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GRDC

GROUNDCOVER SUPPLEMENT

STUBBLE INNOVATION

LEVERAGING STUBBLE FOR GREATER CROPPING GAINS

By Kaara Klepper

"THE SHIFT TO NO-TILLAGE FARMING REPRESENTS ONE OF THE MOST SUBSTANTIAL LANDSCAPE CHANGES IN AUSTRALIAN AGRICULTURE."

– Rick Llewellyn and Jackie Ouzman*

■ The adoption of no-till and stubble retention practices transformed the Australian grains industry in two fundamental ways. First, it reframed agriculture in ways that better resonate with local landscape ecologies. This resulted in concurrent gains in productivity and sustainability, most notably in terms of water-use efficiency and soil health. Second, it initiated a journey of ongoing learning and innovation that today sees conservation agriculture (CA) act as a platform for further major advances in cropping practices.

The key component of CA is stubble retention and, as such, stubble is also a key leverage point for achieving ongoing gains and innovations. The May–June 2023 issue of *GroundCover™ Supplement* is therefore dedicated to benchmarking the impacts of stubble, as friend and foe, in our farming systems.

With that aim in mind, the issue starts with an overview of the global knowledge bank on stubble impacts. This work was undertaken to identify opportunities and target investment where it is most needed. The project served to highlight the breadth of opportunities for cropping gains that can result from improving stubble management.

Opportunities for ongoing gains exist around weed and disease control; the promotion of beneficial microorganisms, meso and macro fauna; emergence and yield gains; nutrient availability and improved soil organic matter; reduced impacts from environmental stresses, including wind erosion; and opportunities to integrate stubble into computer models that can predict optimal stubble management practices under varying landscape and seasonal challenges.

The remainder of the issue explores research efforts underway as a result of GRDC investment that cut across these important leverage points. These articles help highlight the world-leading research capabilities available in Australia. For example, we see CSIRO already developing and testing a computer model that can account for changes in soil moisture dynamics from altering stubble architecture – a valuable tool given the adoption of stripper front headers and strip-and-disc systems.

Key concerns across landscapes are stubble load and weed control, and these are the focus of several articles. Important insights are emerging around the use of herbicides for optimum weed control under no-till. However, we are also seeing the emergence of an entirely new approach based on the discovery that stubble can play a chemical role in weed

Photo: Geoff Comfort

Kaara Klepper

suppression in a process called allelopathy.

Efforts around disease control, too, are producing new insights, with articles on blackleg in canola and sclerotinia across the entire crop rotation.

The issue culminates with discoveries around the relationship between stubble decomposition and soil microbes that have the potential to once again revolutionise CA's sustainability credentials via unprecedented gains in soil organic matter.

With about 80 to 90 per cent of Australia's 23.5 million hectares of winter crops grown using CA, it becomes critically important to ensure that the sector is underpinned by timely and relevant investments in research, development and extension. The pay-offs can be large and the stakes are high. □

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agronomyaustraliaproceedings.org/images/sampledata/specialpublications/Australian%20Agriculture%20in%202020%20web%20PDFs%20larger/Australian%20Agriculture%20in%202020%20Pt1Ch2.pdf

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COVER IMAGE: Innovation to stubble management practices are creating new opportunities to further optimise benefits from conservation agriculture.

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Photo: Evan Collis

What we know and what we need to learn

Information relating to stubble management has been collected and curated to identify knowledge gaps to more fully realise the benefits of stubble retention while avoiding potential downsides

Led by Dr David Minkey, WANTFA with GRDC investment has produced a booklet, *WA Stubble Retention*, that summarises current information on the optimal way to manage stubble.

By David Minkey and Ken Flower
WANTFA

■ Decisions on how best to manage stubble at harvest, over summer and at seeding can have potentially significant impacts on farm productivity. This includes effects on soil organic matter levels, erosion risk, soil moisture, weed levels, disease levels and, ultimately, farm profit.

There are, however, important gaps in our knowledge about the complex dynamics associated with stubble that need to be addressed if we are to optimise stubble management decisions.

With investment from GRDC, the Western Australian No-Tillage Farmers Association (WANTFA) has produced *WA Stubble Retention*, a booklet that summarises current information on the optimal way to manage stubble (see back cover). Included in the booklet is a summary of the scientific literature in addition to local research, grower case studies and lessons learnt from GRDC's Stubble Initiative.

This effort to curate and bring together information on stubble management has helped to identify knowledge gaps and, therefore, opportunities to target research in ways that close the gaps and bring about significant extra gain for growers. An overview of the stubble-related factors that affect crop production is given in Figure 1.

A short overview of what is known and what we need to learn is provided here.

SOIL WATER

Overall, the impacts of stubble on soil water dynamics are site-specific, and its effects are negligible during long dry spells in fallow or extremely wet environments. Results are not consistent in terms of the optimum amount, architecture or deposition of stubble. Simple generalisations are not possible given the variability of rainfall and complexities associated with soil type and soil water loss processes.

Studies with both the Agricultural Production Systems sIMulator (APSIM) and Simultaneous Heat and Water (SHAW) agricultural systems computer models, however, found that simulations based on real climate data can improve recommendations about best practice in each region when it comes to managing stubble for soil moisture benefits.

Opportunities also exist to further calibrate these models. Of particular benefit is data from regional investigations on the optimal amount of residue, its architecture and decomposition. Once linked to the associated yield and crop emergence responses, there could be a role for computer modelling to help inform best management practice.

WEEDS

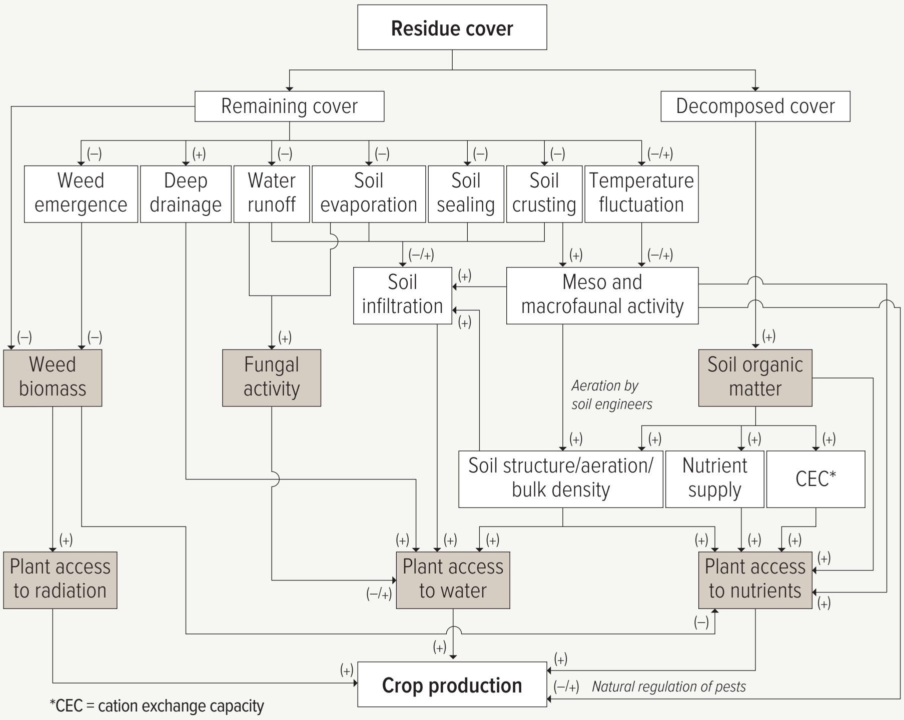
Crop residue can influence weed ecology, with impacts varying depending on the stubble's quantity and position as well as the weed's specific biology and allelopathic potential (the residue's ability to produce biochemicals that affect weed growth).

Most studies, however, have focused only on stubble amounts and types. None have reported on the impact of residue cut height, orientation or location in the row/inter-row space in terms of impacts on weed ecology.

Additionally, crop residues can intercept 15 to 80 per cent of applied pre-emergent herbicides, which reduces the amount of active chemical reaching the soil surface to kill germinating seedlings. It is, therefore, important to evaluate new herbicides for efficacy in different stubble situations, particularly to identify the chemicals that adsorb into the stubble and do not 'wash off' on to the soil. Knowing this will allow crop stubble architecture and load to be better managed to improve herbicide efficacy.

With the rapid uptake of integrated weed management, future research could focus on weed seed predation and decay within practices such as chaff decking or chaff lining.

Figure 1: Crop residue parameters that affect crop production.



*CEC = cation exchange capacity

Source: Derived from Ranaivoson et al, *Agronomy for Sustainable Development*. 2017, 37, 26

MICROORGANISMS

Disease

Residue-borne diseases can be a problem under stubble-retained systems, particularly when similar crops are grown in succession. Research has highlighted the importance of the local environment and type of cropping system in determining disease risk associated with stubble retention.

For example, in WA, crop rotations as short as one year are enough to control yellow spot (*Pyrenophora tritici-repentis*) and Septoria nodorum blotch (*Phaeosphaeria nodorum*) in these dry environments. In contrast, in northern NSW, wheat yellow leaf spot survived longer under more humid conditions. In this case, a two to three-year break was recommended for stubble retention systems.

The impacts of stubble orientation and cut height on disease dispersion also vary according to the pathogen and the environment, making it challenging to generate general conclusions on diseases such as yellow spot, crown rot and blackleg.

A better understanding of the trade-off between stubble management for optimal yield and for disease management is needed so the appropriate fungicide management strategy can be determined.

Beneficial organisms

Stubble conservation systems are known to increase beneficial microbial and fungal populations that suppress soil and stubble-borne diseases.

Research in SA and eastern Australia showed some control of Rhizoctonia root rot (*Rhizoctonia solani*) and take-all (*G. graminis var. tritici*) in 'suppressive soils', indicating that suppression can develop after five to 10 years of no-till and stubble-retained management.

The development of suppressive populations was found to be independent of the rotation but rather arises through changes in soil composition brought about by stubble quality that promotes high carbon turnover and low nitrogen mineralisation. Further work is needed to explore potential applications under different stubble management strategies and over longer time frames.

MESO AND MACRO FAUNA

While it is known that pests and beneficial insects react differently to no-till systems, the best residue management practice to promote soil fauna under the stubble layer is still unknown. What is known is that crop residue retention could be the most effective practice for enhancing soil biodiversity.

For example, studies have found that ants and termites increase wheat yield by up to 36 per cent by increasing soil water infiltration due to their tunnels. They also improved soil nitrogen. As such, they play a similar functional role to earthworms.

The possibility of supporting ants and termites within long-term no-till paddocks is the most under-researched idea that may help increase production in the medium to low-rainfall zones.

EMERGENCE AND YIELD

The current average wheat yield in Australia (of about 2.2 tonnes per hectare) generates about 3.3t/ha of residue (harvest index of 0.4), but this may vary from less than one to more than 9t/ha of residue (for 6t/ha grain yield). While some studies have reported yield increases with increased stubble amount, others have found a negative relationship.

Yield increases can be attributed to enhanced water infiltration, improved soil structure and the control of soil erosion, plus the minimisation of both absolute levels of and fluctuation in soil temperature. Yield losses are ascribed to the immobilisation of mineral nitrogen, reduced soil and air temperatures (mainly during crop emergence), physical impairment and possible phytotoxic effects.

With a few exceptions, results indicate that there is an optimal amount of stubble when it comes to maximising dryland wheat yields. Below or above this optimal band, crop yields could decline. However, research is still needed to quantify optimum levels and to identify the key mechanisms of growth reductions for each crop in a rotation.

There are further gaps around the effect of very tall stubble and an overall need to link yield studies with our understanding of stubble management impacts on water dynamics, nutrition and soil/air temperature.

NUTRIENT AVAILABILITY

Accounting for the impact of crop residue on nutrient availability remains one of the greatest challenges due to the complex nature of nutrient recycling pathways.

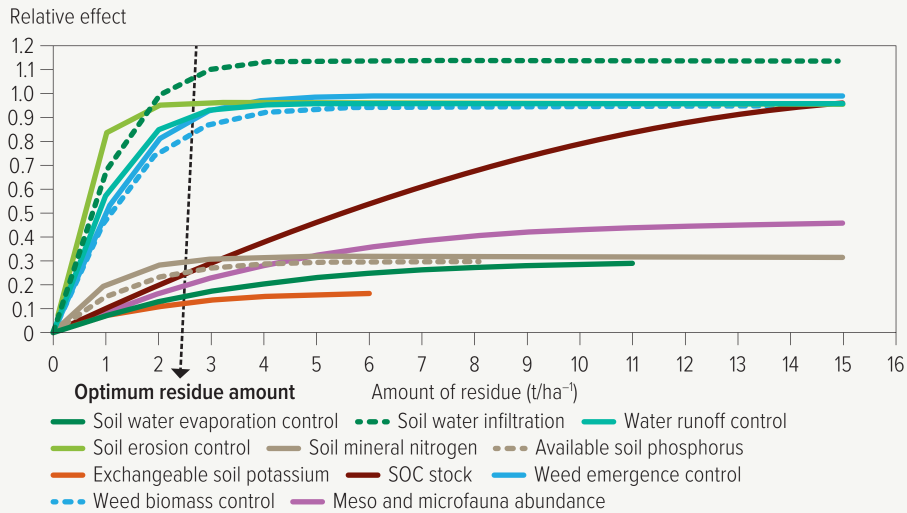
What is known is that short periods of net nitrogen immobilisation can occur following the addition of crop residue to the soil surface due to microbial biomass increases in response to the additional carbon substrate. Other studies show that when high amounts of stubble are retained, stubble may tie up nitrogen from applied fertiliser during the decomposition, mainly when the fertiliser is broadcast.

It has been reported by CSIRO's Dr John Kirkegaard that nitrogen tie-up increases during high-rainfall seasons (above 300 millimetres), causing yield reductions of 0.3 to 0.5t/ha. Cereal-on-cereal is most at risk. He suggests reducing stubble loads or applying more nitrogen (at about five kilograms per t/ha of cereal residue) to overcome these yield penalties. More work is needed to understand the nitrogen budget in relation to stubble type, age, orientation and stubble-derived nitrogen contributions. This information can additionally be used in modelling crop rotations or used in tools for nitrogen management.

TEMPERATURE

Information on stubble impacts during heat stress is limited from a local and global perspective. From the total reviewed papers in our database, no research has correlated stubble management (amount, cut heights, location) with soil and air heat stress during the reproductive phases of different crops. More research is a priority. By contrast, there is research showing certain stubble management practices can be used to avoid crop damage in frost-prone regions.

Figure 2: The maximum effect of surface crop residues in relation to their amount for a set of agroecological functions.



Source: Derived from Ranaivoson et al, *Agronomy for Sustainable Development*. 2017, 37, 26

OPTIMISING RESIDUE LEVELS THROUGH MODELLING AND MONITORING

The concept of an 'optimum level' of residue is complex to unravel and needs to be analysed for each growing environment and farm condition.

A critical stubble threshold has been reported in a project that included 110 case studies from tropical and temperate regions and several residue types, including wheat, maize and rice.

As presented in Figure 2, the residue threshold value of 2 to 3t/ha shows a near-maximum impact on most of the predicted functions.

The boundary lines located at the bottom of the figure confirm that soil fauna abundance, soil water evaporation control and soil nutrient availability had a relatively low response to increasing amounts of surface residues.

On the other hand, the potential maximum effect of crop residues on soil water infiltration, water runoff and soil loss control was large.

Weed emergence and biomass control and soil organic carbon stock also increased with increasing amounts of residue.

This kind of analysis could be used to optimise stubble management and also be included in existing computer models, such as APSIM.

Three areas to focus future research were identified in developing the *WA Stubble Retention* booklet:

1. **Develop optimising models to predict the optimal profit level of residue for each environment as expressed in Figure 2.**
2. **Develop sensing tools that monitor residue levels across the farm so managers can assess stubble levels and future strategies to optimise their levels.**
3. **Delineate the impact of stubble on heat stress during the reproductive stage of grain crops.** □

GRDC Code WAN2004-001SAX

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The booklet *WA Stubble Retention* can be downloaded at: https://grdc.com.au/wa-stubble-retention-booklet

Stubble height trials

Photo: Grassroots Agronomy

A stripper front harvesting wheat in challenging conditions, with lodging and uneven maturity, after a wet year in southern NSW.

Growers have participated in trials to better understand the impacts of taller stubble on soil–water dynamics

By Greg Condon

Grassroots Agronomy

■ The adoption of stripper fronts for harvesting cereal crops has increased over the past decade. The practice leaves tall standing stubbles that growers in high residue farming systems prefer. Perceived benefits include increased groundcover over the summer fallow, improved harvest capacity and reduced hairpinning in disc seeding systems.

The differences in stubble architecture created by stripper versus draper header fronts is being investigated to better understand impacts on the capture, maintenance and storage of soil moisture – in other words, on fallow efficiency dynamics. This project focused on the cereal component of the farming system in southern NSW.

The aim was to address key crop establishment, development and yield metrics, thereby facilitating decisions about the use of stripper fronts.

TRIAL DESIGN

The work was undertaken as a collaborative venture between CSIRO, FarmLink, Charles Sturt University (CSU) and Grassroots Agronomy. The study was initially designed around four paddock-scale replicated trials located at Junee Reefs, Matong, Quandialla and Urana. The project measured and analysed the effects of stubble length and architecture on:

- water capture, storage and conversion to grain yield;
- stubble breakdown rates;
- impacts on soil surface conditions, notably wind speed;
- canopy temperature; and
- weed emergence, pest incursions and impacts of control measures.

Grower-collaborators were engaged to conduct the paddock-scale trials with their own farm machinery, with crops sown with a disc seeder. This reduced any establishment risk around stubble handling across a range of treatments.

Measurements commenced in 2021 and continued until harvest 2022. Additionally, CSU had ongoing trial sites from the previous three years that were continued in 2021 and 2022 at Collingullie and Lockhart.

TRIAL OUTCOMES

The project was fortunate to have some great collaborating growers who were able to establish seven large-scale experiments when the project commenced in December 2020.

In the first year (2020-21), favourable summer rains in February and March were followed by a dry period prior to sowing in April. This provided an excellent scenario to examine differences in surface and stored soil moisture pre-sowing in 2021.

Two very wet years then followed, which caused issues with paddock operations and data collection. By the autumn–winter of 2022, all sites were left unsown by the growers, with trafficability a major issue. CSU was able to maintain a site at Lockhart in 2022. Overall, data was collected across the different sites in the fallow period of 2020-21 and 2021-22. CSIRO and FarmLink now have results from:

- Chameleon sensors on the shallow soil water potential;
- soil temperature;
- the start and finish stubble weights (standing and flat totals) at mid-fallow and pre-sowing; and
- gravimetric soil water at harvest and pre-sowing.

At CSU, the focus was on windspeed and temperature data at different heights within the stubble. This data is expanding our understanding of stubble microclimates. This team also took shallow Time Domain Reflectometry (TDR) soil water and temperature recordings and stubble weights mid-fallow and pre-sowing.

An important use for the field data is to help develop computer models that can extrapolate stubble architecture impacts on soil moisture to other sites across Australia and across different seasonal conditions (see the following story).

The project would especially like to thank the growers for their time and patience plus the research teams that conducted this work, including Tony Swan and Kirsten Verburg at CSIRO, James Holding and Hayden Thompson at FarmLink and John Broster and Phillip Eberbach at CSU. □

GRDC Code FLR2012-003RTX

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Computer model helps clarify taller stubble impacts

Computer simulations are being run to extrapolate likely impacts on a farming system's soil water balance arising from taller stubble produced by stripper headers

By Kirsten Verburg

CSIRO Agriculture and Food

The increased popularity of stripper headers has raised questions about potential impacts on soil moisture dynamics associated with the resulting taller standing stubble versus traditional cereal stubble that is shorter and flatter.

With trials under way to assess soil impacts (see previous story), data will soon be available to add to growers' own observations about benefits and costs of this change in stubble architecture. However, the resulting information is limited to a handful of seasonal conditions at certain locations.

To complement these experimental and observational efforts, CSIRO is using its Agricultural Production Systems sIMulator (APSIM) computer model to build on this knowledge base. Algorithms are being developed that can extrapolate stubble architecture impacts to other sites (starting with southern New South Wales) and against 30 years of climate data.

The simulations are being run with the APSIM NextGen SWIM soil-water balance model that was released in October 2022. It has enhanced capabilities when it comes to predicting the near-surface water balance and temperature dynamics. It will be used to run comparisons of taller versus shorter retained stubble within multi-year cropping simulations.

Since APSIM includes crop growth models – as well as soil water, nitrogen and management models – it can account for the interacting effects of climate, environment and agronomic practices.

The simulations are designed to mimic real-world trials right down to having to consider the impact of possible confounding factors, such as different weed loads. Unlike real trials, however, the virtual experiments are less constrained by time, budget or location, allowing many more scenarios to be explored as well as sampling a wider range of seasonal conditions.

The project started in June 2022 with a preliminary focus on ensuring the model can accurately simulate experimental trial results. This model-verification step is still under way, with ongoing work focused on ensuring the model can dig down to impacts at the level of the stubble's 'micro-climate'.

Information about stubble micro-climates is being generated by a team from project partner Charles Sturt University, including Dr Philip Eberbach, Dr John Broster and Dr Ketema Zeleke as well as several honours students. This work has shown a dramatic drop of wind speed within the stubble can contribute to changes in evaporation and soil moisture.

Once fully calibrated, the modelling will host virtual trials, with discussions underway with project collaborators about the variables they would like to see included. This phase is expected to start in the second half of 2023.

The aim is to complement growers' own observations about paddock impacts associated with adopting stripper headers and help build a broader understanding of where and when stripper headers are most beneficial. □

GRDC Code CSP2203-006RTX

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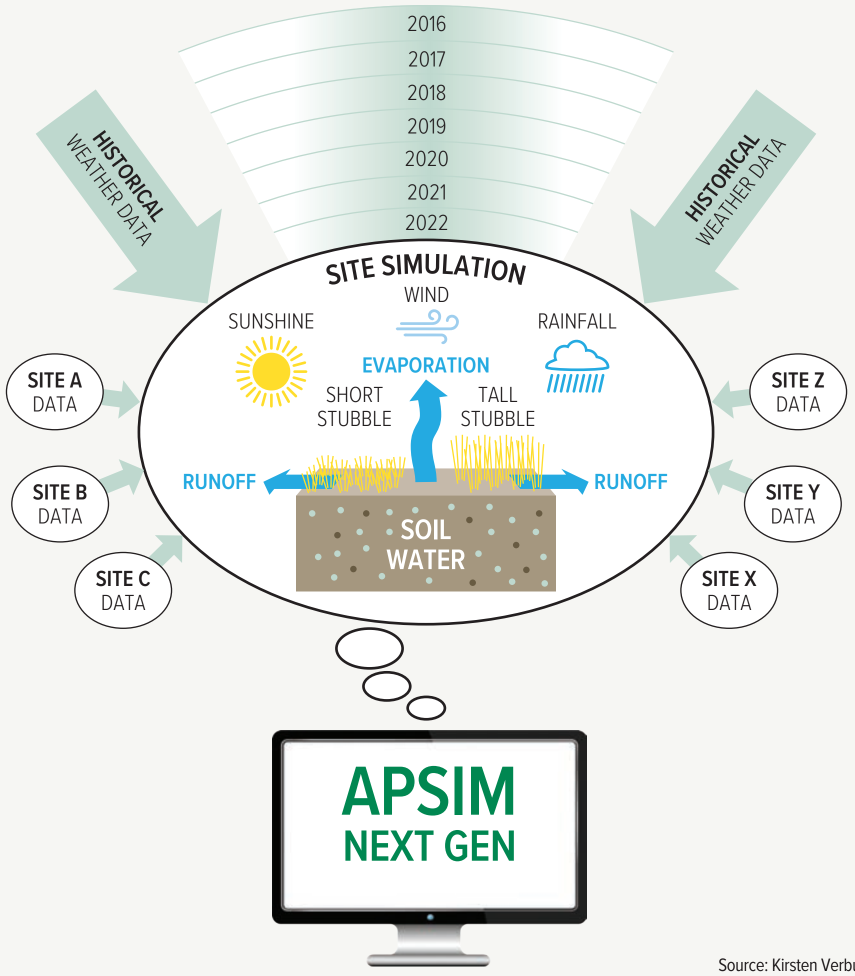
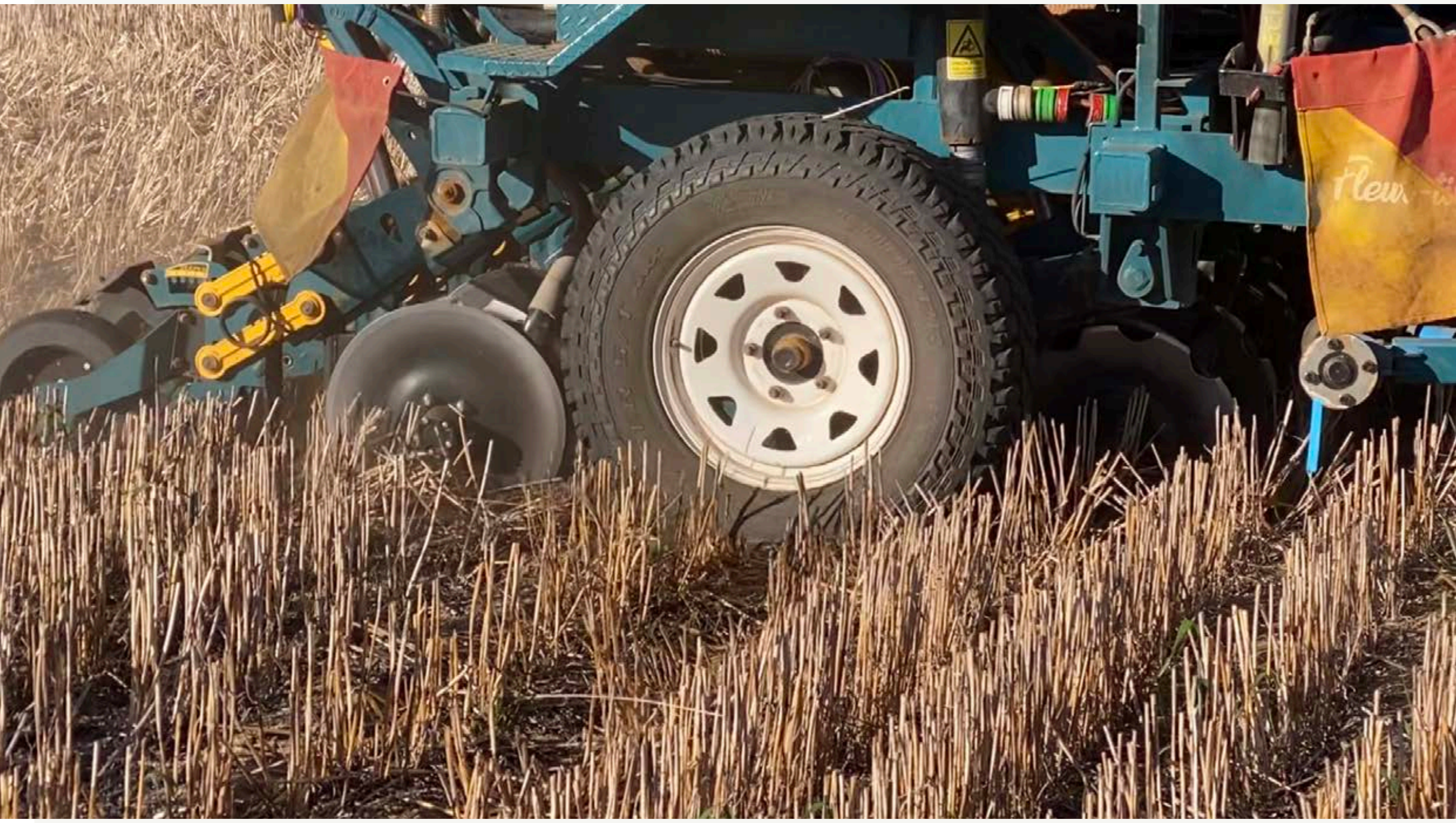
Figure 1: Simulations using the APSIM NextGen SWIM soil-water balance model can run many replicated virtual trials in order to assess impacts from taller stubble on soil water against broadscale variation in soils, rainfall and cloud cover.



Source: Kirsten Verburg



The disc seeder used in this project is a RYAN NT double disc system.

Photo: Grant Thompson

Weed control in high standing residue

A guide to safe and effective chemical weed control is being produced for farming systems in Western Australia's northern agricultural region, where maximum standing stubble is retained as protection against wind erosion

By Grant Thompson

Crop Circle Consulting

In the northern agricultural region (NAR) in Western Australia there are some growers already implementing either disc seeding or stripper front harvest, with a few implementing the complete 'strip and disc' system. While it is important to understand all of the impacts associated with changing from a short to a tall retained stubble system, in the NAR there is a strong emphasis on weed control.

Growers want to be confident they can maintain weed control if they maximise stubble retention with a strip-and-disc system. Currently, the main concern or limitation is the efficacy and safe use of grass pre-emergent herbicides.

A project is under way to assess the efficacy, crop safety and longevity of old and new pre and post-emergent herbicides to control weeds in a range of crops using a disc seeding system. This investment aims to provide growers in the NAR with an understanding of the implications of changing harvest systems to implement a tall standing residue strategy for weed control.

Trials in four locations across this region from Mingenew to Ogilvie are comparing 17 different herbicide treatments in wheat, canola and lupins in a range of soil types. In year two, the trials also include droplet deposition and herbicide efficacy into stubble with three different heights. The project primarily targets annual ryegrass and wild radish, with a secondary focus on brome grass, capeweed, doublegee and wild oats.

THE 2022 FINDINGS

The 2022 trials involved treatments being applied immediately before sowing and/or early post-emergent, with disc seeding being compared with the standard practice of using knife-points and press-wheels.

The trials measured crop establishment, phytotoxicity and vigour, and weed control. All trials were taken through to harvest for crop yield and grain quality measuring. Normalised difference vegetation index (NDVI) assessments were completed at eight weeks after sowing to calculate any differences between the crop canopies.

Overall, the knife-point and press-wheel plus herbicides approach resulted in the highest level of plant establishment and early crop competition in all trials. In most cases this also resulted in the highest level of weed control and resulting grain yield.

The trial also found some safe combinations of pre and post-emergent herbicides that would provide acceptable levels of grass and broadleaf weed control in disc seeding. This was particularly the case in wheat.

It would appear, however, that some herbicides should not be used in disc seeding systems. Luckily, the kind finish to the 2022 season allowed the reduced plant density plots to recover and produce grain yields that did not reflect the early crop injury caused by more-aggressive herbicides.

The lupin trial at Yuna showed that, irrespective of herbicide treatment, seed bed moisture levels and proximity to follow-up rainfall are important for lupin establishment with disc seeders. In this trial, the knife-point/press-wheel seeding system achieved superior plant establishment and crop safety in marginal moisture.

The canola trial at Ogilvie showed that without any incorporation of herbicides from soil throw, the pre-emergent herbicide treatments were not sufficient to control a high infestation of ryegrass. Canola in disc seeding systems will be heavily reliant on post-emergent spraying to control grass weeds.

Similar to the lupin trial at Yuna, this trial highlighted the importance of follow-up rainfall on top of disc seeding in light sand to achieve a good level of plant establishment.

The project will continue into the 2023 season, researching droplet deposition and application of herbicides on to different stubble heights, green-on-brown spot spraying in different stubble heights, and knockdown and pre-emergent herbicide efficacy, followed by disc seeding in wheat. ☐

GRDC Code CRP2201-001SAX

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Photo: Grant Thompson

Drone image of a field trial on the establishment of canola in strip-and-disc versus knife-point and press-wheel seeder systems in short stubble. The trial is exploring nitrogen strategies and the effect of tillage and stubble on weed control.

Photo: Grant Thompson

Disc seeder versus knife-point seeder furrows after seeding a pre-emergence wheat herbicide trial.

Intricate stubble-crop ecosystem relationships revealed

The establishment of certain crops can result in both in-crop and post-harvest weed suppression irrespective of the presence or absence of post-emergent herbicides during the growing season


Photo: CSU

James Mwendwa assessing the weed suppressive potential of a competitive wheat crop that produces more residue compared with common commercial cultivars.

By Leslie A Weston and Saliya Gurusinghe

Charles Sturt University

■ Stubble residue can play both a physical and a chemical role in weed suppression.

This means there are opportunities to exploit crop rotation and stubble management choices to further enhance these weed suppression effects.

The research supporting these findings comes from a cross-disciplinary team at the Plant Interactions Research Group at Charles Sturt University. This team investigates the complex relationships and exchanges that occur in the paddock among plants, weeds, the soil microbiome, insects, stubble residue, soil nutrients and the chemical compounds that mediate allelopathic effects.

Based in New South Wales at Wagga Wagga, the trial paddocks typically produce wheat, barley, canola, oat and lupin broadacre crops, as well as legume and other cover crops used for biological diversity and weed suppression.

Increasingly, growers are adopting intercropping and mixed cropping systems, with particular interest currently in summer cover crops such as teff and buckwheat. This has resulted in an increasing mix of stubble residue and typically high stubble loads (six to seven tonnes per hectare in 2022).

In these circumstances, research is finding that retained stubble plays a more intricate role in paddock ecology than first envisioned.

People are generally surprised to learn that residue roots continue to live for a significant period after the crop is harvested. They also continue to be physically present even after they stop taking up moisture. Rainfall, therefore, can continue to saturate the root channels in the zones underneath crop stubble, which helps fashion soil characteristics in unique ways.

Above ground, too, the residue is sculpting its environment. Work by collaborators at Charles Sturt University, John Broster and Michael Walsh, has examined micro-climatic effects across different types of stubble architecture that result from draper versus stripper headers. They have detected temperature differences on the ground that clearly affect weed seed distribution and emergence.

Overall, the research team is seeing stubble residue providing unique micro-climates above and below the soil surface that can have both beneficial and detrimental impacts.

One striking example relates to decomposing residue. It is broadly understood that soil microbiota can use up nutrients very quickly from the soil profile in order to decompose a large stubble load, which causes a shift in soil nutrient dynamics. However, observations indicate that both the above and below-ground residues can continue to exude or leach interesting, natural plant products – even phytotoxins – that affect the soil microbiome, weed seed germination, soil pathogens and even insects.

The team's work on bioactive natural plant products is particularly focused on bioherbicides and phytotoxins, as well as molecules that could have growth-stimulating properties. Advanced analytical techniques that include separation science, metabolomics, genomics and also population and field ecology are used to investigate the plant and its soil rhizosphere.

What has emerged is a view of plants as being far less passive than previously thought. Our crops deploy chemical signalling agents in complex ways, including:

- as defence strategies against a range of pests, including weeds and grazing herbivores;
- to strategically localise these metabolites in the plant and soil rhizosphere, often for crop protection; and
- as signals that affect the function and dynamics of soil microbial communities.

The team's recent studies have focused on plant toxicity to grazing livestock and the specific mode of action of residue chemicals (both stubble and roots) that function as herbicides, cytotoxins and photosensitisers. For example, residue from wheat, rye, barley and numerous summer annual cover crops have been seen to produce leachates in the soil surface that contribute to weed suppression.

Understanding and characterising the chemical nature of these compounds or metabolites now forms a strong research focus into the future. The goal is to optimise crop rotation choices and stubble management practices to better exploit the crop residue's own ability to suppress weeds. □

GRDC Code UOS1703-002RTX

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Photos: CSU

Summer cover crops: teff; vetch; and white French millet.

WEED SUPPRESSION TRIALS

The ability of various dual-purpose grazing or non-grazing grain crops – and their residues – to suppress weeds during the summer fallow has been investigated. This research includes two successive field experiments in the Riverina region of New South Wales.

Researchers observed significant weed suppression associated with grazing and non-grazing wheat residues, both pre and post-harvest. Grazing wheat exhibited significant suppression of fleabane and witchgrass up to 130 days post-harvest. Grazing and non-grazing canola provided strong and significant suppression of fleabane and witchgrass for up to 140 days following harvest. Interestingly, these crops did not have as much residue remaining on the soil surface as other, less-weed-suppressive cereal crops in post-harvest measurements.

Grazing cultivars were generally more weed suppressive than the non-grazing cereal cultivars evaluated. Grazing oats also tended to be initially suppressive, but long-term suppression of weeds (until planting the following season) was not always observed.

Soil analyses performed in late March indicated that the observed differences in weed establishment were not likely to be reflecting differences in soil moisture availability.

Results suggest that establishment of certain cultivars could effectively suppress weeds both in-crop and post-harvest. The effect is detectable both in the presence or absence of post-emergent herbicide use. It affects problematic post-harvest weeds such as fleabane and witchgrass.

These findings also suggest that cultivar and/or cereal crop choice is an economical form of weed management due to in-crop competition and possibly other factors, such as allelochemicals (weed suppressive chemicals).

Currently the project is evaluating soil samples for the presence of isothiocyanates and glucosinolates associated with weed suppression in *Brassica spp*. and hydroxamic acids present in wheat, rye or barley residues. This will determine whether the presence of canola or certain cereal residues are associated with higher levels of these suppressive chemicals via allelopathy.

Differences were also observed in weed numbers when comparing stubble produced by stripper and draper treatments. The stripper treatments had lower weed numbers compared with the draper treatments. The weeds observed were mostly sowthistle, but also fleabane, crumbweed, cudweed and hairy panic.

In addition, six years of research involving numerous long-term rotations with 10 different cereal and pulse crops has shown that both the crop before harvest and the residues can contribute significantly to out-compete weeds over time. This results in reduced inputs into the soil seedbank over time under typical rainfall and soil moisture profiles.

Trials to fine-tune canola-on-cereal stubble strategy

A new project is examining issues around canola establishment into high cereal stubble loads in the Wimmera, Victoria.

By Ashley Wallace
Agriculture Victoria

While stubble retention has provided a multitude of benefits to Wimmera growers, heavy cereal stubble loads in recent seasons have created new challenges, particularly for canola establishment.

These kinds of trends are captured by Agriculture Victoria and the Wimmera Catchment Management Authority, which conduct land management surveys across the Wimmera twice a year. The data revealed that 35 per cent of canola is grown on cereal stubble. For half of these paddocks, the cereal stubble is actively managed through burning, cultivation, windrow burning or some other form of disturbance prior to sowing canola.

Previous research and grower experience indicate that high stubble loads can affect canola establishment due to factors including:

- the impediment to sowing operations;
- inaccurate seed depth placement;
- shadowing of emerging seedlings and loss of early growth and vigour;
- chemical tie-up; and
- stubble-based harbouring of pests (such as slugs).

In response, GRDC has invested in a new project to help growers mitigate risks to canola establishment following high-production years.

The project is designed to deliver a two-year field trial that will demonstrate the effects of a variety of stubble management and sowing systems on canola establishment. It is led by Agriculture Victoria, in collaboration with the Wimmera Catchment Management Authority, Arapiles South Ag Group and the Wimmera Farming Network.

TRIAL DESIGN

The researchers sought input from Arapiles South Ag Group members when deciding on the trial design. They provided local expertise to guide selection of stubble and sowing systems, as well as general agronomic management.

The team has subsequently established a trial at Douglas in the southern Wimmera. Canola represents about one-quarter of the cropped area in the district, where there is a high potential for heavy cereal stubble loads.

The trial will allow canola performance to be compared against different stubble treatments, including:

- varied height of cutting;
- stubble mulching;
- baling of stubble for straw;
- burning; and
- added straw to simulate an even-higher-yielding environment.

Sowing treatments will include a comparison of tyned versus disc machines and the inclusion of row cleaners.

The project also involves a survey of canola establishment in paddocks across the Wimmera relative to stubble management and sowing system to benchmark current practices.

A key focus of the project is communication and extension, with findings to be promoted through GRDC and Agriculture Victoria networks.

This includes local workshops, with the first event focusing on slug management and its interaction with stubble held in February.

Future events will include a post-emergence field day to demonstrate performance of the various systems.

A decision-making guide will also be developed focusing on rapid assessment of stubble load, stubble condition and potential management options. □

GRDC Code DJP2204-006RTX
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Harvesting wheat to provide different stubble treatments prior to sowing canola in 2023.

Photo: Felicity Pritchard

Stripper-disc systems in the high-rainfall zones

High stubble loads in the high-rainfall zones have proven challenging for the adoption of stripper-disc systems

Photo: P. McIntyre

Stripper front in action at a trial site in Willaura, western Victoria, where management of heavy stubble loads is being investigated.

By Audrey Gripper
Southern Farming Systems

Wet conditions in 2022 delayed the start of a new project that aims to explore the use of stripper-disc systems to reduce stubble loads in south-west Victoria and Tasmania.

In these high-rainfall zones, stubble can reach levels as high as 15 tonnes per hectare.

The high stubble loads mean that many growers use conventional header fronts when harvesting and burn cereal stubble prior to seeding or bail the excess straw. Some growers will plough stubble to reduce loads further if the burn was poor.

However, most growers remark that if there were any other options besides burning that they could use to reduce their stubble loads effectively and economically, they would be doing them.

This project will explore grower interest in stripper-disc systems and their viability in the high-rainfall zones.

Talks with growers and agronomists are ongoing to establish quality trials that are relevant to growers' interests and current practices.

Recently, the first stripper front trial was established at Willaura. It will look at three factors:

1. **header front type (stripper versus conventional);**
2. **stubble management practice (retained versus incorporated); and**
3. **seeder type (disc versus tyne).**

All involved with the trial have been impressed with the stripper front and its efficiency in harvesting a lodged wheat crop. However, the manner in which longer stubble affects operations and the crop over the next two seasons will be the real test.

Issues that need to be explored include concerns around there being fewer herbicide chemistry options when using disc seeders.

This is critical since weeds are a massive issue for growers in the high-rainfall zones and several newer chemistry options are not on-label to be used with disc seeders due to lack of separation between chemical and seed.

Establishment rates with disc seeders versus tynes will also need to be closely examined since disc seeders can more easily pull through stubble without it getting caught and dragging.

In wet conditions, that can cause disc seeders to just make a slot for the seed, whereas tynes are able to get a bit deeper to create a furrow, which is a better seedbed. □

GRDC Code SFS2112-002SAX

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TRIALS INTERRUPTED

The planned field trials for 2022 had to be delayed as the paddocks selected for this work fell through at the last minute due to circumstances beyond anyone's control. The project experienced a heavy rain event the day before a paddock was to be sown, which resulted in the paddock being inaccessible to seeders.

Due to the lateness in the season and potential further accessibility issues, it was agreed that the trials would be relocated to paddocks that were due to be sown in the spring. In Tasmania in particular, spring sowing is very common, particularly into barley. While it is less common in south-west Victoria, spring sowing is quite prevalent.

Staying ahead of canola blackleg

Blackleg disease is constantly changing with respect to the effectiveness of genetic resistance and disease epidemiology – as well as through changes in stubble management

Photo: Marcroft Grains Pathology

Glasshouse-based experiments have found that canola cultivars with no effective major gene resistance can nonetheless have underlying 'quantitative resistance' to blackleg upper canopy infection.

By Steve Marcroft, Angela Van de Wouw, Marcroft Grains Pathology and Alexander Idnurm

Marcroft Grains Pathology / University of Melbourne

Blackleg disease, caused by the fungal pathogen *Leptosphaeria maculans*, is a stubble-borne disease that leads to seedling, crown canker and upper canopy infection. Blackleg disease is minimised through a three-pronged approach of genetic resistance, cultural practices (including stubble management) and fungicides.

With investment from GRDC, a collaboration between the University of Melbourne, Marcroft Grains Pathology and CSIRO is working to improve management strategies to reduce the impact of this disease through molecular and field-based approaches.

Central to this analysis was the establishment of 32 monitoring sites across canola-growing regions in association with the National Variety Trials program. The project uses canola cultivars that represent different resistance groups (which harbour different complements of major resistance genes) and monitors them for changes in disease severity.

The project is near completion, with the data from the past five seasons pointing to some key findings.

CHANGES IN STUBBLE MANAGEMENT

As long as stubble stays intact, it will release blackleg spores within the growing season. In fact, spore release has been measured from canola stubble that is four years old. This means stubble quantity (rather than stubble management) has the largest effect on blackleg disease. However, blackleg will release fewer spores as the stubble and the fruiting bodies age.

An increase in area cultivated with canola will result in increased canola stubble and, therefore, increased blackleg spore density. Spore density typically (but not always) results in increased disease severity. The increase in the area of canola stubble also reduces the ability of growers to maintain a 500-metre buffer between one-year-old stubble and current crops.

Seasonal conditions will then influence whether crown canker or upper canopy infection (UCI) will be more significant and potentially warrant control. It will be rare to have severe forms of both versions of blackleg in the same year.

- Crown canker years occur from late sowings, which results in plants remaining as seedlings during the winter infection period.
- UCI years will likely arise from early sowings, which result in plants starting flowering in late July to early August. Early flowering will result in increased infection and will give the fungus more time to cause damage prior to harvest.

Overall, the canola industry is likely to become more reliant on fungicides due to increasing canola production. However, the decision to use a fungicide is not clear-cut. Growers must first understand their crop's disease risk profile.

Prior to sowing, the BlacklegCM decision support app can be used to identify high-risk paddocks and explore management strategies to reduce yield loss.

Fungicide application for UCI is a separate decision-making process from crown canker control. UCI fungicide application can result in very variable yield returns.

Blackleg lesions on canola leaves.

Blackleg infection on a canola flower.

Growers must first understand their crop's disease risk profile.

STRATEGIES TO CONTROL UPPER CANOPY INFECTION

UCI refers to the development of blackleg lesions on the upper stem, branches, flowers and peduncles.

Trials have shown that the 30 per cent bloom fungicide spray timing is effective at minimising the severity of UCI.

While fungicides reliably reduce disease levels, the likelihood of the fungicide giving a yield return varies dramatically. Data suggest that thermal time, water stress and genetic resistance could all be contributing to the ability of a fungicide application to generate a yield response.

Further investigations are underway to determine the factors contributing to yield responses, which will then be incorporated into the BlacklegCM app.

Additionally, glasshouse experiments at Horsham and Canberra under controlled environments (using individual fungi isolates) found additional effects worth noting. These findings relate to cultivars with no effective major gene resistance (MGR). Field observations had previously led to assumptions that these cultivars are all equally susceptible to UCI. However, data now suggests that there is underlying genetic 'quantitative resistance' to UCI, which acts in a similar manner to the control of crown canker.

Further investigation in 2022 in the glasshouse and field confirmed that the presence of quantitative resistance is effective against UCI, with all commercial cultivars now undergoing screening. The aim is to produce UCI blackleg ratings for all commercial cultivars.

That means cultivars lacking effective MGR might still have useful quantitative resistance and are not as susceptible to UCI as initially thought. This could contribute to variability in yield returns when fungicides have been applied to minimise disease.

MONITORING MAJOR GENE RESISTANCE

While MGR effectively minimises blackleg disease, the blackleg can rapidly evolve to overcome resistance, especially when MGR-harbouring cultivars are sown in multiple consecutive years.

Monitoring at 32 trial sites is providing data relating to which resistance genes are effective in various canola-growing regions. This regional data is released annually and can be found at marcroftgrainspathology.com/index.php/resources.

An example of how this monitoring works occurred in 2020 when data indicated that Group H resistance was being overcome in the Hamilton region in western Victoria. Molecular analysis of the isolated fungi revealed that they harbour virulent mutations.

Discussions with the affected grower found that the Group H cultivars had been sown for a number of years there as a grain-and-graze option.

In 2021 and 2022, the following was found:

1. **resistance Groups A, B and C were ineffective in all regions;**
2. **blackleg resistance Group BF was effective at three sites and in the process of being overcome at an additional 13 sites; and**
3. **blackleg resistance Groups AD, ABDF and H were effective at almost all sites.**

While our monitoring data can be used to complement grower decisions, we recommend that growers monitor disease levels in their own paddocks to determine whether the MGR in their cultivars is effective. See the *Blackleg Management Guide* for additional details on best approaches for monitoring a paddock. □

GRDC Code UOM1904-004RTX

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All current management strategies and advice regarding blackleg can be found in the *Blackleg Management Guide* (grdc.com.au/GRDC-FS-BlacklegManagementGuide), which is updated biannually, as well as the BlacklegCM app, available for Android and Apple users.

Sclerotinia transmission across a crop rotation

How Sclerotinia moves from canola stubble into the whole of a farm's crop rotation is under investigation in the northern and southern growing regions with the aim of learning how to manage or possibly break the disease cycle

Photo: Nicole Baxter

Kurt Lindbeck is heading a new national Sclerotinia project to study disease dynamics across entire cropping rotations and farming systems.

By Kurt Lindbeck

NSW Department of Primary Industries

■ Modern farming systems that direct drill into retained stubble are able to capture numerous productivity benefits. The stubble, however, can promote the build-up of certain fungal pathogens.

Among the most problematic are Sclerotinia species due to their ability to infect all broadacre crops and large numbers of weeds, with a total host range of about 400 plant species. Additionally, the fungi can form hard black survival structures – called sclerotia – on and within stubble. Sclerotia are about the size of cloves and allow the fungi to survive in a dormant state in soil and plant residue for upward of five years.

These two characteristics mean that Sclerotinia fungi can be ticking away, unseen, waiting to re-emerge when conditions are favourable – particularly prolonged wet conditions in late winter and spring. The fungi can then rapidly reach damaging levels within susceptible crops.

The yield losses due to Sclerotinia can be costly. Previous research has documented losses as high as 30 to 35 per cent in canola. And while canola is an especially good disease host, impacts can spill over to the next susceptible crop in a rotation.

For example, in preliminary findings, yield losses of up to 25 per cent were detected in narrow leafed lupin sown into previously infected canola stubble at Wagga Wagga in 2022. The same experiment also detected a staggering sclerotia production load estimated at up to 200 kilograms per hectare following the lupin crop. These results demonstrate the potential legacy-effect of a Sclerotinia epidemic on future crops in the rotation.

To better understand the cross-rotation

Photo: Nicole Baxter

The Sclerotinia project will focus on field studies and include monitoring of commercial pulse crops and collection of infected pulse material to better understand infection pathways.

Photo: NSW DPI

Sclerotinia fungi can form survival structures called sclerotia that allow the pathogen to remain in a dormant state in soil and plant residue for upward of five years.

impacts of the disease, GRDC has invested in a new national Sclerotinia project to study disease dynamics across entire cropping rotations and farming systems. Work commenced in 2022 led by the NSW Department of Primary Industries with the aim of developing strategies to reduce inoculum loads, manage disease outbreaks and reduce yield losses.

Given the scale of this project, the research is being undertaken as a collaboration that involves activities in SA, Victoria, NSW and Queensland. These studies will have a strong research focus on five pulse crops: lupin, faba bean, chickpea, lentil and peanut (see Table 1).

The project will focus on field studies in the northern and southern growing regions and include the monitoring of commercial pulse crops for disease development and collection of infected pulse material to better understand infection pathways. Measurements of the 'in-crop' incidence and severity of Sclerotinia disease will be taken and estimates of yield loss calculated.

As a picture emerges of in-field infection pathways, additional work will be undertaken. Included are glasshouse experiments that can mimic disease pathways from the field and allow for controlled testing of strategies to break or reduce disease transmission.

Table 1: A multi-state project to break Sclerotinia disease cycles across crop rotations is underway.

Partner	Crop focus	Study sites
Kurt Lindbeck and Ian Menz NSW DPI – south	Lupin, chickpea, faba bean	Southern NSW – South-west Slopes and Riverina
Sean Bithell NSW DPI – north	Chickpea	Central NSW – Trangie
Josh Fanning Agriculture Victoria	Lentil, chickpea, lupin	Victoria – Wimmera and Mallee
Steve Marcroft Marcroft Grains Pathology	Canola	Victoria – Wimmera and Western District
Sara Blake SARDI	Lentil	SA – Mid North and Yorke Peninsula
Kylie Wenham University of Queensland	Peanut	Queensland – Darling Downs and Granite Belt

Laboratory studies will also be undertaken to further investigate the production of sclerotia from plant residues collected from the field to improve our understanding of sclerotia production in the field during non-host crop years.

Examples of potential new disease management strategies that will be tested through the life of this project include:

- practices to change crop canopy architecture or the timing of canopy development in order to delay or avoid disease onset;
- understanding the optimal timing of fungicide application for the different legumes; and
- modifications to crop rotations to avoid the build-up of sclerotia.

The project aims to have solid recommendations for growers available no later than 2026, with findings communicated as soon as they are available through channels that include GRDC Grower and Advisor Updates and Field Days, such as those conducted at the Wagga Wagga Agricultural Institute. ☐

GRDC Code DPI2206-023RTX

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Mice control in the era of no-till

Trials have investigated the potential of mechanical stubble management options to control mice numbers

By Wendy Ruscoe and Peter Brown

CSIRO Health & Biosecurity

Photo: Peter Brown, CSIRO

Mouse moving about under crop stubble.

■ The recent transformation in cropping practices from conventional to conservation agriculture (CA) has changed the population dynamics of mice. Paddocks now appear to provide a year-round safe environment for mice, which includes undisturbed nesting sites and shelter provided by standing stubble. Overall, the shift has created large areas of the landscape where mouse populations can increase and potentially form plagues.

There is a long history of house mouse (*Mus musculus*) outbreaks in Australian grain growing regions where considerable damage occurs. However, current management regimes for mice are based on work undertaken before CA was commonly used. Some strategies even target mouse populations in refuge areas that were used by mice following paddock ploughing.

Given the multiple benefits of CA, it is unlikely growers will consider ploughing their fields to manage mice. Therefore, other modifications to CA practices could be required to minimise the benefit of this system to pest rodents.

Long-term studies have been undertaken of mice populations at Walpeup, Victoria, to lay the groundwork for these innovations. These studies have provided detailed knowledge of mouse ecology, demographic changes, spatial behaviour and disease ecology. The important drivers of mouse population dynamics are rainfall and habitat characteristics that affect the availability of food supply and nesting sites.

Trials are now underway with GRDC investment to inform best-practice mouse management strategies. A replicated before–after design was used to examine how cropping practices affect population densities of mice and their individual movements (using data from radio-tracked animals).

During the 2020-21 mouse plagues, various stubble management practices were compared which included stubble mulching, mechanical management (cabling, chain rolling or slashing) and burning. Mouse trapping and radio tracking were also used to assess the effect of harvest and stubble management practices on the distribution and abundance of mice.

It was expected that the physical disturbance and/or reduction in habitat complexity associated with harvest and subsequent stubble management would lead to:

1. **reduced mouse abundance in paddocks following harvest;**
2. **individual animals leaving the paddock to areas potentially more favourable; and**
3. **reduced mouse abundance in paddocks following stubble management (flattening).**

FIELD TRIALS

Paddocks were harvested by growers within a few days of each other in early December. Crops were less than one metre high, with near-total canopy cover. Following harvest, the remaining stubble was about 20 centimetres high, with about 30 per cent canopy cover remaining (Figure 1A).

Stubble management was undertaken using a prickle chain, disc chain or Ajust-A-Bar®. All three methods involved a tractor pulling a set of chains or discs across the ground, resulting in stubble being cut and laid across the ground to a height of less than 5cm (Figure 1B). There was a small amount of soil disturbance, but not enough to affect burrows.

HARVEST IMPACTS

Following harvest, more than 90 per cent of radio-collared mice that survived the harvest operations remained resident (using burrows) in the paddocks. Two radio-collared mice were found to be dead in shallow burrows we dug up under a harvester's wheel tracks, and two animals could not be located on or near the trapping grids a week after harvest. Either they had left the area or their transmitters had failed.

From our trapping studies, it was estimated a 41 per cent reduction in the population size immediately following harvest (Figure 2), but this might have been due to a temporary reduction in the research team's ability to trap mice related to the disturbance of harvest machinery.

STUBBLE ROLLING IMPACTS

On average there was no real change in mouse density across the six sites as a result of stubble rolling (Figure 3). Population estimates peaked with a mean of 1200 mice per hectare, which is considered to be a plague. Even if the mechanical process of crop harvest kills some animals and/or induces other animals to leave the harvested area, the effect is temporary. It is also not sufficient to overcome the natural population increase at this time of year or prevent re-invasion by animals once the harvest disturbance has abated. Spilled grain remaining on the ground following harvest presents a bountiful food supply for mice.

Previously, studies have shown that mice will select increased habitat complexity and vegetative cover to reduce predation risk. In contrast, however, it was found that stubble rolling itself did not cause a consistent emigration of mice (mouse numbers increased on three out of six sites). Mice were seen running both above and underneath the flattened stubble. The stubble rolling did not appear to have sufficiently altered the above-ground habitat (overall did not reduce plant biomass) and the burrows remained intact, making it an unsuccessful management practice.

Another option for managing mouse populations is to reduce food availability. This could be achieved by minimising the amount of grain left on the ground after harvest by improving harvesting machine efficiency or using 'seed destructor' technologies.

Other approaches to reduce the amount of spilt grain is to graze the stubble post-harvest, if livestock are part of the enterprise. A light tillage post-harvest could bury some remaining food sources, making it harder for mice to find, but is unlikely to provide additional benefit via burrow disturbance. □

Photo: Peter Brown, CSIRO

Mouse with a radio collar about to be released into a wheat paddock. Mice can be tracked with a special radio receiver and antenna to trace their movements at night and location of their burrows during the day.

GRDC Code CSP1806-015RTX

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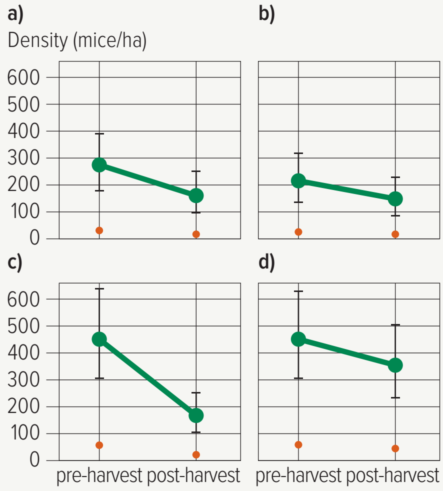
Mouse management guide: grdc.com.au/resources-and-publications/resources/mouse-management

Photo: Peter Brown, CSIRO

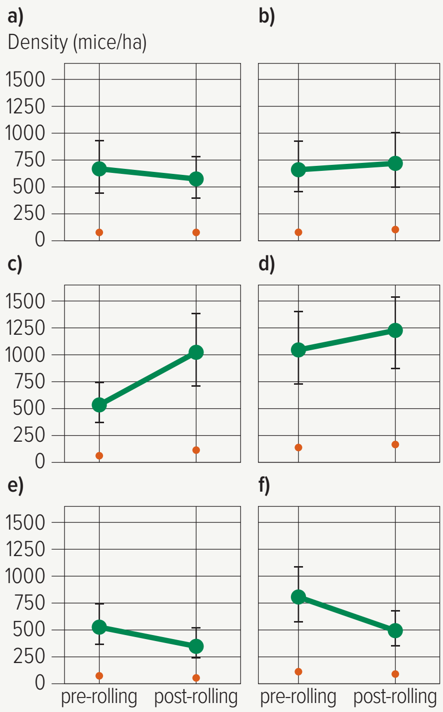
Obvious mouse runways leading between mouse burrows in cereal stubble. These burrows remained active after stubble rolling.

Figure 2: Change in mouse density (number of mice/ha) from pre-harvest to post-harvest on four farms.



Source: CSIRO Health & Biosecurity, Canberra

Figure 3: Change in mouse density (number of mice/ha) from pre-rolling to post-rolling on six farms.



Source: CSIRO Health & Biosecurity, Canberra

Figure 1: Photos taken at various stages of crop height treatment on our study sites. a) Pre-harvest, b) post-harvest and c) post-rolling.

a) b) c)

a) Mature pre-harvest crop, 1m high

b) Post-harvest (pre-rolling) stubble, 25cm high

c) Post-rolling stubble, less than 5cm high

Source: CSIRO Health and Biosecurity, Canberra

Case studies show the value of proactive soil protection

By Tanja Morgan and Chris McDonough

Mallee Sustainable Farming / Insight Extension for Agriculture

■ By helping to bind soils together, no-till farming systems help to mitigate erosion risks in ways that boost a farm's sustainability. These benefits are especially valuable given the tendency of Australia's climate to cycle between extremes of drought and floods.

Maintaining groundcover during these extremes, however, can be challenging. Yet, such seasons have provided growers with a living laboratory in which to watch, learn and test methods to protect groundcover until the rain arrives (or the floods recede).

To capture, curate and disseminate these on-farm lessons, GRDC invested in producing a series of on-farm wind erosion case studies. These convey practical tactics to both protect a farm from soil degradation during successive years of drought and rehabilitate the land back into production if blowouts occur.

In all, eight case studies (covering 32 paddock monitoring sites) were produced and can be viewed at the GRDC website (see link below).

The study sites were based in the low-rainfall zones of the southern region, including the Victorian and NSW Mallee and the Eyre Peninsula, which were affected by successive dry years in 2018 and 2019.

A key message that emerged from these studies is the need to maintain at least 50 per cent anchored soil cover. Dropping below 20 per cent makes soils extremely vulnerable during dry years.

Maintaining this level of cover requires vigilance and a proactive approach. Monitoring the levels of groundcover and stored moisture is recommended in August/September and again in autumn – annually. These assessments then drive a strategic management decision between three options:

- continue the normal management plan;
- stabilisation: take strategic decisions to protect vulnerable soils and minimise risks; or
- full reclamation: soil levelling and sand amelioration.

Proactive management of vulnerable zones within paddocks is possible and can prevent large rehabilitation costs and long-term production losses. For example, sandy zones should be fixed with delving, clay spreading, spading and so on. Additional tactics then depend on the nature of the farming system.

FOR CONTINUOUS CROPPERS

1. **Pay attention to existing cover levels, particularly with late breaks and low stored moisture levels. Satellite technology can now assist with monitoring.**
2. **Maintain soil organic matter, clay fines and soil fertility.**
3. **Watch your wheel tracks and other trigger points for blowouts and resow where needed.**

FOR MIXED FARMERS

1. **Identify the paddocks with the least vulnerable soils and target these for more summer and autumn grazing.**
2. **Sowing summer crops late in the season can provide safe, productive summer and autumn grazing.**
3. **Take a proactive approach to confinement feeding and feedlotting rather than using them when it is too late.**

At Walker Flat in SA, Phil, Yvonne, Aaron and Liz Haby farm 4000 hectares. They maintain 1000 breeding ewes and cultivate cereals and legumes on about 3000ha using no-till on their erosion-prone sandy soils.

In 2020, a large blowout area quickly got out of control after a heavy traffic strip was further exacerbated by the combined effects of sheep camping around a trough area, low rainfall and strong winds (Photo 1). Despite a late season break and minimal rainfall throughout the year, the Habys were confident they would still achieve adequate groundcover to rehabilitate the site.

The Habys used their 4.5-metre-wide O'Brien Laser Bucket that holds about 13m^3 soil (or about 25 tonnes when full) to drag, shift and level the blowout sand area (Photo 2). They pulled it with a 425HP dual-wheeled articulated tractor. They cut through the centre of the blowout area to establish an even grade line, filling in holes, knocking down ridges and then working each side to level the area. The first levelling operation brought plenty of moist sand to the surface (due to soil being essentially fallowed since mid-2020) and this moisture assisted in crop establishment.

The area then had 10t/ha of chicken manure spread over the surface. The site developed a crusty surface layer that protected the sand from blowing during the early crop establishment phase. The surface sand dry aggregation (DA) measured a very low 5 per cent in March 2021. After levelling, spreading manure and seeding, this site showed a safe 35 per cent DA by December of the same year.

The area was sown to barley but the crop suffered erosion damage and was cross-sown using a disc seeder with Vampire⁽ᵇ⁾ cereal rye to maximise soil coverage. The cereal rye established well after good July rains and continued to grow, producing adequate biomass (Photo 3) and providing sufficient soil cover through the following summer, with no erosion (Photo 4) despite only 130 millimetres of growing-season rainfall. This strategy helped the Habys to maintain more than 50 per cent soil cover from December 2021 to May 2022 at this site.

No grazing on the rehabilitated area will be undertaken in the foreseeable future and the traffic lane has been diverted to a different route.

In 2022, the area was resown to another cereal to establish a strong root base in the topsoil, which resulted in a well-anchored standing stubble for the second year in a row. The Habys are now confident this paddock will

CASE STUDIES

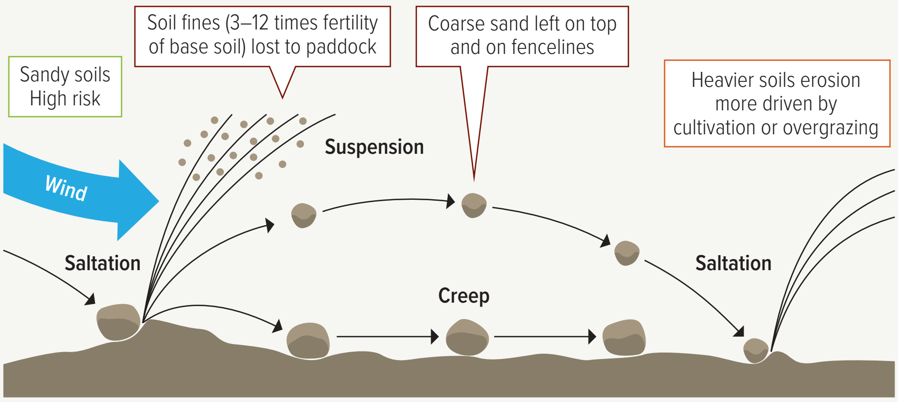
- CASE STUDY 1: Introduction – Practical tactics to improve groundcover and ensure soil preservation following successive low-rainfall seasons.
- CASE STUDY 2: Proactive soil cover strategies within sustainable continuous cropping programs – including pulses. Features grower Robin Schaefer from Bulla Burra, Loxton, SA. See wind erosion videos at youtube.com/watch?v=NSNFGds64aQ.
- CASE STUDY 3: Repairing severe blowouts at Walker Flat in decile 1 season. Features growers the Habys from Walker Flat, SA.
- CASE STUDY 4: Re-levelling blowout areas for effective seeding and harvest. Features growers the Habys from Walker Flat, SA.
- CASE STUDY 5: Changing sand mechanically and biologically to support drought resilience. Features grower Ben Ranford from Cleve, SA.
- CASE STUDY 6: Cropping land restoration and the lessons following successive years of drought in NSW. Features grower Nigel Baird from Wentworth, NSW Mallee. See wind erosion videos at youtube.com/watch?v=QSUNfgTqoBI.
- CASE STUDY 7: Rules of thumb for optimal cropping paddock management. Features grower Ben Pollard from Wentworth, NSW Mallee. See wind erosion videos at youtube.com/watch?v=nc1-6E4VmmQ.
- CASE STUDY 8: Livestock management strategies safeguarding against wind erosion. Features grower Ed, Carolyn, Evan and Lauren Hunt from the Eyre Peninsula, SA.

The case studies can be viewed at grdc.com.au/resources-and-publications/all-publications/publications/2023/case-studies-soil-preservation.

Photo: Dr Chris McDonough, IEA

The consequences of wind erosion can be costly and involve huge soil movement, loss of fertile soil components, buried fences and the difficult task of bringing land back to production.

Figure 1: Wind erosion processes.



Source: Mallee Sustainable Farming

SNAPSHOT OF CASE STUDY 3

Eroded site in March 2021 before levelling

Using the O'Brien Laser Bucket to shift sand and level the soil

Cross-sown crop growth in early October 2021, with adequate soil coverage despite poor season

December 2021 showing adequate soil cover during summer

Photos: Dr Chris McDonough, IEA

support a productive cropping rotation, including a legume, into the future.

See more on the Habys' wind erosion and levelling experience as it happened:

Case study part 1: youtube.com/watch?v=vDs4zd0yo9U

Case study part 2: youtube.com/watch?v=2xgPKTskX84 ☐

GRDC Code MSF2010-002SAX

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Fertilising the system, not just the crop, can build soil organic matter

The frustration of seeing no change in soil carbon after 20 years of stubble retention prompted one CSIRO scientist to ask 'Why?'

By John Kirkegaard

CSIRO

SOIL ORGANIC MATTER IS MORE THAN JUST CARBON

In 2007, Clive Kirkby was a soil scientist with CSIRO working on ways to deal with heavy crop stubbles when he proposed a hypothesis that was to become the basis of his PhD studies. Clive was frustrated that in a long-term tillage trial at Harden (managed by CSIRO's John Kirkegaard), soil carbon levels had changed very little despite 20 years of stubble retention.

Clive knew that soil organic matter (SOM) is not just carbon. It contains nitrogen, phosphorus and sulfur in predictable ratios that reflect the ratios found in the soil microbes.

This is because up to 70 per cent of stable SOM is made up of dead microbes. Microbes require nutrients (nitrogen, phosphorus and sulfur) as well as energy (carbon) to grow their populations in soil, and then die to create new SOM. It was expected that SOM would provide fertility, but it had been forgotten that fertility was needed to build it.

Clive hypothesised that a lack of nutrients, not just a lack of carbon, could be limiting SOM formation when retaining stubble at Harden. Nutrients were only applied when the crop needed them, and the focus on 'nutrient use efficiency' was leaving the microbes short.

He showed that irrespective of the soil type or amount of carbon in the soil, each tonne per hectare of soil carbon sequestered in SOM required 85 kilograms of nitrogen, 20kg of phosphorus and 14kg of sulfur. If those nutrients were not available in the soil when heavy carbon-rich stubble was retained, the microbes could not grow. In fact, they would break down existing organic matter to get the nutrients they needed, with a loss of carbon dioxide. This loss of existing SOM offset much of the benefit that the new carbon added. Finally, it appeared Clive had an answer to why long-term stubble retention in some cases had not increased SOM as expected.

To test the hypothesis in the laboratory, experiments were conducted with stubble added to moist soil with and without nutrients. Figure 1a shows that in the absence of nutrients, the microbes could not utilise the carbon in the residue to grow their populations and the chopped stubble remained largely intact. In contrast, Figure 1b shows that when nutrients were added in the correct ratios, the microbes grew rapidly, used all of the stubble and their residues and exudates (new SOM), and generated a very different soil. On four contrasting soils, carbon sequestration was increased two to four-fold with the addition of the supplementary nutrients.

PROOF OF CONCEPT IN THE FIELD

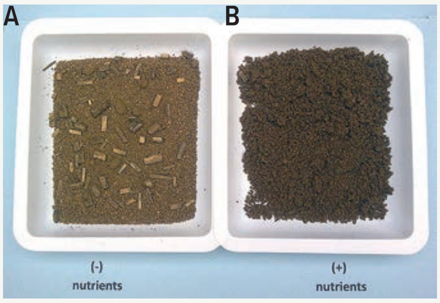
The CSIRO team went on to prove the concept in the field at Harden. Crop residue (9 t/ha cereal or canola stubble) was incorporated on the first rain after harvest using a rotary hoe with and without supplementary nutrients every year for five years (Figure 2). The nutrients were applied to achieve ratios favoured by the microbes (equivalent to around 5kg of nitrogen, 1.5kg of phosphorous and 1kg of sulfur per tonne of wheat stubble).

After five years, the treatment without nutrients had lost 3.3t/ha of carbon while the treatment with supplementary nutrients gained 5.5t/ha of carbon – a difference of 8.8t/ha of carbon over five years despite both receiving the same amount of residue. This was the first treatment to reverse the loss of SOM at the site under continuous cropping.

The CSIRO team continued adding nutrients for a further three years during which the soil carbon increased further to around 10t/ha. They then ceased the nutrient addition but kept the stubble incorporation going for a further five years. During this period the extra SOM that had been sequestered began to diminish, with the difference reducing to 3t/ha. This demonstrated

Figure 1: The effect of added nutrients on the conversion of wheat stubble to new soil organic matter on a sandy soil.

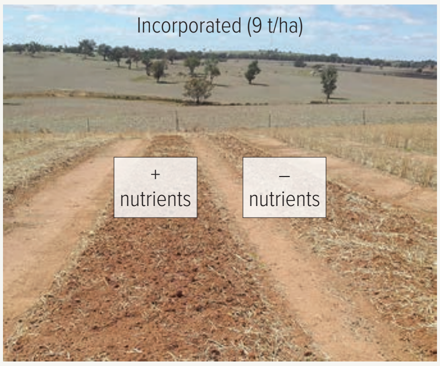
Laboratory experiment



Source: CSIRO

Figure 2: The effect of supplementary nutrients applied to incorporated crops residues at Harden over five years. Granular fertiliser was sprinkled onto the stubble before incorporation.

Field 2007 to 2012



Change in stable C
– Nutrients –3.2 t/ha C
+ Nutrients +5.5 t/ha C
Net difference 8.7 t/ha

Source: CSIRO

that adequate nutrient supply must be maintained in the system to avoid ongoing mining of the SOM.

ECONOMICS

A simple economic analysis compared the cost of the additional fertiliser against the change in income from increased yield and potential payments for sequestered carbon (at $40/t carbon dioxide equivalents). Using average costs, a profit of $1586 from an investment of $1109 (return on investment of 1.43) was achieved over eight years.

The best-case scenario (high grain and carbon prices, low fertiliser prices) generated a potential profit of $2722 (return on investment of 2.45), while only the worst-case scenario (low grain and carbon prices, high fertiliser prices) generated a small loss ($240/ha over eight years).

Overall, while nutrient addition was maintained, the likelihood of economic loss was low. However, after five years without nutrient addition, the likelihood of generating a loss increased, because the extra SOM had diminished and reduced the income from carbon sequestration. This reinforces the fact that the SOM created can be lost if the system returns to a negative nutrient balance for a long period.

NEW QUESTIONS – NEW PROJECT

A farming system in which inadequate nutrients limit crop productivity, microbial activity and maintenance of SOM clearly requires a paradigm shift.

And the shift is not to simply add more or less fertiliser, as different farming philosophies advocate. The new paradigm must focus on the balance and timing of nutrient supply with a focus on the system, not just the crop.

The project team's hypothesis is that novel nutrient supply strategies based on the stoichiometric ratios of the microbial biomass can rebuild SOM and soil health in productive, profitable farming systems.

Such a paradigm shift to 'fertilise the system, not just the crop' must operate within the economic and risk framework of real farms, a fact firmly embedded in the research approach.

Based on the underpinning theory, we hypothesise numerous avenues to reduce cost and increase effectiveness of the strategy on different soils by manipulating:

- the nutrient forms (liquid, granular, mixtures, formulations);
- timing and rates;
- positioning (on stubble, broadcast, in-furrow); and
- tailoring the nitrogen, phosphorous and sulfur applied to existing nutrients in soil and residue.

No commercial fertilisers currently target nitrogen, phosphorous and sulfur ratios to build SOM from residue, meaning that fertiliser companies could innovate in product development.

A new, collaborative GRDC investment involving CSIRO, Kalyx Australia and Delta Agribusiness commenced in 2023. It will establish and test 10 different nutrient supply strategies in fully replicated on-farm field experiments at eight sites representing key soil types and climatic diversity across Australia's grain belt:

- northern NSW – Narrabri (black soil);
- southern NSW – Young (granite/red brown);
- north-eastern Victoria – Corowa (red brown);
- Victoria – Horsham (grey clay);
- south-eastern SA – Naracoorte (black soil);
- SA – Tarlee (red brown);
- WA – Cuballing (duplex); and
- WA – Moora (sand).

The project will focus on medium to high-rainfall sites where nutrient supply (rather than stubble quantity) may limit carbon sequestration. The sites will also test some approaches in commercial strips and build local networks to ensure technical feasibility and acceptable economic risk at farm scale.

The treatments will be reapplied annually to stubble after harvest in randomised field plots with four replicates over a five-year period (2022 to 2026 stubbles) to measure effects on soil carbon sequestration, soil health and biological activity, crop productivity and profitability.

New approaches to nutrient management that can avoid the long-term mining of SOM for crop production are desperately needed in Australian and international farming systems.

Understanding the nutrient requirement of the soil microbial biomass (from which up to 70 per cent of the stable SOM is derived) must be lifted to the same level as the nutrient requirements of crops and communicated as effectively if we are to maintain both food productivity and soil fertility.

These are issues that have been largely overlooked in the debate about sequestering carbon in soil. The knowledge generated in this project regarding the underpinning impact of nutrients on microbial and SOM dynamics will be vital to develop the most effective and economic strategies to restore Australian soils. □

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Photos: CSIRO

The CSIRO and Kalyx teams sampling the soil at the Corowa site prior to the application of the nutrient and stubble management treatments in February 2023.

The soil cores extracted for measurement of soil carbon to 30cm depth prior to the application of the nutrient and stubble management treatments.

Treatments imposed as part of the new project at Monteagle: standing stubble (left), rotary hoe (centre), and speed tiller (right). All these treatments are being tested with and without foliar and granular nutrients.

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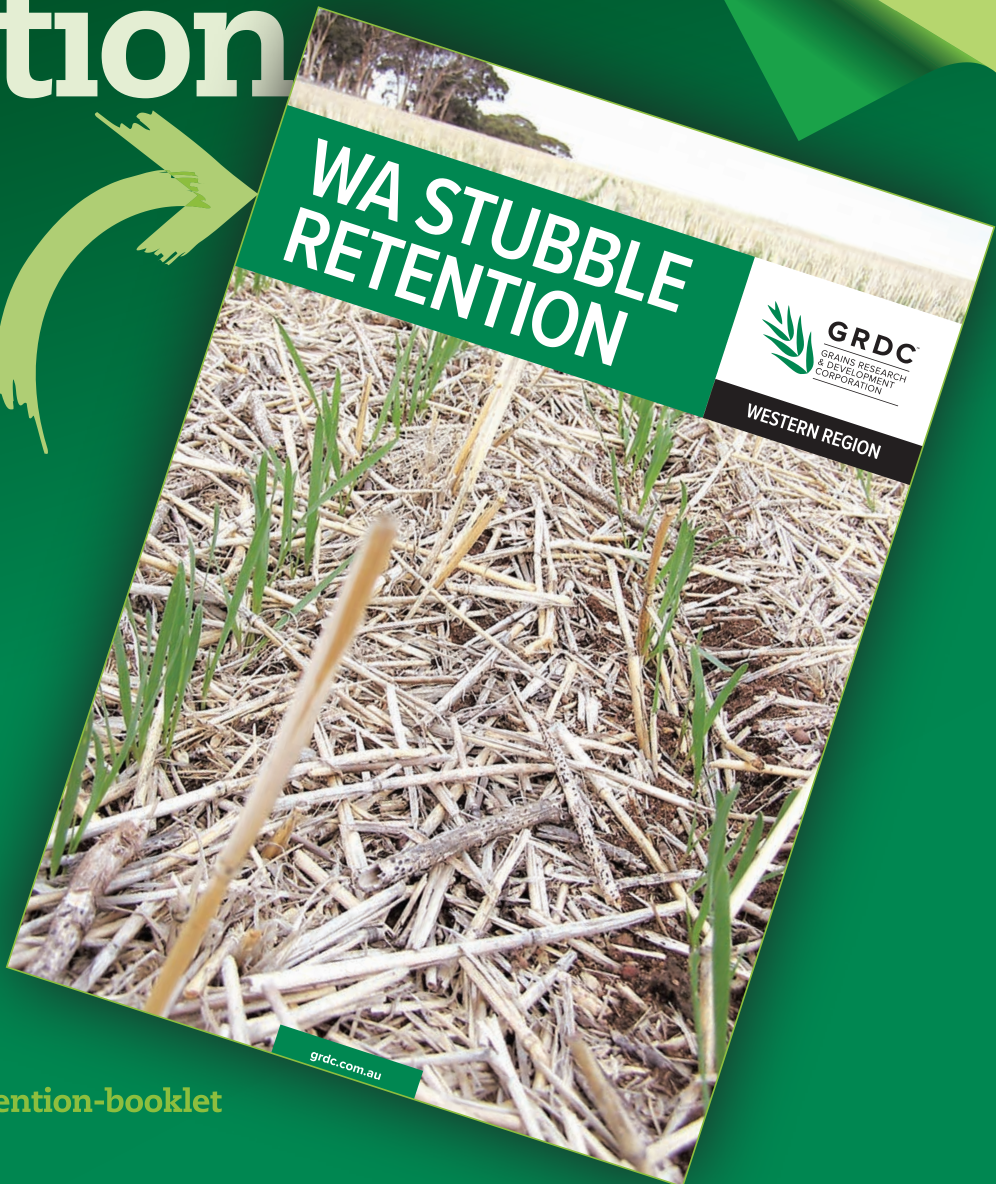

Also available at:
grdc.com.au/wa-stubble-retention-booklet

This booklet summarises current information on the optimal way to maintain profitable farming systems with retained stubble. It presents results from local research, grower case studies and lessons learnt from GRDC's stubble initiative.

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