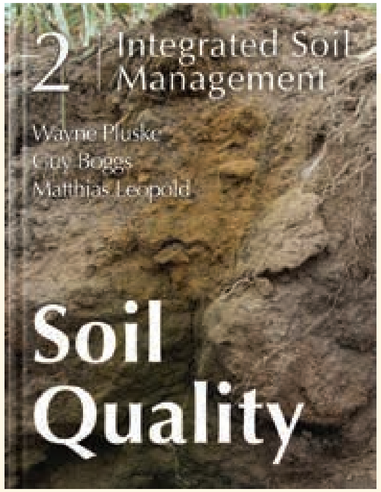
Enter iLime, a decision-support tool developed by DPIRD in consultation with farmers to help take the stress out of developing liming strategies. iLime calculates the best value-for-money lime source based on cost, freight, quality and reaction for the defined soil type. The tool estimates the effect of lime applications on soil pH, yield and profitability of a paddock over 20 years.

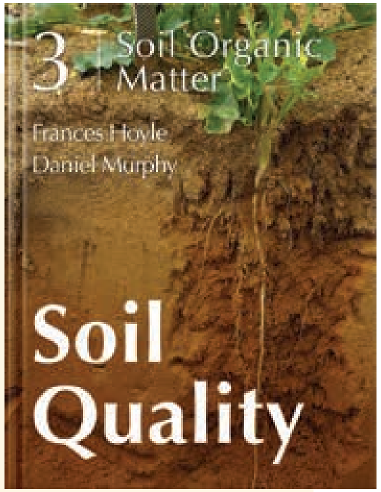


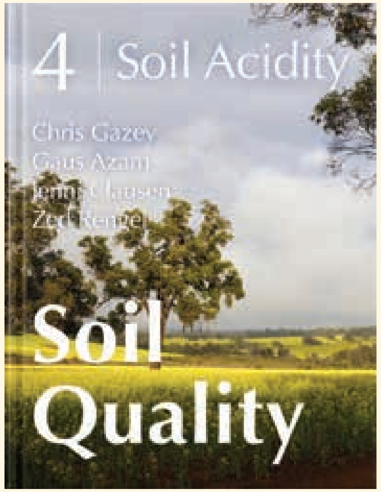
The app works entirely off-line and is available for Android and iOS operating systems. To date, almost 1000 copies have been downloaded.

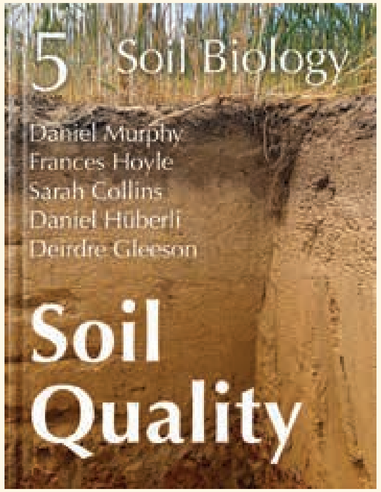
Soil management ebooks





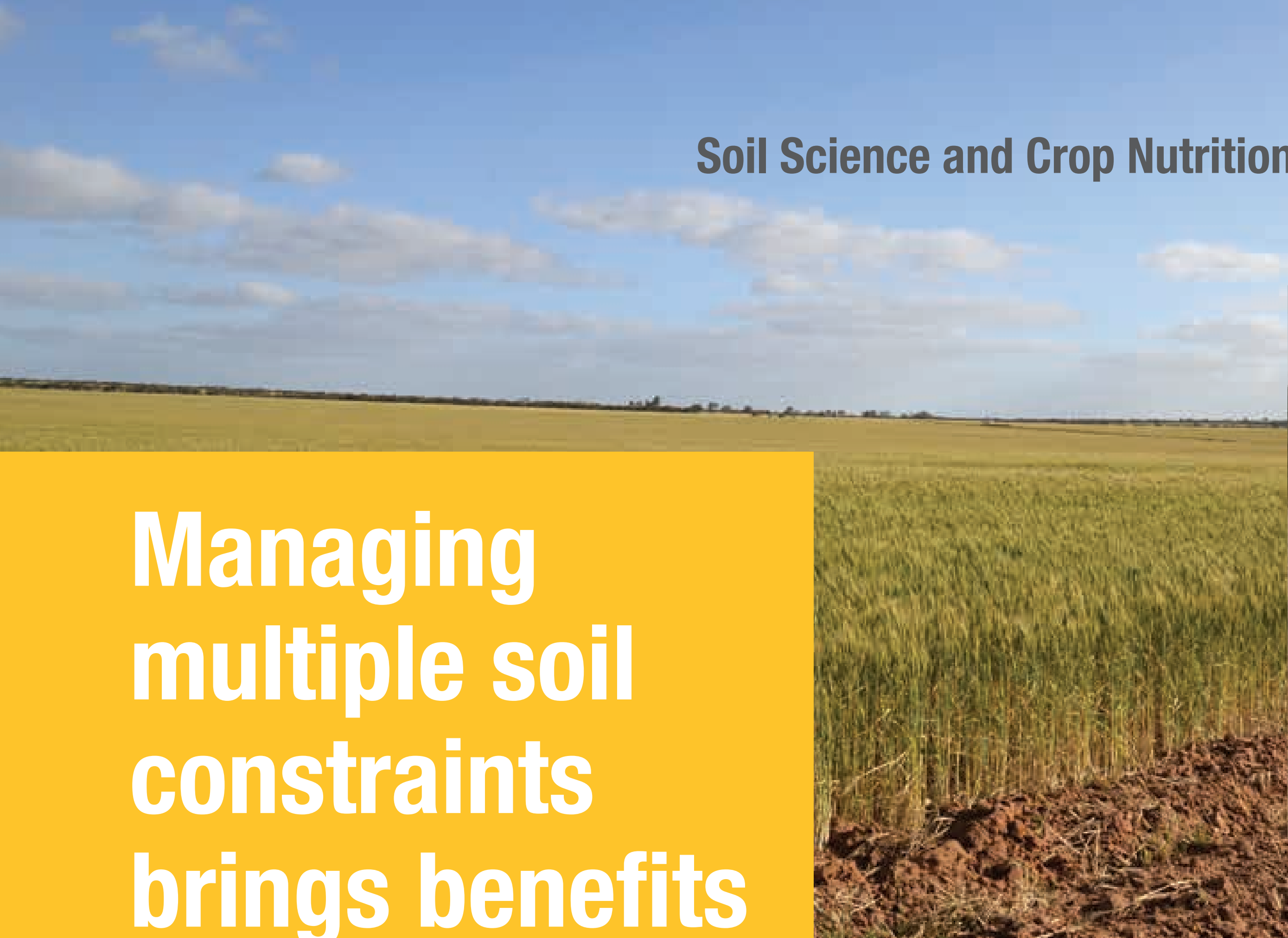






Researchers from DPIRD and the University of Western Australia have created a series of multi-layered ebooks on soil quality. The ebooks include interactive graphics, image galleries and video content and are carefully structured to enable readers to choose the level of detail they require. The Soil Quality ebook series is a valuable resource for farmers, agricultural professionals and students. Book 4 Soil Acidity explains the causes and implications of soil acidity in broadacre agriculture.

The books are available as a free download from Apple Books.



Managing multiple soil constraints brings benefits

One-off inversion of repellent sandy gravel near Badgingarra.

AMELIORATING SOIL CONSTRAINTS could increase wheat yield by 0.6–1.4t/ha, adding $600–800 million to WA grain growers' income annually.

Plant roots do not penetrate soil with significant constraints. DPIRD soil scientist Dr Stephen Davies has shown that crop roots are often restricted to the top 40cm in soils suffering from multiple constraints, but in deep sandy soils where those constraints are not present, roots can grow down to 200cm.

The interaction of multiple soil constraints — such as acidity, compaction, sodicity, poor soil structure and water repellence — reduces plant-available water, crop productivity and long-term profitability across the majority of WA's cropping soils. This has a combined effect of reducing yields by an estimated 40–50 per cent compared with what could be attained if crops were unconstrained by soil factors.

If water is available during grain-fill this would translate to an estimated additional wheat yield opportunity of 0.6–1.4t/ha.

When multiple soil constraints were ameliorated, DPIRD research found crops could access an additional 10–40mm water, depending on soil texture and structure through the soil profile.

Soil Science and Crop Nutrition

Current soil amelioration options (liming, clay spreading, delving, deep ripping, deep soil mixing, soil inversion) address one or more constraints, typically to a depth up to 40cm. Deeper and more effective amelioration of soil profiles can result in larger and longer-lived productivity benefits.

Sandplain soils comprising deep sands, deep sandy earths, sandy gravels and sandy duplex soils make up 12 million hectares, or nearly 50 per cent, of the agricultural soils of south-west WA. Deep sandplain soils typically have low soil water and nutrient storage capacity and are susceptible to acidification, subsoil compaction, topsoil water repellence and wind erosion.

Sandy duplex soils are even more difficult. These soils have a sandy layer on top (A-horizon) and a clay-rich layer below (B-horizon). Their A-horizons have similar constraints to deep sands, but can also have poorly structured B-horizons that may be sodic (dispersive). The B-horizons may also be strongly alkaline, have multiple chemical toxicities and are often susceptible to transient waterlogging. Managing the diverse combination of constraints in the A-horizon together with a completely different set of constraints in the B-horizon and their many interactions is challenging. Crop responses to costly soil management options on these soils are often inconsistent.

The Soil Science and Crop Nutrition team is assessing the implementation and interaction of soil amelioration and amendment practices to ensure that they provide the greatest benefit for the longest possible time. They are tailoring amelioration strategies for specific soil types, soil depths, constraint types and environmental interactions.

A compacted pale sand over a highly alkaline, unstructured heavy clay deeper in the profile.

Unlocking system yield potential

By fundamentally changing the physical and chemical properties of the soil, crop yields could be dramatically increased. An unconstrained soil has increased water holding capacity.

It is estimated that crops grown in remediated soils could deliver up to 95 per cent of the potential yield for a given seasonal rainfall. It may also be possible that crop yield potential could increase beyond what is currently considered typical on these soils.

Compacted white sand.

Root growth in mouldboard ploughed soil.

In WA dryland cropping systems, access to water is usually the most limiting factor to grain yield. Soil amelioration packages can improve the efficiency with which grain crops convert water into grain yield. Research by the Soil Science and Crop Nutrition team has shown that soil amelioration can increase soil water use efficiency in cereals by 5–8kg/ha for every millimetre of additional water accessed by the crop. Grain growers who have, over time, implemented a 'package of soil amelioration' have seen their paddock average water use efficiency in cereal crops increase from 13kg/ha/mm up to 18kg/ha/mm.

The successful soil amelioration package comprises:

- soil inversion for water repellence, lime and nutrient incorporation and weed seed burial
- further application of lime to correct acidic soil
- deeper ripping below the plough depth to remove deeper hard pans.

Current amelioration practices mainly work within the top 40cm of the soil. Accessing deeper subsoil water potentially has huge benefits, especially on duplex soils. Finding ways to achieve this is a current focus of DPIRD researchers.

Soil inversion of deep gravelly sand at Mingenew.

Strategic tillage improves root access to soil water and nutrients

DPIRD soil scientists found that after deep ripping, mixing or inversion, more roots grew in the subsoil. The roots tended to follow the breakout pattern of the tine used to rip the soil (Figure 15). When soils were inverted rather than being deep ripped, roots grew differently. In inverted soils, roots tended to mostly grow around patches of organic matter that had been buried by the machinery.

In some cases, removing constraints can allow crop roots to access previously untapped pools of nutrients, such as potassium and nitrogen, deeper in the subsoil where clay content has increased, and leached nutrients have been captured. This can result in increased crop growth and higher nutrient concentrations in plant shoots. With higher productivity, however, can come higher crop demand. Nutrition levels that might have been adequate for a crop on constrained soil may become marginal for a crop with much higher yield potential. On deeper sands, it is becoming increasingly important to ensure adequate potassium supply so that the full productivity benefits of soil amelioration can be realised.

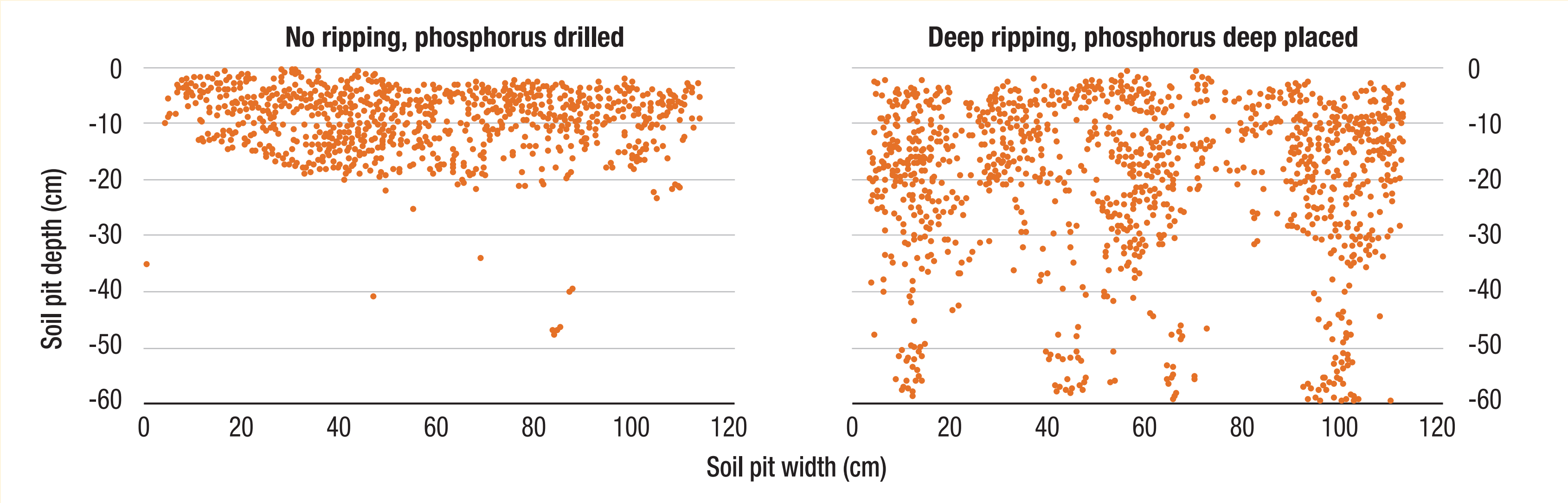


FIGURE 15. The dots in the images represent plant roots and show how the compacted layer at 20cm prevents roots from penetrating deep into the soil

Deep ripping has enabled wheat roots to penetrate well below 30cm (right) while roots not on the rip line (left) are being restricted to a depth of less than 20cm.

DPIRD research scientist Wayne Parker highlighting a compacted acidic layer between 20 and 45cm.

Getting roots to dig deeper

Distributing lime at depth to determine how its placement interacts with soil amelioration practices such as rotary hoeing to affect crop yields.

DPIRD SOIL SCIENTIST Dr Gaus Azam established a long-term field experiment in a cropping paddock near Kalannie, WA, to understand the effect of different amelioration treatments on soil that was continuously cropped. How would the roots of wheat and barley respond to the different treatments?

Gaus found that when the soil constraints were not ameliorated, wheat and barley roots grew to a maximum depth of 25cm (Figure 16). When the soil compaction was ameliorated, wheat roots grew down to 53cm. However, barley only grew below the 25cm barrier if lime was incorporated. Gaus also found that the root growth patterns determined how the crops used water and this in turn determined the yield of the crops.

FIGURE 16. Wheat and barley rooting depth and density in an acidic deep loamy sand at Kalannie, WA, 56 days after sowing using no disturbance and no lime or removal of compaction only (rotary hoed) or removal of compaction and acidity (rotary hoed + lime incorporation)

Dealing with difficult soils

SOME SOILS ARE ESPECIALLY DIFFICULT to deal with. Among the most difficult are soils that are dispersive, and which collapse when wet. Clay particles within these soils fail to stick together, which causes them to disperse and clog soil pores, decreasing water infiltration. Fertilisers and salt accumulate in these soils.

Many soils are naturally dispersive, usually because they are sodic. Sodicity (an excess of sodium in the soil) forces the clay particles (platelets) apart. At neutral pH (around 7) the soil particles are strongly held, and the soil has a good structure but at high pH (alkaline) the bonds between particles fail and the soil particles disperse.

Salinity presents an added difficulty in dispersive soils. There is a small amount of salt in rain, so every time it rains, a little bit of salt is deposited on the soil. Over hundreds of years, this salt accumulates in a process called transient salinity. Soils that are more sodic or more alkaline (up to a pH of just over 9) accumulate more salt. Concentrations of salt in crop root zones are particularly high after dry summers and autumns.

Dr Ed Barrett-Lennard and Dr Rushna Munir with the water harvesting trial at Merredin. A barley crop grown at Merredin in 2019 yielded 50 per cent more when the water harvesting system was used, and a further 20 per cent more when gypsum was added.

DPIRD researchers have been examining three ways to respond to these challenges — maintaining soil hydration, using gypsum and using elemental sulfur.

Soil hydration

It is not the salt concentration in the soil that affects crop growth, but the salt concentration in the soil solution. This is an important distinction. It means that if there is more water in the soil, it will decrease the salinity of the soil solution. This will benefit crop growth even if the salt remains in the soil.

Gypsum

Applying a small amount of gypsum to soil furrows decreases soil dispersion in the furrow, enabling water to enter deeper into the root zone.

Sulfur

Adding sulfur to soil furrows acidifies the soil which can reduce dispersion and enable water to penetrate further into the soil, which benefits crop growth later in the growing season.

DPIRD soil scientists Drs David Hall, Ed Barrett-Lennard and Rushna Munir are determining how well these approaches work on dispersive soils. They have used mounding and plastic sheeting to increase the amount of rain flowing into furrows and applied gypsum and sulfur to the furrows. A barley crop grown at Merredin in 2019 yielded 50 per cent more when the water harvesting system was used, and a further 20 per cent when gypsum was added.

Capturing the opportunity

DPIRD research scientist Dr George Mwenda and technician Kanch Wickramarachchi in a crop rotation–amelioration trial near Meckering. The importance of rotation in maintaining soil amelioration benefits is being researched at sites with a history of biological constraints, such as weeds and soil borne pests and pathogens.

SOILS SCIENCE AND CROP NUTRITION researchers, together with researchers in the DPIRD Crop Protection portfolio and the Farming Systems Innovation directorate, are investigating ways to minimise erosion, maximise crop establishment and maintain higher yields on ameliorated soils. Techniques being investigated include crop rotation, herbicide use and management of biological constraints such as weeds and soil borne pests and pathogens.

Once a grower has decided on a specific soil amelioration method, they then need to determine the timing of amelioration. Many growers ameliorate soils with strategic deep tillage in autumn, before the winter cropping season begins in April to May. While this is convenient and allows crops to be sown at the standard time, it can leave soils exposed to damaging wind erosion and, if the soil is not wet, amelioration success can be compromised. While ameliorating soils at other times (winter, spring or the end of seeding) can overcome these potential problems, it can also reduce crop yield potential due to the later sowing, or even prevent a crop being grown at all in the year of amelioration.

The new research program is developing a better understanding of the benefits and costs of ameliorating soils at different times to help growers minimise wind erosion and crop establishment problems.

Following amelioration, growers need to prepare the seedbed and decide which seeding approach to use. The firmness and finish of the seedbed and the seeding system used (including amelioration and seeding at the same time) are all being considered by the research team.

Soil Science and Crop Nutrition

Tom Edwards (centre) in DPIRD's screenhouse in Northam with visiting researchers, growers and consultants. Tom is explaining how herbicides interact with soil amelioration using hundreds of intact soil cores collected from field sites across the grainbelt.

Herbicides and amelioration

Following amelioration, changes in organic matter and clay levels at the soil surface, along with increased soil wettability and movement, can increase the activity and risk of crop damage from pre-emergent herbicide. In some cases, herbicide crop damage can be severe enough to reduce crop establishment, ground cover and grain yield potential. DPIRD research scientist Tom Edwards is leading research to understand how amelioration changes the bio-availability of herbicide and how crop damage and establishment risks can be minimised.

Soil biology

Soil amelioration using strategic deep tillage can also affect biological constraints. DPIRD Crop Protection researchers are working in collaboration with Soil Science and Crop Nutrition researchers to understand these interactions. Dr Catherine Borger and Dr Sultan Mia are assessing how soil amelioration interacts with weed populations and their control. Deep soil mixing and soil inversion can bury significant proportions of the weed seedbank, but can also change herbicide efficacy and influence the types of weeds that might survive. For example, Sultan has found that paddocks with a ryegrass problem before amelioration often have a greater issue with brome grass after amelioration.

Dr Sarah Collins, Dr Daniel Hüberli and Dr Carla Wilkinson are examining how strategic deep tillage in the form of ripping, mixing or inversion, with and without lime application, affects soil borne diseases and pests. They are studying the effect of one-off deep tillage practices on the numbers and distribution of plant parasitic nematodes and the root rot disease Rhizoctonia down the soil profile, and how this subsequently affects root infection. It is already evident that mixing and inversion practices reduce inoculum and nematode levels in the top 10cm of soil, but they can increase in the 10–20cm and sometimes 20–30cm layers. Crop roots, however, are more established by the time they encounter these pests and pathogens deeper in the soil and some improvements in crop root health have been measured. Ongoing research will determine if, over time, the pests and diseases re-colonise the topsoil and reduce crop growth.

MAIN IMAGE: DPIRD research scientist Catherine Borger examines a barley grass trial.

INSETS: Soil amelioration can have significant effects on biotic constraints including weeds. In an experiment established at Yerecoin, grass weeds in the no-till untreated soil (left) have been controlled by a one-off soil inversion treatment (right).