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THE AUSTRALIAN AGRONOMIST MAGAZINE

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THE AUSTRALIAN AGRONOMIST

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AGSKILLED 2.0 DRIVING INNOVATION IN NSW AGRICULTURE

The NSW Government has committed $15 million to upskill primary producers across plant-based sectors of the agricultural industry.

Minister for Skills and Tertiary Education Geoff Lee said AgSkilled 2.0 expanded on the success of the original program in driving the productivity, profitability and competitiveness of NSW agriculture through training and upskilling.

“AgSkilled 2.0 will continue to 30 June 2023 and has expanded the opportunity for training to a much greater range of plant-growing primary producers,” Mr Lee said.

“This expanded AgSkilled program will offer training across the key agricultural industry sectors of production horticulture, viticulture and rice growing in addition to the cotton and grains production covered in the original program.”

The original program delivered training to 5,227 people, over 849 courses across 189 locations to support cotton and grains farmers in regional NSW.

Mr Lee said the key to the program’s ongoing success was the engagement with industry to ensure training in agriculture is designed to be relevant, current and responsive to industry needs.

“This training increases the productivity and safety of existing workers in the sector and can offer career pathways for people to work in the agriculture sector,” Mr Lee said.

Minister for Agriculture Adam Marshall said the expansion of the AgSkilled program would provide a boost for workers who wanted to upskill or are new to the agricultural workforce.

“These expanded opportunities are targeted directly at emerging needs and skill gaps that have been identified by industry, which means the State’s agricultural businesses can get a leg up when hiring skilled labour,” Mr Marshall said.

“Never before has it been so critical that we develop locally-based workers for the agricultural sector, so this will give them crucial training on the header, cultivating soil and plant health in the paddock, using new technology and more.

“Our farming businesses are the best in the world, and with programs like AgSkilled 2.0 they will have the workforce to match.”

The training is complemented by a range of other Training Services NSW initiatives to support regional NSW.

For more information, visit www.training.nsw.gov.au

What's new for canola growers in 2023

It is an exciting season ahead for growers and Nuseed alike. Some highlights include:

- Expansion of our canola portfolio to provide you with more choice
- Superior genetics bred at our Horsham Innovation Centre
- The proven performance you expect from our TruFlex®, HyTTec® & OP TT varieties
- Continued focus on quality assurance to ensure first class seed in every bag you buy

And that's how Nuseed keep delivering Value Beyond Yield® to you.

To learn more about how Nuseed varieties will fit into your cropping program speak to your friendly, local Nuseed representative or check them out at your local field days.

For general enquiries and customer service call: 1800 993 573

nuseed.com/au

nuseed®

AGRISCIENCE SHOWCASES LEADING R&D PIPELINE ADVANCEMENTS

Sustainable innovation fuels Corteva's future product offerings, creating value now and for decades to come for farmers, shareholders and society

Corteva, Inc. (NYSE: CTVA) highlighted its leading pipeline of seed and crop protection innovations focused on increasing farmer productivity and profitability with best-in-class, differentiated, and sustainably-advantaged solutions at the Company's Investor Day and R&D Field Showcase."We have refined our company's strategy, our operating model and our culture, all designed to meet the global challenges of food security, climate change and the energy transition, but also drive greater value for farmers and allow Corteva to reach its full potential," said Chuck Magro, Chief Executive Officer, Corteva Agriscience. "We have a very attractive long-term growth profile fueled by our innovation engine that is unique and different than others in the industry."Sustainable innovations address productivity, climate and food security

An industry leader in innovation, the Company is building on its 100-year corn breeding history with new advanced breeding techniques and proprietary biotechnology traits while developing next generation sustainability-advantaged crop protection products.

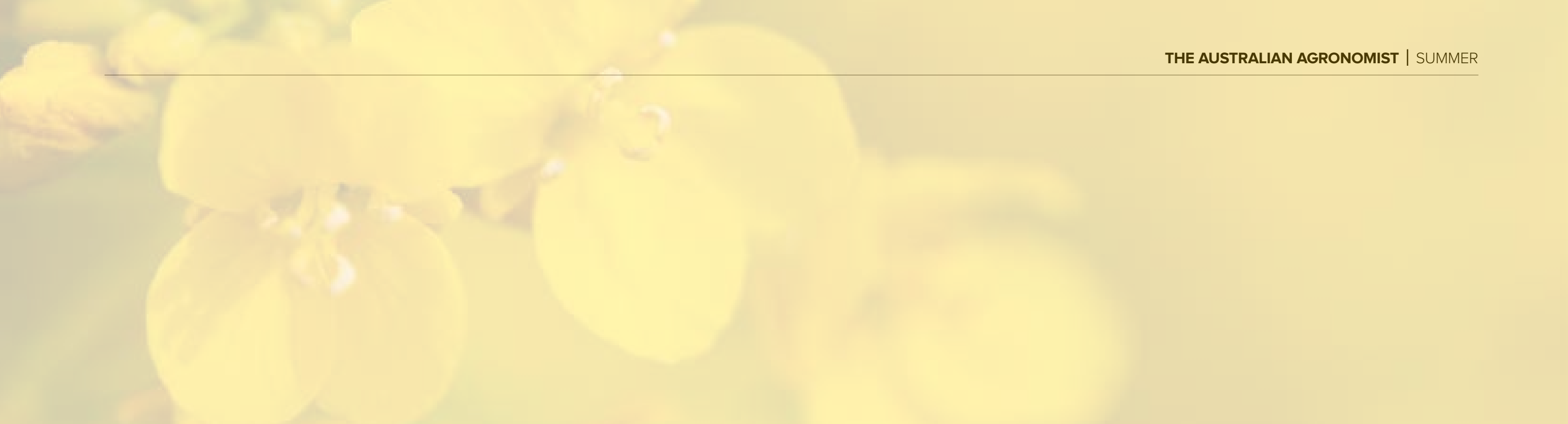
"Farmers need improved products that solve farm-level and field-level specific challenges, all while helping improve the overall sustainability of agriculture," said Sam Eathington, Chief Technology Officer and Digital Officer, Corteva Agriscience. "Corteva is up to this challenge."

Corteva showcased how its R&D pipeline will help farmers increase yield potential and protect that yield as they face increasing pressure from weeds, insects, diseases, and weather events, including:Reduced stature corn that allows farmers to optimize how they manage their fields while having a more climate resilient crop.Advanced seed breeding and gene editing to unlock additional power of native genetics to improve yield potential, enhance disease resistance, and build new value-added seed protein and oil products. Differentiated and sustainably-advantaged crop protection products like Inatreq™ active, Adavelt™ active and Haviza™ active - three naturally inspired actives for disease control. This family of fungicides uses a new mode of action, has numerous favorable sustainability benefits, and represents generations of innovation for food production and sustainability.

Expanded source of renewable energy, with a new winter oilseed/soybean double cropping system. Corteva has developed and tested proprietary varieties of winter canola for a double crop system in the southern U.S. to create a new feedstock option for the renewable fuels market, an additional revenue opportunity for farmers, while reducing the carbon intensity of oil production.

Digital insights on how to get more yield and yield protection from Corteva seed and crop protection products."These highlights are representative of our robust pipeline and our ongoing commitment to provide farmers with the tools they need to increase productivity, profitability and sustainability on their operations – which in turn results in healthy, nutritious and affordable food for the rest of us," said Eathington. "We look forward to advancing these innovations to ensure farmers have access to technology that benefits them and society."

Learn more about Corteva's industry-leading R&D pipeline advancements from yesterday's webcast, which can be accessed from our Events and Presentations page of the Corteva Investor Relations website.



About Corteva

Corteva, Inc. (NYSE: CTVA) is a publicly traded, global pure-play agriculture company that combines industry-leading innovation, high-touch customer engagement and operational execution to profitably deliver solutions for the world's most pressing agriculture challenges. Corteva generates advantaged market preference through its unique distribution strategy, together with its balanced and globally diverse mix of seed, crop protection, and digital products and services. With some of the most recognized brands in agriculture and a technology pipeline well positioned to drive growth, the Company is committed to maximizing productivity for farmers, while working with stakeholders throughout the food system as it fulfills its promise to enrich the lives of those who produce and those who consume, ensuring progress for generations to come. More information can be found at www.corteva.com.

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Cautionary Statement About Forward-Looking Statements

This press release contains forward-looking statements within the meaning of Section 21E of the Securities Exchange Act of 1934, as amended, and Section 27A of the Securities Act of 1933, as amended, which are intended to be covered by the safe harbor provisions for forward-looking statements contained in the Private Securities Litigation Reform Act of 1995, and may be identified by their use of words like "plans," "expects," "will," "anticipates," "believes," "intends," "projects," "estimates" or other words of similar meaning. All statements that address expectations or projections about the future, including statements about Corteva's capital allocation strategy, performance outlook, and strategy are forward-looking statements. Corteva disclaims and does not undertake any obligation to update or revise any forward-looking statement or other estimate, except as required by applicable law. A detailed discussion of some of the significant risks and uncertainties which may cause results and events to differ materially from such forward-looking statements or other estimates is included in the "Risk Factors" section of Corteva's Annual Report on Form 10-K, as modified by subsequent reports on Form 10-Q and Current Reports on Form 8-K.

Corteva has already won six Green Chemistry Challenge Awards from the U.S. Environmental Protection Agency, more than any other agricultural input company combined.

SOURCE Corteva, Inc.

A 'MINI-ROTATION' TO TURN THE TABLES ON RESISTANCE

Although all farmers are very familiar with the principles of crop and chemical rotation, not everybody makes changes as often they should.

Unfortunately, logic dictates that it's the crops and products they most value that growers are most likely to put at risk.

It goes without saying that there's no herbicide that's currently more highly prized than Sakura, which helped create such high expectations from – and reliance on – the pre-emergence application window. When a single product has made such a difference to the viability of cropping, and there's so much potential profit at stake, growers are understandably reluctant to move away from it.

The problem is that there is an even more powerful logic to the development of resistance. Repeated use of the same herbicide mode of action accelerates the development of mutated weed biotypes that it can't control.

In short, the more people rely on a product in the short-term, the sooner it will become unreliable. The latest data on the CropLife website shows resistance to Group 15 mode of action, which includes Sakura and Boxer Gold, has already been confirmed at over 100 sites in Australia.

BASF have now come up with a circuit-breaking 'mini-rotation' strategy that should reduce the pressure all round, as the company's Portfolio Manager Cereals Roger States explains.

"The introduction of Group 15 (then called Group J & K) chemistry really turned things around for a lot of growers who were struggling to manage big populations of resistant annual ryegrass," he says. "It took a few years for some growers to make the switch, but now those products – and Sakura especially – are mainstays of most programs.

"We've come up with the '30 on 30' strategy to cut down the lag between the release of important new chemistry and its widespread use, and to slow the development of resistance to Group 15 and other, older products. This is particularly important because of the cross-resistance risk between herbicides in Groups 3, 13 and 15 that has been described in recent scientific publications by prominent researchers like Steve Powles, Roberto Busi and David Brunton.

"The plan is simply for growers to use the unique Group 30 chemistry of Luximax® on 30% of their wheat crop as an extra 'mini rotation' within the standard program.

Source: croplife.org.au/resources/programs/resistance-management/herbicide-resistant-weeds-list-draft-3 Accessed 16/9/2022

"That '30 on 30' initiative will help growers ease into using the newer chemistry with the reassurance that they'll be able to go on using other older alternatives more widely and effectively for longer. We've got to protect what we've got.

Roger says that both replicated trial results and commercial use have repeatedly confirmed that Luximax can match the high level of weed control growers expect from Sakura. It has similar tank-mix compatibilities too, so the '30 on 30' scheme can be used very flexibly.

"Over the course of a few seasons, the weed seedbank in each paddock will be exposed to an entirely new mode of action."

"Luximax is very effective as a standalone treatment," Roger explains, "but of course it would very seldom be applied that way. The premium grassweed pre-ems are generally applied in tank-mixes with multiple extra products. All the most likely mix partners like glyphosate, paraquat, trifluralin, triallate, prosulfocarb, carfentrazone and metsulfuron are on the Luximax label.

"Our early trial work highlighted Luximax and prosulfocarb (Arcade) as a particularly effective combination. Now we have an even better recommendation because since then we've launched Voraxor®, which can do several jobs at once. Growers who haven't already tried Voraxor could take the 'mini-rotation' concept one step further and use it as part of their '30 on 30' applications. Voraxor can play the same role as trifluralin in spiking the superior grassweed herbicides' control of annual ryegrass, but with the massive added benefit of extended residual pre-emergent control of key broadleaf weeds.

"Adding both Luximax and Voraxor to the mix is all part of spreading the load to maintain the highest standards of control while also protecting the chemistry our broadacre cropping has become so reliant on. That's what '30 on 30' is all about."

"Over the course of a few seasons, the weed seedbank in each paddock will be exposed to an entirely new mode of action."

OPPORTUNITY BLOOMS FOR ABORIGINAL ENTERPRISES IN NORTHAM FORUM

The State Government is assisting the Aboriginal community to become a key supplier in satisfying growing demand for plants for revegetation projects A forum held last Friday brought Aboriginal enterprises together to better understand opportunities to satisfy growing demand for native seeds and plants for carbon farming sequestration. A grants program will also be established to assist emerging and established Aboriginal businesses to increase their competitiveness, accelerating enterprise development and supply chain partnerships.

Agriculture and Food Minister Alannah MacTiernan told the Seed and Nursery Industry Forum for Aboriginal Organisations forum that $250,000 would be allocated to cultivate opportunities for Aboriginal seed and nursery suppliers. The forum attracted established and emerging landowners, seed and seedling suppliers, as well as nursery businesses from throughout the agricultural region.

The Aboriginal community - with its connection to country and long history in sustainable land management - is well placed to satisfy surging demand for native seed and plants, driven by an increasing interest and investment in land regeneration and carbon farming. The forum included a site visit to Boola Boornap native tree farm nursery, a recipient of a Round 4 Regional Economic Development Grant provided by the Wheatbelt Development Commission.

Minister MacTiernan will lead a panel discussion with industry representatives exploring the challenges and opportunities facing Aboriginal businesses in becoming preferred suppliers for carbon and land restoration initiatives. The day also included sessions on how to accelerate business development to build supply, while satisfying accreditation and customer requirements.

- **Forum to explore opportunities for Aboriginal enterprises in seed and plant supplies**
- **Massive growth expected in demand for indigenous plants as carbon farming takes a major step forward**
- **State Government grants helping assist Indigenous businesses understand the commercial requirements**

For more information about the new grants program, visit

www.agric.wa.gov.au/aboriginal-economicdevelopment

" Experts from industry, science and government are contributing to discussions to give Aboriginal enterprises the best chance of success."

Agriculture and Food Minister, Alannah MacTiernan.


Luximax®
Herbicide
Give your wheat* a proper break
Recharge your pre-em rotation by using Luximax's Group 30 chemistry on 30% of your wheat crop every season to:
• maintain the highest levels of grass-weed control
• reduce resistance pressure on older products
• keep Group 3, 13 & 15 products in the program
Luximax®
Herbicide
THE LUXIMAX 30 30 PLAN
Stay one step ahead of annual ryegrass
BASF
We create chemistry
Find out more at crop-solutions.basf.com.au
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TRIALS SHOW IMPROVED WEED CONTROL IN BARLEY ON THE WAY

On the heels of its welcome registration for early post-emergent (EPE) application in barley to control grass and broadleaf weeds, latest trials with the recently released Mateno® Complete herbicide in this use pattern have further reinforced its performance over several years of development.

The EPE use pattern in barley adds to the existing registrations for Mateno Complete, including incorporated by sowing (IBS) in barley and wheat and the wheat EPE registration (not durum wheat), while a host of new weed control claims also have been added to the label in both crops.

Mateno Complete has already been praised for its weed control effectiveness in its first year of application by growers this season, thanks to its introduction of a new herbicide mode of action to the Australian industry, aclonifen (Group 32), in a unique and complementary co-formulation with pyroxasulfone (Group 15) and diflufenican (Group 12) herbicides.

The EPE use pattern in barley was again investigated in multiple trials across the country this season to evaluate both its weed control effectiveness and crop safety.

> **"With Mateno Complete EPE, you get coverage across the furrow, which results in fewer weed escapes."**
>
> **Gus MacLennan**

Replicated trials where annual ryegrass was dominant at the sites included EPE application with Mateno Complete at 750 mL/ha following IBS application of trifluralin at 2 L/ha. This treatment was compared alongside IBS-only applications of trifluralin at 2 L/ha, Boxer Gold® at 2.5 L/ha in a tank mix with Callisto® at 200 mL/ha, Overwatch® at 1.25 L/ha and Mateno Complete at 750 mL/ha.

Average annual ryegrass control in the IBS-only applications was highest with Mateno Complete at more than 70%, rising from below 50% with trifluralin, however the EPE application of Mateno Complete following IBS application of trifluralin increased the control to about 80%, with several sites achieving near 100% effectiveness.

It's been a similar story in previous years of development trials, where EPE application of Mateno Complete at 750 mL/ha following IBS application of an effective ryegrass herbicide has enhanced control of registered grass weeds up to near 90-100% and major broadleaf weeds up to 85-100%.

EPE applications of Mateno Complete in tank mixes with MCPA and bromoxynil herbicides also proved highly effective.

Crop effects from EPE applications of Mateno Complete at 750 mL/ha alone and following applications of trifluralin at 2 L/ha were again assessed across 10 replicated trials this season and were also compared with effects from the same IBS applications used in the grass weed control trials.

Using a peak biomass reduction rating from 0 to 100, the average rating for the EPE application of Mateno Complete alone was less than five and just over five when following the trifluralin application. This was comparable with the IBS applications of trifluralin, Boxer Gold with Callisto and Mateno Complete, whereas the average rating with Overwatch was just under 20.

Bayer Market Development Agronomist in New South Wales, Gus MacLennan, said the trials this season and over previous years had clearly shown that compared with other standard applications, the EPE application of Mateno Complete following an effective IBS treatment with alternate herbicide delivered superior weed control levels.

"The weed control from EPE applications of Mateno Complete in barley has been consistently better due to the control of in-furrow weeds and the residual control it offers of both grass and broadleaf weeds. That's what sets it apart from all other herbicides," Gus said.

"With Mateno Complete EPE, you get coverage across the furrow, which results in fewer weed escapes.

"Boxer Gold and Callisto is a combination with a similar grass and broadleaf weed control spectrum, but it can still miss the weeds in the furrow, which is inherent with most IBS-applied herbicides."

He said the EPE application of Mateno Complete in barley was highly effective across a wide weed spectrum, with particular strength on capeweed, annual ryegrass and toad rush.

On crop safety, Gus said the company had taken significant time and care with the registration of Mateno Complete for EPE application in barley to ensure crop health and, in turn, grain yields were not compromised.

"We completed work with Mateno Complete applied EPE by itself and following IBS herbicide applications and with the vast majority of products, it showed that it is fine to go with an IBS application and then to follow it with Mateno Complete."

In South Australia, Bayer Market Development Agronomist Tim Murphy said the EPE application of Mateno Complete in State-wide barley trials was demonstrating better long-term control of the majority of broadleaf and grass weeds than all other available applications.

"When compared with traditional applications like Boxer Gold applied post-sowing pre-emergent, Mateno Complete applied EPE is out-performing with longer control of a wider range of weed species," Tim said.

"We recently assessed a number of trials between 180 to 200 days since the herbicide applications were made and there are pretty well no weed panicles in the Mateno Complete-treated plots."

He said application of an effective IBS herbicide such as trifluralin followed by the EPE application of Mateno Complete provided excellent length of annual ryegrass control in barley.

The 750 mL/ha rate has shown strong activity on broadleaf weeds, highlighted in this year's trials by its effectiveness on weeds such as capeweed.

The SA trials also evaluated crop effects from the high rainfall areas of the Mid North to the cooler, slower growing conditions in the South East and over to the Eyre Peninsula region.

"From the trials this season and last season, we noticed that Mateno Complete applied EPE in barley resulted in a level of crop effect over a number of varieties, but even under the slower growing conditions in 2021 with some transient bleaching, the crops recovered strongly, they were clean, with no weed competition, and they yielded equal to or above all other trial treatments," Tim said.

Bayer Market Development Agronomist Matt Willis (WA North) said trials through the region also showed that following an effective IBS herbicide such as prosulfocarb, triallate or trifluralin, the 750 mL/ha rate of Mateno Complete applied EPE provided grass weed control that was equivalent or better than current industry standards.

In terms of crop safety, Matt said the IBS application of an effective alternate herbicide followed by Mateno Complete applied EPE can result in minor transient crop effects, however the trials showed no significant damage.

"We saw nothing commercially unacceptable in the trials and there was no yield limiting damage, but growers should adhere to the label instructions with regard to crop safety and follow the usage instructions to ensure a good outcome," he said.

The new EPE registration for Mateno Complete in barley provides for control of annual ryegrass (following an effective pre-sowing herbicide), silver grass, toad rush, Indian hedge mustard, prickly lettuce, mouse-ear chickweed and stonecrop and suppression of

volunteer canola, lesser loosestrife and wireweed.

The new label registrations for the IBS use pattern include control of stonecrop as well as suppression of Indian hedge mustard, denseflower fumitory and deadnettle in wheat, as well as suppression of Indian hedge mustard and stonecrop in barley, while the registration for EPE application in wheat has been extended to include Indian hedge mustard, volunteer canola, deadnettle, denseflower fumitory, mouse-ear chickweed, stonecrop, lesser loosestrife, wireweed and common sowthistle.

Growers and advisers seeking further information on the EPE application of Mateno Complete in barley can contact their local sales agent or Bayer Crop Science Territory Business Manager.

Mateno® is a Registered Trademark of the Bayer Group.

About Bayer in Australia

Bayer is a global enterprise with core competencies in the Life Science fields of healthcare and agriculture. Its products and services are designed to benefit people and improve their quality of life. It has operated in Australia since 1925 and has a long term commitment to the health of Australians. Locally, Bayer currently employs almost 900 people across the country and is dedicated to servicing the needs of rural Australia and the local community. Bayer is deeply committed to research and development and has a strong tradition of innovation. The company's focus on people, partnerships and innovation underpins all aspects of its operations, consistent with its mission, "Bayer: Science For A Better Life." crop.bayer.com.au

Forward-Looking Statements

This release may contain forward-looking statements based on current assumptions and forecasts made by Bayer management. Various known and unknown risks, uncertainties and other factors could lead to material differences between the actual future results, financial situation, development or performance of the company and the estimates given here. These factors include those discussed in Bayer's public reports which are available on the Bayer website at www.bayer.com. The company assumes no liability whatsoever to update these forward-looking statements or to conform them to future events or developments.

Gus MacLennan, Bayer Market Development Agronomist in New South Wales, says barley trials this season and over previous years have clearly shown that compared with industry standards, the early post-emergent application of Mateno Complete herbicide following an effective incorporated by sowing treatment with alternate herbicide delivers superior weed control levels.

ALMOND YIELD AND KERNEL SIZE BOOSTED SIGNIFICANTLY WITH SOIL ENZYMES

Nucleon liquid enzyme had been developed for use with liquid fertilisers, or as a stand-alone product.

Chris Ramsey
Elemental Enzymes national sales and marketing manager, Australia

The simple inclusion of Nucleon liquid fertiliser enzyme additive to drip irrigation has boosted South Australian almond yield by 17 percent (at 50mL/ha), and by 33 percent (at 100mL/ha), as well as increasing the percentage of larger kernels at harvest.

Other important impacts of Nucleon application included improved soil-nutrient solubilisation, cycling and accessibility, and improved microbial balance in the soil.

These very significant results were achieved in 2021-22 trials at the Loxton Almond Centre of Excellence in South Australia, where treated sections of the commercial almond crop earned the equivalent of an extra $8,868/ha at the higher Nucleon application of 100mL/ha.

How Nucleon works

Suitable for all dryland or irrigated horticulture and sugarcane crops, Nucleon contains two essential enzymes – lipase and mannanase – that stimulate soil microbial populations to provide more nutrients to plants, and reduce the workload on plant roots moving through the soil to access those nutrients.

The lipase in Nucleon allows soil organic matter to release more bio-available nutrients that can be directly absorbed by plants, plus feed the soil microbes. The mannanase component makes it easier for plant root's slippery mucilage layer to move through the soil, and works with soil microbes to convert inaccessible nutrients so they can be absorbed by plant roots.

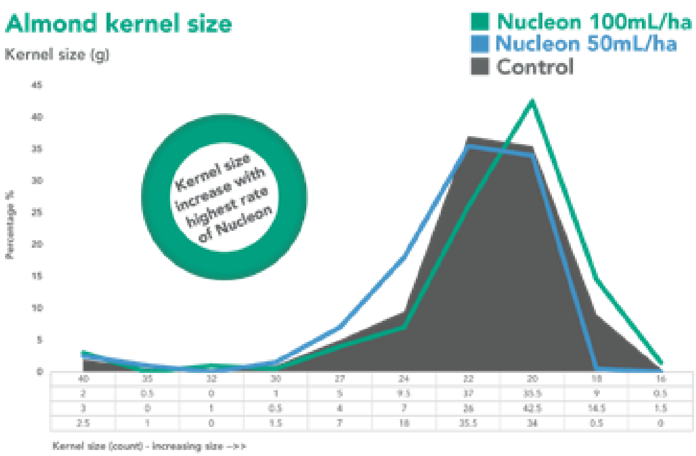
Applying Nucleon provides the right amount of enzyme in the right place at the right time, meaning greater nutrient availability and uptake – leading to stronger plant growth, higher yields and better quality produce.

Manufactured by US biosciences company Elemental Enzymes, Nucleon is being distributed in Australia by sustainable agriculture specialists Agreva, a company supporting Australian growers' response to increased local and global demand for more sustainably-grown produce.

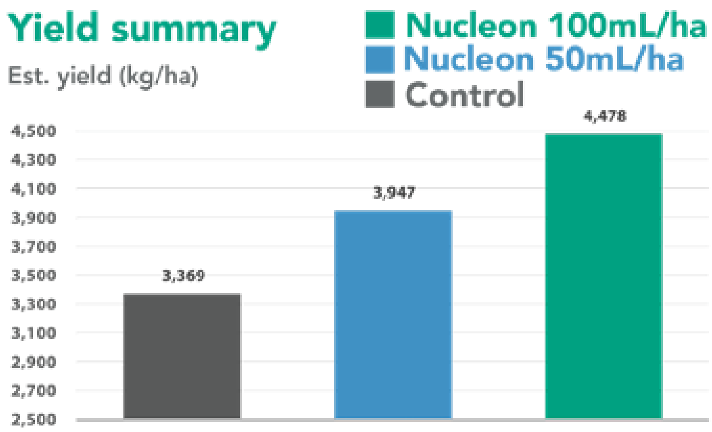
Agreva

Agreva CEO Danny Thornton said the new Agreva Sustainable Agriculture brand had been developed to support this changing future for agriculture.

"With synthetic chemistry slowly withdrawing from the market, growers require access to alternative, commercially-effective inputs.



40	35	32	30	27	24	22	20	18	16
2	0.5	0	1	5	9.5	37	35.5	9	0.5
3	0	1	0.5	4	7	26	42.5	14.5	1.5
2.5	1	0	1.5	7	18	35.5	34	0.5	0



"Agreva is developing a trusted range of sustainable products to provide commercial growers, packers and processors with access to the most demanding local and export markets. Many products are currently being tested in Australian conditions across a wide range of crops."

Elemental Enzymes national sales and marketing manager in Australia, Chris Ramsey said Nucleon liquid enzyme had been developed for use with liquid fertilisers, or as a stand-alone product.

"Nucleon stimulates microbes in the soil, enhancing both soil-nutrient availability and uptake by the plant, as well as increasing water uptake.

"The South Australian trials confirmed that Nucleon improved the health of both soil and plants, resulting in stronger almond tree growth and improved yields of quality produce."

Nucleon almond trials

Mr Ramsey said there had been many successful trials of Nucleon in a variety of cereal, field and horticultural crops in Australia, including these almond trials.

"This trial was conducted on drip-irrigated 4-year-old Nonpareil almond trees at Loxton, at a tree spacing of 7 x 4.5m, with Nucleon applied to the whole row via Ezeflow injector. Applications were made at early nut-fill, late nut-fill and post-harvest.

"Trees were harvested commercially and weighed into bins, with kernel samples taken randomly, hand-cracked and weighed individually. Results are summarised in the accompanying bar chart."

Positive impact on soil microbes and nutrient availability

With soil microbes known to play a key role in nutrient availability and regulating plant stress and resilience – and Nucleon also known to improve soil health by increasing nutrient release from the organic fraction of soil – the almond trials with Nucleon included Microbe Wise tests, to check for improved efficiency of microbes present in trial soils.

Using DNA technology, the test measured the living biomass of key microbial groups important to soil health and productivity, plus a measure of microbial diversity – a valuable indicator of soil-system resilience.

15 soil cores were taken randomly to a depth of 20cm along the treated row, from all sides of the tree within the wetted area. Samples were taken after 3 Nucleon treatments during the growing season, and were tested by Microbiology Laboratories Australia.

The results summarised in Figure 2 show the positive impact of Nucleon treatments on soil nutrient solubilisation, cycling, and accessibility, and the impact on plant resilience.

Under the grower's own standard fertiliser program, soil indicators of microbial balance and diversity ranged from poor to fair, while overall microbial balance in Nucleon-treated sections was considered to be good.

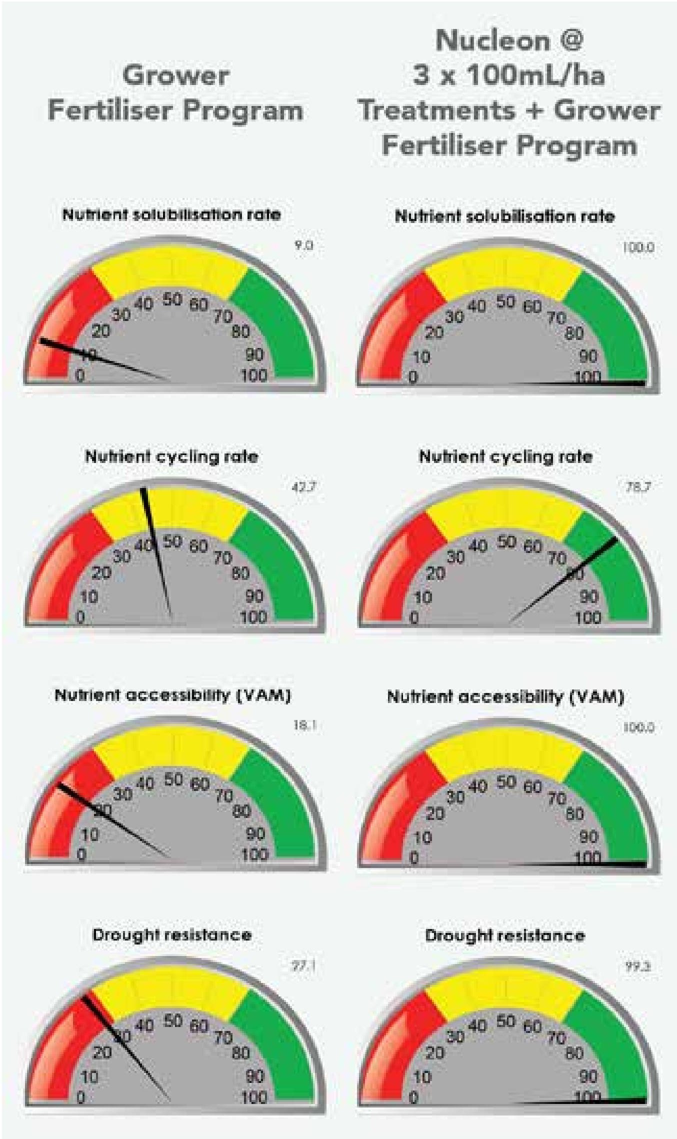


FIG 2. Microbe Wise test results - comparing Grower's Fertiliser Program vs Growers Fertiliser Program plus 3 x 100mL/ha Nucleon treatments.

TECHNOLOGY IN THE AGRICULTURAL INDUSTRY

By Darren Pesen - Tech Business News

The agricultural industry is one of the most critical areas for technological innovation to be effective and successful.

- Technological innovations can make a positive difference in the efficiency of agricultural processes and help reduce costs while increasing yield or quality.
- It's not only about producing more food at lower cost but also improving the quality of life for farmers and their communities.
- Agricultural technology refers to any type of device or software used in farming, food production, and processing.
- These technologies are designed to add efficiency, convenience, flexibility, or precision to these processes.

Agriculture has been altered profoundly throughout the last 50 years as a result of machinery improvements that have expanded the scale, speed, and productivity of farm machinery. In addition to increasing yields, seed, irrigation, and fertilisers have also improved.

Now, agriculture is about to experience another revolution, at the heart of which will be data and connectivity. Artificial intelligence, analytics, connected sensors, and other emerging technologies may increase yields, improve the efficiency of water and other inputs, and enhance sustainability and resilience across crop cultivation.

According to the McKinsey Center for Advanced Connectivity without a solid connectivity infrastructure, none of this can happen. It reported the agriculture industry could add $500 billion to the global gross domestic product by 2030, if

connectivity is properly implemented.

Advanced connectivity is expected to contribute $2 trillion to $3 trillion in additional GDP to the global economy over the coming decade, one of only seven sectors that will be responsible for this.

Importance of Agricultural Technology

Rather than applying water, fertilisers, and pesticides uniformly across entire fields, farmers can now target very specific areas or treat individual plants differently.

Agriculture plays a critical role in providing income and food for millions of people across the world. The methods of contemporary agriculture and agricultural operations are strikingly distinctive from those of decades past, thanks to technological advances including sensors, equipment, machines, and information technology.

The demand for food.

Land and farming inputs are becoming scarcer at the same time that demand for food is on the rise. In order to meet the world's 2050 population of 9.7 billion with the 70% increase in calories needed, the cost of the inputs required to produce those calories is increasing even as the world's population grows.

Labor, nutrient, and energy costs are already pressuring profit margins, and by 2030, water supply will fall 40% short of meeting global water demands.

Enhanced connectivity in agriculture Enhanced connectivity in agriculture could increase global

gross domestic product by $500 billion by the end of the decade, improving productivity by 7 to 9 percent. Much of this value will require additional connectivity investments, which are currently scarce in agriculture.

Other industries already use LPWAN, cloud computing, and cheaper, higher-quality sensors requiring little hardware, which will significantly reduce the cost of implementing them.

AgTech

Any innovation in the agribusiness sector (farm to fork) that improves efficiency, profitability, or environmental sustainability is considered AgTech.

Examples include:

- Devices
- Sensors,
- Virtual reality,
- Robotics,
- Automation
- Artificial intelligence

AgTech can function independently or in conjunction with an IoT network (see below), in which devices can communicate with one another and the internet.

5 Examples of AgTech used on farms:

- Electronic identification tags.
- Soil moisture monitoring Weather stations
- Gate and fence sensors.
- Autonomous vehicles.
- Water sensors for tanks, irrigation and troughs

Drones in Agriculture

One of the latest technologies in the agricultural sector is drone technology, which has been applied to different areas of the industry. Drones can be used for pest control, soil analysis, and drone imagery.

Pest control using drones can be a powerful alternative to traditional methods, especially for large commercial farms.

There is a range of pest control drones on the market, such as the autonomous drones that uses a UV light to attract pests and dispense a pesticide that is distributed by a fan and is harmless to people.

Drone images are a cost-effective way to monitor and manage crops. They can be used to assess soil quality, detect pests and diseases, and estimate the volume of produce.

Soil analysis can be conducted by taking a sample of the soil and sending it to a lab. Alternatively, farmers can take an image of the area with a drone and send the image to a company that can analyze it and send the data back to the farmer.

Computer vision may be used by drones to analyze field conditions and deliver the correct nutrients, pesticides, and fertilisers, or to plant seeds in remote locations, lowering equipment and workforce costs. By lowering expenses and increasing yields, drones might generate between $85 billion and $115 billion in value.

Automated Farms

Automated farming has been around for years and continues to be one of the most common types of agricultural technology innovations.

It includes a wide range of robots and equipment that perform tasks such as irrigation, soil management, nutrient application, and crop harvesting.

Robot harvesting has been used in commercial farming for decades. In recent years, the technology has also gained popularity in small-scale farming.

Crop Management and Soil Management are other areas where automated farming can make a difference. In crop management, a timing device can be used to trigger the application of fertiliser or pesticides at the optimum time. This can help improve the efficiency of these chemicals and reduce costs.

Soil management systems help create optimal conditions for growing crops by monitoring soil conditions and releasing nutrients as needed.

Autonomous Farming Machinery

Autonomous machines are better at working fields than

human-operated ones, which could save fuel and generate higher yields. By increasing the autonomy of machinery through better connectivity, $50 billion to $60 billion in additional value could be produced by 2030.

Robotic Processes

Robotics has been used in the agricultural sector for many years, mostly in the harvesting of fruits and vegetables. Robotics can also be applied to other agricultural operations such as planting, weeding, and harvesting. These robotics can also help with repetitive and strenuous tasks, which can improve safety and reduce costs. Seed planting is a common application of robotic processes.

The application of seeds is usually done manually using a process that requires accuracy and precision. Plant weeding is a process that is often done manually, but it can be automated using robotics. The weeding robots can be programmed to move between different areas, such as between rows of plants.

Harvesting can be a challenging process, especially given the need to be precise, accurate, and careful. For example, harvesting fruits such as apples can be dangerous when done manually due to the risk of falling. Robotics can be used to automate this process and make it safer.

Cloud-Based Technologies

Cloud-based technologies are commonly used in agriculture. This can be used in a variety of applications, such as a centralised data management system, telematics, and customised software.

Cloud-based technology also helps with data collection and management. Data can be collected from different equipment such as sensors and be sent to a centralised system for analysis and modelling. This can be useful for managing large farms with various pieces of equipment.

Advanced data management systems can be used for best management practices (BMPs) and tracking produce. BMPs refer to management practices designed to reduce pollution and protect public health. These systems can be used to track and trace produce from source to destination, which can be useful in case of food-borne diseases.

Machine Vision in Agriculture

Machine vision is a technology that has been used in many industries and is now also beginning to be applied to agriculture. It is the process of using computer vision and image recognition to get information from images or videos.

Machine vision can also be applied to a range of activities in agriculture, such as :

- **Crop condition analysis**
- **Weed identification**
- **Harvesting.**

Machine vision can also be used to identify and automate the harvesting of crops such as apples and oranges. This can be done by mounting a camera on the harvesting equipment to detect when the fruit is ripe and ready to be harvested.

Internet of Things (IoT)

A “thing” or “device” that is connected to the internet and equipped with sensors and other technologies is known as an IoT device.

When IoT devices communicate with each other and the internet, they can send notifications or automate other features, such as sprinklers in an orchard.

Farmers often use an interface or dashboard to receive the information generated by IoT devices. This is how farmers receive the information they need to make informed decisions in real-time. For example, a trough’s water level or wind speed in a paddock can be determined using a smartphone app, saving time and ensuring peace of mind

Crop Sensors

Farmers may benefit from using crop sensors by effectively applying fertilisers and pesticides, especially the amount required. Variable rate technology is an excellent approach in this scenario. This technology allows you to feel the sensations of plants and then reduce the risk of leaching or runoff. The crops sensor calculates the amount of resources needed for a particular crop and when to apply them.

Global Positioning Systems (GPS)

GPS is becoming an ubiquitous technology in farming. Agriculture is one example where GPS is employed to document the state of the land. By using GPS, it is simple to record and quantify crop yields from a certain farm, as well as application rates. These technologies are advantageous in that farmers may reference the recorded and documented information for assistance when making any choices.

Yield maps are an excellent method to document yields from a year. These maps may be used to provide a summary of the entire year’s activities. They are very valuable because they may provide a wide variety of data, such as the status of drainage systems.

Extended Summary

The agricultural sector has long been the focus of technological innovation, with new technologies emerging all the time.

Technology in the agricultural industry can reap a multitude of benefits thanks to the adoption of modern technology, including increased crop yields, reduced environmental impact, increased worker safety, reduced water, fertiliser, and pesticide use, among others.

From the use of drones and autonomous machines to improve crop management and harvesting, to the implementation of cloud-based technologies to optimse agricultural operations, new technologies have the potential to benefit both farmers and consumers.

Source www.techbusiness news.com.au

FLOODED PRIMARY PRODUCERS ACCESS TO ADDITIONAL FUNDING

Source: Department of Primary Industries

Primary producers affected by the February-March flooding event in New South Wales this year can now access additional funding of up to $100,000 thanks to a jointly funded program developed by the Commonwealth and NSW governments.

The $100 million Critical Producer Grant Program will provide primary producers hardest hit by floods with support to restore production systems and rebuild essential infrastructure to a standard that will better withstand future disasters.

Federal Minister for Emergency Management Senator the Hon Murray Watt said the Australian and New South Wales Governments remain committed to the recovery of flood-affected primary producers.“We recognise that the farmers and individual families who put food and fibre on our plates have been significantly impacted by these immense flood events,”

Minister Watt said.“These grants will help play an important role in supporting those in the sector who are trying to rebuild and continue producing after overwhelming losses.“We will continue to work with and listen to all levels of government to provide support where and when it’s needed over the time it takes to recover.”NSW

Minister for Agriculture Dugald Saunders said the grants will help primary producers in the key agriculture, horticulture, forestry and aquaculture industries get their businesses back on track.“This package is part of more than $3.5 billion committed by both governments to help communities and industries recover from the devastation of repeated flooding events over the past year,” Mr Saunders said.“The grants will provide the direct and much-needed assistance many primary producers need to recover, so they can get on with producing the vital products that Australia and the rest of the world relies on.“Our state’s agriculture, horticulture, forestry and aquaculture industries have played an essential role in building a strong and thriving economy, and we are committed to keeping our farmers and key regional industries in business.”Funding is available to primary producers for:

- Dairy – up to $100,000;
- Extensive livestock, broadacre cropping, turf production and perennial tree crops – up to $75,000
- Apiary, poultry and pork – up to $50,000;
- Aquaculture, commercial fishers and other horticulture such as berries, vegetables, vine crops, cut flowers and nurseries – up to $30,000,
- Private native forests and timber plantations – up to $10,000.

The Department of Regional NSW has comprehensively reviewed the impacts from the floods and consulted with industry to ensure this funding meets the unique recovery needs of each of the impacted sectors.

Applications for the Critical Producer Grant program are now open.

The Critical Producer Grant Program is designed to complement existing flood recovery measures for individuals and businesses in disaster-declared regions, many of which are co-funded by the Australian and NSW governments under the Disaster Recovery Funding Arrangements.

THEN, NOW AND TOMORROW OF AUSTRALIAN PASTURES

SPECIES SELECTION FOR SOUTHERN AUSTRALIA

By Anthony Leddin

Research Valley Seeds

Source: valleyseeds.com

Introduction

Australia has a rich history of breeding and development in temperate pasture species. From early European settlement, the demand for more productive pasture species has led to a change from the native grasses that were dominant in the landscape to introduced temperate and tropical pasture species for southern Australia. With the onset of climate change, there is an increased focus on the selection of pasture species that can maintain increased productivity under extreme environmental conditions. Farmers are inundated with new pasture varieties in the marketplace and it can be a difficult decision to choose the best species that matches their environment and their specific needs. To make this process more interesting for farmers, this paper will look at the history of the different pasture species that are used in temperate Australia, how they are currently used, and how they could change in the future to adapt to our variable environment. This story may help farmers improve their choices of what species work best for their needs on their farm. The knowledge of this story allows farmers to choose the best pastures species to suit the specific needs of their enterprise.

Native grasses

The main pasture species present in southern Australia prior to European settlement and the introduction of hard hooved livestock, consisted of the following:

- Weeping grass (*Microlena stipoidies*)
- Wallaby grass (*Rytidosperma caespitosum* (*syn. Austrodanthonia caespitosa*)
- Kangaroo grass (*Themeda triandra*).

Before the arrival of these European settlers, these grasses were grazed primarily by kangaroos. With aboriginal management, these grasses survived and thrived. However, when livestock were introduced in large numbers, these grasses decreased in persistence. This may have been due to the slower growth rates of these grasses with the added pressure of a higher stocking density. With the correct management, these species can survive in extreme environments. Some of the beneficial attributes for these species include:

- Greater tolerance to drought and persistence under dry conditions.
- Greater tolerance of lower-fertility soils.

With these characteristics in mind, there is a great opportunity to develop native grasses for the turf industry, as their slower growth rates would mean they would require less mowing. This may eventually lead to the development of more successful native grass cultivars for agriculture systems. Selection work to improve emergence vigour and seed production would create a more cost-effective product that would have a better chance of surviving when sown using conventional sowing equipment. Until this work happens, the best way to establish native grasses is through seedling recruitment of pre-existing native plants with timed grazing management. As most native grasses flower later than annual grass weeds, heavy grazing by stock in November followed by the paddock being closed up over summer allows native grasses to produce seed without the annual grass seed competition.

Perennial ryegrass

Perennial ryegrass was one of the first introduced pasture species in Australia with European settlement. In the 1800's seed or hay which contained seed arrived from England and was sown directly or indirectly by farmers. Those early perennial ryegrass plants had a growth pattern adapted to the environmental conditions of northern Europe with little forage production over the winter due to their colder condition and increased growth over the summer, not suited to southern Australia's temperate/Mediterranean environment. Over time and with natural selection, these plants have evolved to become ecotype cultivars such as Victorian ryegrass (released in 1936) and Kangaroo Valley (released in 1967). These plants are more adapted to the Australian environments that they evolved in with improved winter growth and greater persistence over drier summers.

Over time farmers demanded greater forage production from perennial ryegrass varieties and this led to the release of New Zealand (NZ) bred cultivars in the 1980's such as Ellett, an ecotype selection from dairy pastures in NZ that had a greater production under higher input systems and a later heading date. This was later improved again in the 1990's with even later heading perennial ryegrass varieties such as Impact, being developed from seeds collected from north-eastern Spain. Most of the late heading varieties seen in the Australian marketplace today are genetically based on this north-eastern Spanish material.

Another development in perennial ryegrass was the identification of endophyte (*Epichloë (syn. Neotyphodium)*) in the early 80's. This is a fungus that lives inside the perennial ryegrass plant in a symbiotic relationship with the grass, both benefiting from each other for survival. The grass shares nutrients with the endophyte and in return, the endophyte produces chemicals called alkaloids that help protect the ryegrass plant from stress such as insect attacks and grazing animals during false autumn breaks. It was found that some of these alkaloids such as Lolitrem B could cause ryegrass stagger in livestock or high levels of Ergovaline that could cause heat stress in livestock. This endophyte could be removed from the perennial ryegrass with heat treatments of seed but in areas where insect pressure was high, this was seen to decrease persistence. Work was carried out to identify novel endophytes that contained low or no levels of Lolitrem B and Ergovaline. The first successful novel endophyte, AR1, was released into the marketplace in 1999 and this has been followed by other successful types such as NEA2, Endo 5, and AR37. There will be more novel endophytes to be released in the future. As perennial ryegrass is a species used extensively around the world, it is the most likely species to see the future release of varieties bred using molecular techniques such as F1 hybrids and genetically modified organisms (GMO's).

Phalaris

Phalaris has been one of Australia's success stories for temperate grasses. Up until recently, it was the only grass that had its own long-term breeding program. Australia has been the leader in *Phalaris aquatica* variety development and it is well suited to the southern Australian environment with it being the most winter productive for forage growth out of all the temperate perennial grasses. The variety, Australian, was developed in the subtropical environment of Toowoomba in 1906. It was later found to be more adapted to predominately winter rainfall environments and this led to the release of the more winter active varieties such as Sirocco in 1967 and Sirosa in 1974. With a long-term breeding program, many weaknesses in the species could be bred for improvement. One of these was seed shattering which led to lower seed yields. In 1982, the variety Uneta was released which contained a gene that decreased the amount of seed shattering. This gene is present in many of the latest varieties to help improve seed yields and decrease the cost of seeds to farmers.

In the 1970's, alkaloids were identified in phalaris that caused phalaris staggers in sheep. This led to the development of Sirolan in 1976 and the more well known Holdfast in 1991. There are two types of toxicity in phalaris, those being phalaris staggers and sudden death. Phalaris staggers, can be decreased with selection for lower tryptamine alkaloids in plants. Sudden death is rarer than staggers, however, the causal agents for this are unknown.

Another trait selected for, in the breeding program, was grazing tolerance in the more winter active, upright varieties. This unique breeding method not only led to the creation of the grazing-tolerant Holdfast GT in 2008 but it still maintained high forage yields, a characteristic not usually seen in grazing-tolerant breeding programs.

At the same time Holdfast GT was released, Advanced AT was also released. This was a variety that was bred by crossing *Phalaris aquatica* with *Phalaris arundinacea*, a more summer-active and acid-tolerant species. This helped improve the acid soil tolerance of this Phalaris aquatica variety. With the onset of climate change, phalaris has an important future in Australia. Future breeding will see the development of F1 hybrids in phalaris and the use of phalaris in other pasture industries such as dairy, where the persistence of perennial ryegrass is being decreased due to drier summers linked to climate change. However, in extreme drought, even phalaris has struggled to persist.

Cocksfoot

When it comes to drought tolerance, cocksfoot is the most persistent of the temperate perennial grasses. However, there is a diverse range of cocksfoot varieties that are currently available in the Australian marketplace, from those that are active in summer to those that are completely summer dormant. Therefore, not all cocksfoot varieties are drought tolerant. The Hispanica subspecies can go dormant in the summer and actively begin to grow again when the cooler temperatures of autumn occur. Even within the Hispanica types, there are different levels of summer dormancy, so the selection of the correct cocksfoot variety requires knowledge.

Currie was the first cocksfoot variety to be bred and released in Australia in 1958 after extensive seed collection in the Mediterranean region in 1937. Kasbah was bred and released in Australia in 1960 and is still known as the most persistent perennial grass species in Australia due to its high level of summer dormancy.

For a more summer-active variety of cocksfoot, Porto was bred and released in Tasmania in 1972 from a seed collection done in Portugal in 1954. It is still one of the most productive varieties of cocksfoot in Australia today. For a higher level of summer growth, the 1980's saw a release of NZ-bred varieties of cocksfoots such as Wana and Kara. There has not been much breeding done on cocksfoot due to the low sowing rates of the species, but this may change in the future with the need for more summer dormant varieties for drought regions where phalaris cannot persist.

Tall fescue

Tall fescue has been identified as an alternative to perennial ryegrass in locations where poor persistence occurs due to drier summers. There are two separate groups of tall fescues, the most common one being the summer active or continental type and the second group being the winter active or Mediterranean type. The main difference between the two groups is their growth pattern. The continental types grow mainly over the spring/summer/autumn period, and the Mediterranean types grow mainly over the autumn/winter/spring period. The Mediterranean types also can go summer dormant, although this is not a complete summer dormancy, so rain in the summer can activate them to grow again. Due to their alternative growth patterns, these different species are suited to different annual average rainfall environments. Continental types are suited to areas where summer moisture is dominant and the annual rainfall is 600mm. The Mediterranean types are suited to annual rainfall amounts of 400mm and areas that experience dry summers due to their summer dormancy.

Demeter was the first continental tall fescue bred in Australia and was released in the 1930s. The first Mediterranean tall fescue bred in Australia was Melik in 1971 from an Israel collection. A new generation of softer-leaved continental tall fescue varieties began in 1994 with the release of Advance from NZ. Following this was the development of novel endophytes in tall fescue in 2003 with the release of Max P. What makes this endophyte different from the one in perennial ryegrass is that one of the chemicals it produces, loline, is translocated into the roots, giving possible protection against some root-feeding insects.

The future of Mediterranean tall fescue may be in partnership with phalaris as a safe species to graze in the autumn while phalaris toxicity may be an issue with a false autumn break. Tall fescue endophyte may also be important as more festulolium (ryegrass x fescue) is being created that can be inoculated with the fescue endophyte.

Sub clover

Sub clover would arguably be the most important pasture legume in Australia's history due to the way that it has changed cropping rotations and how it is adapted to our dry summers but can still be grazed at flowering and can reseed.

The first sub clovers were identified in Australia in 1887 and most likely indirectly introduced through hay. The first released variety of sub clover in Australia was the subterraneum subspecies, Mt Barker, in South Australia in 1907. With a greater demand for sub clovers that could tolerate waterlogged soils, there was the first release of a yannicum subspecies, Yarloop in Western Australia in 1947. Later, a higher-yielding subspecies of sub clover called brachycalycinum was identified and the cultivar, Clare, was released in 1949. Around this time in the 1940's, the first high estrogen sub clovers were identified (Dwalganup, Geraldton, Dinninup, Yarloop, Tallarook) and this led to the selection of low estrogen levels in all the later bred varieties. In the 1960's the disease clover scorch became a major issue in Australia and later varieties are selected for tolerance to this disease. One of the latest advancements in sub clover breeding in 2009 was the selection of redlegged earth mite tolerant varieties (Bindoon, Narrikup, and Rosabrook).

In selecting a sub clover variety, it is important to look at the subspecies that match the environment and grazing management, allowing the selection of the right flowering date that matches the annual rainfall. Hard seededness will become a more important trait in the future due to the increased variability that we are experiencing with autumn.

Lucerne

Lucerne trialling first occurred in Australia in the 1930's with CSIRO. Hunter River was the predominant lucerne variety sold in Australia up until the 1970's. This is a winter dormant type (5). In 1968 there was the release of an alternative creeping lucerne variety, "Cancreep" from CSIRO with a winter activity of 2-3. It was not until 1977 that there was an increase in aphid numbers in Australia that wiped out more than 60% of lucerne stands in Australia. This saw a major effort in breeding within lucerne. Combined with selection for increased resistance to insects and diseases there was an emphasis on winter activity. In the early 1980's Siriver was released with a winter activity of 9. One of the most popular varieties sold today is Aurora, released in 1983, with a winter activity of 6. Today, lucerne breeding programs in Australia focus on new traits such as tolerance to grazing, increased tolerance to acid soils, and tolerance to waterlogging with branch-rooted types. The main trait to consider when selecting a lucerne variety is its winter activity. Winter dormant types (3-6) are more suited to hay or grazing and will persist for more than 10 years. Winter active types (7-11) are suited to cropping rotations and rotational grazing and usually last around 5 years. It is critical not to rely on legumes to produce much dry matter (DM) yield over winter. Even highly winter-active types only produce around 30% of their annual DM yield over winter. Grasses can tolerate colder soil temperatures than legumes and will grow more in the winter than a legume because of this.

White clover

Up until the 1920s in Australia, the introduced varieties were predominantly Dutch and English white clover. Farmers were looking for a more winter-active white clover which led to the introduction of Ladino white clover from the USA in 1925 and NZ white clover (Huia) in 1930. It wasn't until 1936 that the local ecotype, Irrigation with a medium leaf size was selected and released in Australia. Haifa was released in 1971 after a collection in Israel in 1951 and is now the most widely used white clover in Australia. Future work must focus on drought tolerance and persistence in Australia, and this may come from hybrids with other species, e.g. uniflorum and ambiguum. When selecting a white clover variety, the larger the leaf the shorter the stolons that are formed but the higher the DM yield. It is also important to know that the tap root of white clover dies after 18 months and then the plant must survive from the roots formed from the stolons, so the more stolons, the better the chance of survival in a dry summer environment.

Strawberry clover

Strawberry clover was identified in Australia before 1900. The first successful cultivar, Palestine, was released in 1929 from seed collected in Israel. It is known for its improved drought tolerance over white clover, its higher level of salinity tolerance, and tolerance to waterlogging. There has been no cultivar released since Palestine but there are opportunities to produce more active winter lines for a grass seed mix.

Annual legumes

There are many different species of annual legumes to choose from. These are just a few that have been bred specifically for Australian farmers. In the mid 1980's, the first releases in this era were cv. Paradana balansa clover and cv. Persian kyambro clover (T. resupinatum var. resupinatum) for acid and neutral-alkaline waterlogged soils, respectively.

Biserrula cvv. Casbah and Mauro (2010), are a more hard-seeded, deeper rooted, and more persistent pasture legume than subterranean clover for ley farming systems in acid soils.

Gland clover (T. glanduliferum Boiss) (2002) cv. Prima, is an easy-to-harvest aerial seeding species resistant to red-legged earth mites and aphids. Its released to address the issue of soil erosion caused by the harvest of sub clover seed.

Eastern star clover (T. dasyurum C. Presl) (2007) cv. Agwest® Sothis was selected as an erect, aerial-seeding fodder legume for low tomedium rainfall areas. With delayed germination, it allows for the control of crop weeds following the break of the season by non-selective herbicides or cultivation before its germination.

Bladder clover (T. spumosum L.) (2012) cv. Agwest® Bartolo is a semi-erect, aerial-seeding alternative to subterranean clover that is able to set seed on hard-setting soils, where subterranean clover is unable to bury its burrs.

French serradella was bred as an alternative species to yellow serradella for deep, acidic, sandy soils with much greater ease of seed harvesting and processing, cvv. Cadiz, Margarita, Erica, and Eliza (2009).

Crimson clover is an erect, aerial-seeding legume suited to grazing and fodder production in short-term phase pastures—cvv. Caprera and Blaza (1998). Arrowleaf clover is an aerial-seeding erect, deep-rooted legume that is suited to grazing and feeding production with late flowering for longer growth in the season: cvv. Arrotas and Cefalu (2012).

Berseem clover is a fodder legume suited to fertile, medium to heavy textured soils of mildly acidic to neutral pH cvv. Elite II and Memphis (2012).

Messina (Melilotus siculus), is a new annual pasture legume bred for saline soils prone to winter waterlogging.

When choosing an annual legume, match the traits of the variety with the system. The grass companion species in a mix with annual legumes should have similar emergence vigour, therefore, displaying compatibility.

Tropical forages

When you think of southern temperate pastures, tropical forages are not a species group that comes to mind. With the onset of climate change, there will be an increased opportunity to use tropical forages to manage a variable climate. A prime example of this was in the 2007 drought where kikuyu was the only species to survive at Hamilton in the sacrifice paddocks. Some grasses that have opportunities in southern Australia include Rhodes grass (Chloris gayana) that was introduced into Australia in 1901, green panic (Panicum maximum) that was first grown in Australia in 1930 and Kikuyu (Cenchrus clandestinus), introduced into Australia in the early twentieth century, becoming naturalised in Victoria in the 1940s. The holy grail in tropical breeding is to find a tropical legume that can compete with grasses, but this has been elusive to date.

Conclusion

Australia is the leader in the development of temperate pasture species for a Mediterranean environment. The foundations of this work should be attributed to the many people in the 1900s who had the vision to do seed collections overseas. These collections are close to the centre of origin for these species and allowed the material to be brought back to Australia to eventually breed the first of our pasture varieties. Modern techniques such as molecular breeding can build on these foundations to create varieties more rapidly adapted to our environment. However, breeding is just one piece of the puzzle. Agronomic

practices such as grazing have just as much influence over the production and persistence of our pastures.

The clear message is that research and breeding of pastures in Australia must continue if we are to create the next generation of temperate and tropical pasture species that are adapted to a variable environment.

Anthony Leddin

Anthony Leddin grew up on a dairy farm in Yambuk in South west Victoria. He went on to study Agricultural science at Melbourne University where he discovered his passion in plant breeding. After volunteering for a year teaching agriculture in Samoa he came back to do a Masters in pasture breeding based at the Ag Department in Hamilton.

After that he worked as a pasture agronomist at the Warrnambool CO-OP, a pasture research scientist with Heritage seeds, a seed production agronomist with Bayer and finally to his current role as Pasture breeder and Research manager with Valley Seeds for the last 14 years. He is passionate about plant breeding in Australia as he sees that our climate is unique in the world and it warrants specific varieties for specific needs.

MAKING SILO FUMIGATION EASIER WITH SILOKEEPER

A new easy-to-use tool that plans, monitors and tracks QuickPhos fumigation in on-farm storage is soon to be released in Australia.

SiloKeeper, developed by UPL Australia, is an easy-to-use app that will guide farmers through fumigating grain silos and bunkers effectively and safely.

Ian Cass, marketing manager UPL Australia, said SiloKeeper helps to ensure the critical success factors for effective fumigation are adhered to – right dosage, correct exposure time, airtight enclosures, temperature and humidity inside enclosures, and the right air distribution and ventilation.

“SiloKeeper provides clear directions for each stage of the fumigation process,” said Mr Cass. “It monitors and tracks the entire fumigation process, sending update alerts to your smart phone.”

The app records details of silos that are fumigated and ready for grain removal. Once fumigation is complete a record of fumigation is generated for grower’s records which can be passed onto the next owner of the grain.

“Safety alerts can also be sent to app users and farm staff if they come within 50 metres of a silo or bunker being fumigated,” added Mr Cass.

With a large percent of stored grain in Australia being treated with phosphine, the active ingredient in QuickPhos, the grain industry is somewhat reliant on the continued effectiveness of the fumigant as an economical and efficient pest management tool. However, phosphine resistance has increased in past years because of failed fumigation practices.

“Following industry best management practices and using properly sealed storage is essential to the efficacy of QuickPhos,” said Mr Cass. “Otherwise, we potentially risk future access to this product – which would have industry-wide repercussions.”

Not only does SiloKeeper assist with adhering to best practice for effective fumigation, but it also makes life easier for growers and their staff with clear processes from start to finish.

“SiloKeeper provides an easy-to-follow process when preparing for fumigation plus a planning timeline, a dashboard providing fumigation status details, and safety reminders and alerts.”

The app also captures the critical success factors of temperature, humidity and moisture, as well as calculating the right dosage of QuickPhos needed.

“We focussed on making SiloKeeper user-friendly and intuitive,” said Mr Cass. “We wanted a good planning and recording tool but knew it also needed to be simple to use so that it becomes a valuable on-farm tool.”

SiloKeeper is currently in the final testing phase and will be available for release via the Apple App Store and Google Play store in early December.

For more information visit the new Silokeeper.com website.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REVISED EPPRD CONTINUES TO MEET CHANGING NEEDS OF BIOSECURITY SYSTEM

A revised version of the Emergency Plant Pest Response Deed (EPPRD) came into effect this week to meet the needs of signatories and a contemporary Australian biosecurity system. The new EPPRD offers enhanced operation and clarity across a number of provisions and outcomes.

The EPPRD, also commonly referred to as the 'plant deed', is a formal legally binding agreement between Plant Health Australia (PHA), the Australian Government, all state and territory governments and national plant industry bodies.

The EPPRD covers the management and funding of responses to Emergency Plant Pest (EPP) incidents, including the potential for owner reimbursement costs for growers. It also formalises the role of plant industries' participation in decision making as well as their investment in the costs related to EPP responses.

"The EPPRD is a landmark agreement, laying strong foundational partnerships in plant biosecurity," said Sarah Corcoran, CEO of PHA.

From an agricultural, environmental and community viewpoint, the plant deed supports nationally consistent and structured responses to emergency plant pests, where it is in Australia's interest to be free of that plant pest.

"Importantly the plant deed also provides clarity regarding roles and responsibilities, assisting in managing expectations of each other and allowing for those involved to effectively prepare," said Ms Corcoran.

In a world first, the EPPRD was ratified in 2005, significantly increasing Australia's capacity to respond to emergency plant pest incursions.

"Before the arrangement came into effect 17 years ago, collaboration between government and industry in responses was not guaranteed," said Dr Susanna Driessen, General Manager Emergency Response at PHA.

Each response managed under the plant deed has had its own challenges and opportunities. Past responses provide signatories to the deed with opportunities to reflect on changes that may be needed to assist the national plant biosecurity system.

Working collaboratively, PHA, plant industries, and all governments have identified a number of opportunities to enhance the functionality of the plant deed, negotiating to action improvements and embedding practices that have evolved over time.

"Amendments to the revised version of the EPPRD include improved functionality, clarifying roles and responsibilities, and refining understanding of how to apply the agreement," said Dr Driessen.

Other amendments support improved outcomes during a biosecurity response and include:

Supporting growers directly affected by emergency containment activities that may be implemented immediately following the detection of a suspect emergency plant pest. The EPPRD now allows for the National Management Group (NMG), which is the key decision making body in respect of national responses, to determine the provision of reimbursement for losses, even if a national response does not occur. This is a discretionary decision point and aims to facilitate equity for impacted growers and support early reporting and response actions.

Flexibility to respond to exceptional circumstances in a transparent and collaborative way. In the instance where eradication following implementation of a response plan may no longer be feasible, the EPPRD allowed for a short period of time where national coordination and funding could continue whilst the response 'transitioned' from eradication to ongoing management. COVID-19 restrictions highlighted that these timeframes may need to be reconsidered and adaptable, and the signatories to the plant deed supported the option to extend these timeframes when it is agreed that 'exceptional circumstances' have arisen.

"The EPPRD will continue to provide a platform for improved preparedness and raising the profile of plant biosecurity, providing for better outcomes for all stakeholders," said Ms Corcoran.

"Overall the plant deed provides for a cohesive, structured national approach to plant biosecurity responses, to benefit all Australians."

For more information, visit the PHA website.

THE POWER OF COMPOST - MAKING WASTE A CLIMATE CHAMPION

A new way of using compost could boost global crop production and deliver huge benefits to the planet, according to a study co-led by The University of Queensland.

Professor Susanne Schmidt (https://agriculture.uq.edu.au/profile/389/susanne-schmidt) from UQ's School of Agriculture and Food Sciences (https://agriculture.uq.edu.au) said adopting a Precision Compost Strategy (PCS) in large-scale agriculture could improve crop yield, soil health and divert biowaste from landfill where it generates harmful greenhouse gases.

“Instead of relying just on mineral fertilisers, PCS involves supplementing the right type of compost with nutrients to match the needs of soils and crops,” Professor Schmidt said.

“Soils that have become compacted and acidic are then aerated and neutralised.

“The result is they can retain more water, facilitate root growth and nourish the organisms that keep soils and crops healthy.”

Professor Schmidt said soil plays a crucial role in ensuring global food security. “But currently 30 per cent of the world's agricultural soil is classified as degraded, with projections that this could rise to 90 per cent by 2050,” she said.

“Our research estimates PCS could boost the annual global production of major cereal crops by 96 million tonnes, or 4 per cent of current production.

“This has flow-on effects for consumers by addressing food shortages and price hikes.” The study found applying PCS to large-scale agriculture could also help mitigate climate change.

“In Australia alone, more than 7 million tonnes of bio-waste ends up in landfill every year where it generates huge amounts of avoidable greenhouse gases and other undesirable effects,” Professor Schmidt said. “If we repurpose it, we can restore crucial carbon in cropland topsoil. “There are cost benefits too - diverting just 15,000 tonnes of bio-waste could save a local council as much as $2-3 million a year.”

Far North Queensland sugarcane farmer Tony Rossi said his family's company V. Rossi & Sons had been using precision compost for seven years with great success.

“We've been able to almost halve our fertiliser use which is so much better for the environment, and our crop yield is the same,” Mr Rossi said.

More than 2,000 examples of compost use in the agricultural sector across the globe were analysed as part of the PCS study. The research was supported by Fight Food Waste CRC (https://fightfoodwastecrc.com.au/) and has been published in Nature Food. (https://www.nature.com/articles/s43016-022-00584-x)

Tony Rossi's family sugarcane farm in Far North Queensland is successfully using a Precision Compost Strategy. Image: Supplied

INSTANT CROP N ANALYSIS TO BOOST FERTILISER EFFICIENCY

GROWERS can now gain the nitrogen (N) nutrition status of a range of crops instantly following the launch of a unique smartphone app that aims to assist the most efficient application of fertilisers in order to maximise returns and protect the environment.

Croptune uses smartphone cameras to take leaf photos, upon which it measures chlorophyll and provides both a plant N uptake and percentage range reading for annual crops, as well as a percentage range measurement for perennial crops.

Where the N percentage lands on an indicator bar that transitions from green to red for the selected annual crop suggests whether applications can be reduced or are required to achieve optimum nutrition and production, while the recommendation also includes a calculation of phosphorus (P) and potassium (K) requirements.

In perennial crops, the percentage measurement allows growers to track the N nutrition status in real-time and, if necessary, adjust applications immediately, rather than be delayed waiting for laboratory plant analysis results.

So far, the Croptune app has been calibrated for 18 crops, including wheat, cotton, corn, rice, tomato, potato, carrot, capsicum, lettuce, cucumber and onion annual field crops and banana, avocado, pear, peach, nectarine, clementine and cherry perennial orchard crops, and with sugarcane expected to be added from the start of 2023.

Croptune Product and Agronomy Manager Eldad Sokolowski, who travelled to Australia from Israel to launch the app with Haifa Group, which partnered its development, said calibration required a full season and hundreds of samples for each crop. It aligns laboratory N analysis with leaf greenness levels, and which continually improves through the use of artificial intelligence.

Eldad said currently there were about 40 greenness layers used for nitrogen measurement of each crop, with the aim to achieve more than 100 layers to further improve its accuracy.

“Currently the accuracy is 85-90pc with the laboratory results, which also are not perfectly accurate. We estimate labs have 90pc accuracy and indicate a single figure rather than a range, so the correlation is very close,” Eldad said.

Growers also can target specific areas within whole paddocks or blocks with the app to help further fine-tune their nutrition management and, together with their agronomist or adviser, they can access a developing databank of the areas. In future, it can contribute to aerial N maps for paddocks or blocks.

Eldad said for the N application recommendation as well as P and K calculation in annual crops, growers entered several details into

Jake McLagan, Lindsay Rural Tully, takes a banana leaf photo with the new Croptune app to identify the crop’s nitrogen percentage, overlooked by Haifa Northern Sales Agronomist Peter Anderson, local growers Michael and Gerard Laspina, and Croptune Product and Agronomy Manager Eldad Sokolowski.

Haifa Australia Northern Sales Agronomist Peter Anderson (right) takes North Queensland growers David Rolfe, Mena Creek, and Michael Russo (second from right), Boogan, as well as Mac Keenan, Frank Lowe and Sons Innisfail, through the workings of the new Croptune app.

the app including the planting date and plant density.

"From the age of the crop and the plants per area, the app knows what the N level should be at that time."

He said one of the key aims was to allow growers to apply the minimum base fertiliser required upfront and then to use the app to understand the crop nutrition status and make applications accordingly.

"It depends how frequently fertiliser is applied, but with crops like potatoes during the critical part of the season, growers could check the nutrition once a week."

Use of the app in crop trials has shown a reduction in fertiliser application in potatoes of 40 kilograms per hectare, resulting in 30pc increased nutrient use efficiency, while in wheat the fertiliser saving was 35kg/ha for 46pc higher nutrient use efficiency and in carrots the same yields were achieved despite 20kg/ha less fertiliser applied. The lower fertiliser applications also reduced carbon dioxide emissions.

Eldad said the app was developed initially for the widest-grown crops in the world and the most popular varieties, however the list of crops would continue to grow and work was ongoing to add further varieties.

It also will undergo accreditation for use to meet environmental regulations in Israel and this could pave the way for similar developments in Australia.

Haifa Australia Managing Director Trevor Dennis said as part of the company's commitment to the 17 Sustainable Development Goals (SDGs) under the United Nations Global Compact initiative, the adoption of systems for sustainable agriculture was a key focus and the primary target with the app was to improve the efficient utilisation of fertilisers for growers and also the broader community and environment.

Eldad said the Croptune app was suitable for use with a wide range of iphone, android and Google handsets, while default camera settings should be maintained and photos via the app should be of leaves similar to those used for laboratory plant analysis. In areas with poor connectivity, the app can store the images for analysis later.

The Croptune app is available to growers and advisers via app stores, where users can annually subscribe to field crop or orchard crop versions based on the crop area it is to be used over.

Users can take advantage of a free trial with the app before incurring a fee of around $20 per month, while availability through rural resellers also is being explored to make it as cost-effective as possible for users.

Haifa Australia Northern Sales Agronomist Peter Anderson, Croptune Product and Agronomy Manager Eldad Sokolowski, Aaron Myrteza, Lindsay Rural Mareeba, and Helen Bensilum, Farm Manager at Kureen Farming's 'Avomac' property at Kairi, near Tolga in Northern Queensland, take a look at the new Croptune app analysing the nitrogen percentage of Shepard and Hass avocado trees.

N-GAUGE NUTRIENT MANAGER APP

MANAGE NITROGEN FERTILIZATION APPLICATIONS FROM THE PALM OF YOUR HAND

Protein to Prescription

Protein and Yield data across the farm are extremely valuable. Farmers need tools that capture all the data layers across their fields and present them in meaningful formats. The NEW N-GUAGE Nutrient Manager App is the most advanced mobile app available for farmers that brings together all data layers and places them in the palm of the farmer's hand.

CropScanAg is pleased to announce the official release of N-GAUGE Nutrient Manager App in November this year. To learn about N-GAUGE go to the link and watch the N-GAUGE Nutrient Manager video. https://vimeo.com/763236017

The N-GAUGE Nutrient Manager App delivers a complete suite of field and analytical maps to the farmer, their agronomist and other authorised partners, directly to their smart devices. The field and analytical maps include;

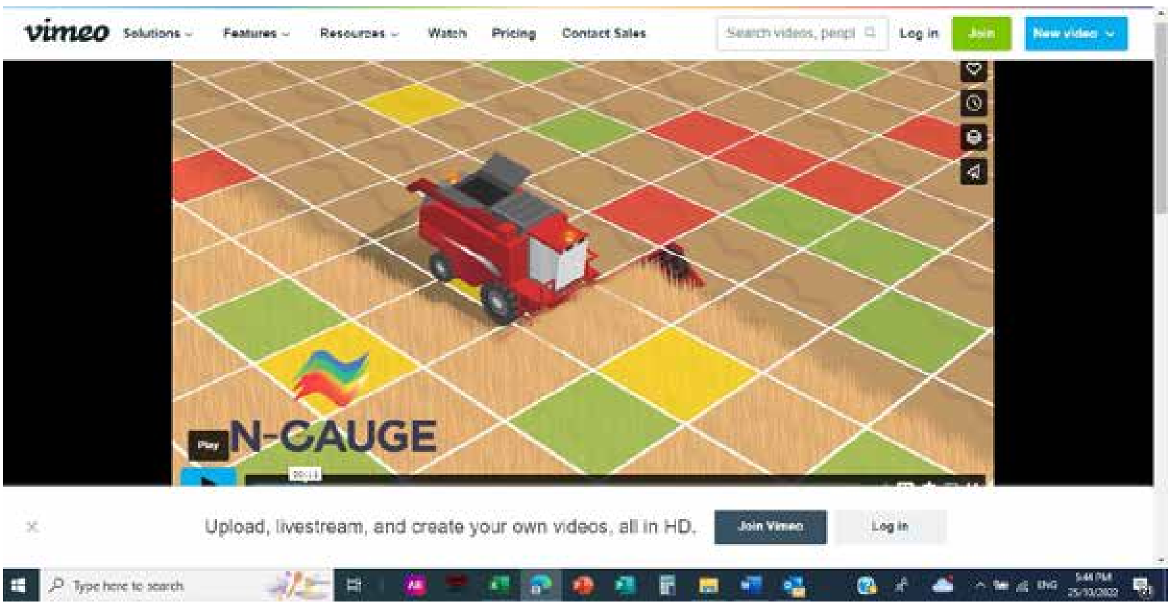
- **Protein, Moisture, Oil, Starch**
- **Yield and Elevation**
- **Protein/Yield Correlation Quadrants**
- **Nitrogen, Sulphur, Potassium and Phosphorus Removal**
- **Nitrogen Use Efficiency (NUE)**

A unique feature of the N-GAUGE Nutrient Manager App is that the prescription applications are aligned to the AB lines across the field. The prescription maps are grid lined with the recommended rate of fertilizer shown in each grid location. By selecting the grid location, the famer and their agronomist can increase or decrease the rate as they see fit.

When each prescription is created the area and fertilizer rates are reported via the reports screens. N-GAUGE quickly calculates the fertilizer totals which allows the grower to adjust the rates based on the available fertilizer on order or assist in the fertilizer required for the season.

Farmers can then generate Variable Rate Fertilization Prescription maps for their fields and edit them on their smart devices. Once the prescriptions maps are complete, they can be exported to the CASE IH AFS, New Holland PLM or John Deere Operations Centre platforms. The last step is to download them to the spreader, sprayer or seeder.

For more information on the N-GAUGE Nutrient Manager and Grain Logistics Apps, visit the web site: **www.cropscanag.com,** watch the videos or contact us on 02 9771 5444 (Australia) or 1 720 435 1139 (USA/Canada).



Stress-aid

TECHNICAL INFORMATION

STRESS LESS WITH STRESS-AID

Stress-aid is formulated to protect plants from damage caused by biotic and abiotic events that could impact sterility, and overall plant yield. In frost events especially, Stress-aid can increase accumulation of soluble sugars, which play an essential role in stabilising various biological components such as the cellular membrane and membrane-bound organelles. By stabilising these components, Stress-aid can minimise electrolyte leakage and limit the effects of frost damage.

Seasol Liquid Seaweed Extract

Potassium

ABOUT STRESS-AID

Stress-aid improves frost tolerance in plants through biochemical, molecular, and physiological changes. Stress-aid reduces frost-induced electrolyte leakage by maintaining membrane integrity during freezing stress.

Stress-aid helps regulate sugar and acids in plants. Sugar accumulation helps plants to reduce frost stress by playing an essential role in stabilising various biological components such as the cellular membrane and membrane-bound organelles.

Soil and Fertiliser

Water / Seasol

FEATURES AND BENEFITS

- Aids plant establishment and reduces transplant shock
- Stimulates root growth and enhances flowering
- Increases tolerance to adverse environmental conditions
- Enhances soil microbial activity

TYPICAL ANALYSIS

W/V: Nitrogen (N) 0.0%. Phosphorus (P) 2.8%. Potassium (K) 10.0%

MICROSPECTROSCOPIC VISUALIZATION OF HOW BIOCHAR LIFTS THE SOIL ORGANIC CARBON CEILING

Zhe (Han) Weng[1,2,3,4], Lukas Van Zwieten [1,5], Ehsan Tavakkoli [6,7], Michael T. Rose[1], Bhupinder Pal Singh[2], Stephen Joseph[8,9], Lynne M. Macdonald[10], Stephen Kimber[1], Stephen Morris[1], Terry J. Rose[5], Braulio S. Archanjo [11], Caixian Tang[3], Ashley E. Franks [12,13], Hui Diao[14], Steffen Schweizer [15], Mark J. Tobin[16], Annaleise R. Klein[16], Jitraporn Vongsvivut[16], Shery L. Y. Chang[17], Peter M. Kopittke [4] & Annette Cowie [2,18]

ABSTRACT

The soil carbon (C) saturation concept suggests an upper limit to the storage of soil organic carbon (SOC). It is set by the mechanisms that protect soil organic matter from mineralization. Biochar has the capacity to protect new C, including rhizodeposits and microbial necromass. However, the decadal-scale mechanisms by which biochar influences the molecular diversity, spatial heterogeneity, and temporal changes in SOC persistence, remain unresolved. Here we show that the soil C storage ceiling of a Ferralsol under subtropical pasture was raised by a second application of *Eucalyptus saligna* biochar 8.2 years after the first application—the first application raised the soil C storage ceiling by 9.3 Mg new C ha^{-1} and the second application raised this by another 2.3 Mg new C ha^{-1}. Linking direct visual evidence from one-, two-, and three-dimensional analyses with SOC quantification, we found high spatial heterogeneity of C functional groups that resulted in the retention of rhizodeposits and microbial necromass in microaggregates (53–250 µm) and the mineral fraction (<53 µm). Microbial C-use efficiency was concomitantly increased by lowering specific enzyme activities, contributing to the decreased mineralization of native SOC by 18%. We suggest that the SOC ceiling can be lifted using biochar in (sub)tropical grasslands globally.

INTRODUCTION

Human activities risk releasing 260 Pg of ecosystem carbon (C) as carbon dioxide (CO2) globally that is irrecoverable on a timescale relevant to avoiding profound climate impacts[1,2]. Agriculture contributes a major part, releasing an average of 2 Mg C ha^{-1} y^{-1} from soil globally[3,4,5]. Plants release ~50% of photosynthetically fixed C into the soil, which supports microbial growth and metabolism, including respiration that produces CO2. It has been estimated that 122 Mg soil organic C (SOC) ha^{-1} to a depth of 1 m has been lost over 1 Mha of land converted to tropical grasslands[6], with 40% of this area occurring on Ferralsols[7]. The grand challenge humanity now faces is to urgently reverse this loss of SOC and associated decline in soil health by increasing the amount of C retained in soil[5,8,9].

The Intergovernmental Panel on Climate Change (IPCC) has identified that substantial CO_2 removal will be required to limit global warming to 2 °C. To this end, the IPCC has identified soil C management[4,5,6] and the application of biochar[10] as carbon dioxide removal (CDR) methods[11] with considerable potential, with corollary benefits of improving soil health, sustaining agricultural productivity[12,13], and increasing the resilience of ecosystem services[14,15]. Protecting and rebuilding soil C could sequester 5.5 Pg CO2 y^{-1}, representing 25% of the potential of natural climate solutions to deliver CDR through conservation, restoration, and improved land management practices[6,16,17].

Application of biochar is a recognized CDR method because of its persistence[9,11] in the environment. The pyrolysis of biomass can deliver bioenergy, as well as agronomic and non-CO_2 greenhouse gas benefits through the use of biochar as a soil amendment[18,19,20,21,22]. Biochar systems generally show life-cycle climate change impacts of net emission reduction in the range of 0.4–1.2 Mg CO_2 equivalent Mg−1 dry feedstock[23], through C persistence and avoided non-CO_2 emissions. The capacity for biochar to further contribute to mitigation by protecting and building SOC is often overlooked.

Here, we assess the capacity and mechanisms by which biochar builds new biogenic SOC reserves. We propose a mechanism by which biochar accelerates the formation of microscale organo-mineral and nanoscale organo-organic interfaces in soil microaggregates (53–250 µm) and mineral fractions (<53 µm) to protect SOC from degradation[24,25,26,27,28,29] (Fig. 1). These processes are examined in detail, including SOC mineralization in the presence of roots, microbial C-use efficiency, spatial distribution of C functional groups, and mineral protection of SOC, to quantify the potential of biochar to lift the SOC storage ceiling. We demonstrate the importance of fine-scale spatial heterogeneity and temporal variability of diverse C functional groups associated with mineral fractions for building and protecting rhizodeposits over a decade.

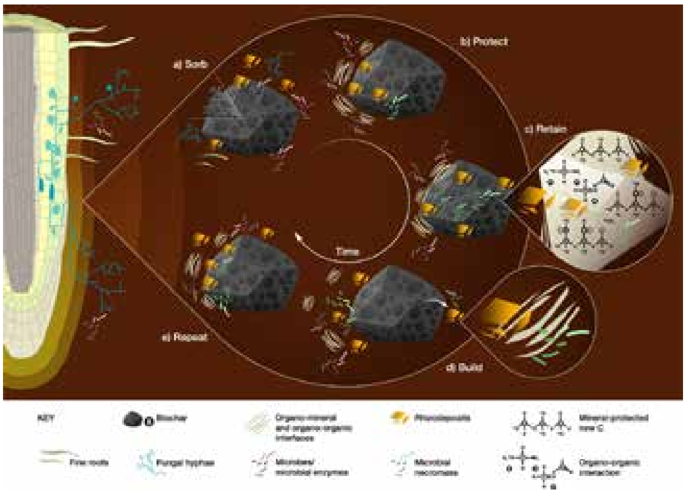


Fig. 1: Conceptual diagram of the formation of protected aggregates from catalytic biochar surfaces over time in a Rhodic Ferralsol.

a Biochar sorbs root-derived carbon (rhizodeposits) onto its surface, protecting the rhizodeposits from immediate microbial consumption. **b, c** The rhizodeposits form organic interfaces with biochar, and organo-mineral interfaces with very fine layers of soil minerals that accumulate on the biochar, that protect **(b)** and retain (**c)** rhizodeposits within the biochar coating. Over time, microbial necromass also adsorbs to biochar being retained in similar protective interfaces. **d** New organic and organo-mineral coatings can build on the biochar surface. **e** The process repeats, to develop new, protected SOC over time.

RESULTS AND DISCUSSION

Lifting the storage ceiling of soil organic carbon

To examine the potential for biochar to protect soil organic matter from microbial degradation, we measured SOC stocks in a biochar-amended, managed pasture over 9.5 y. The field site, converted to managed pasture from subtropical forest 100 y ago,

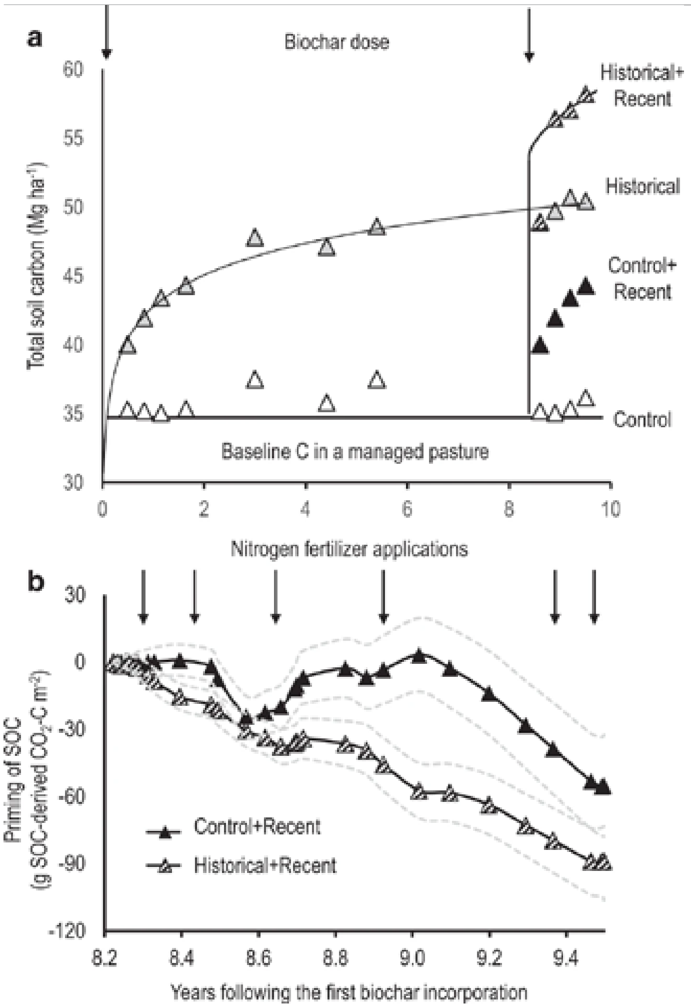


Fig. 2: Belowground carbon dynamics in a long-term continuous biochar field experiment.

a Changes in total soil organic carbon (SOC, Mg C ha−1) in the 0–75 mm soil layer of the Control and biochar-amended soils over 9.5 y (n = 3, LSD = 1.1). **b** Rhizosphere priming, shown as the difference in cumulative SOC mineralization between planted and unplanted systems of Control+Recent and Historical+Recent soils. Shaded regions in **b** represent 95% confidence intervals normalized against the mean squares across both treatments at each sampling event (n = 3). Confidence intervals were based on a sensitivity analysis that considers the extreme scenarios of contrasting SOC pools (C3 vs. C4-dominated) by differences in δ13C soil signatures.

had a SOC stock 17% lower than the adjacent native rainforest in the 0–75 mm topsoil layer. Soil was subjected to four treatments as Control: no biochar application; Historical: biochar applied once at trial establishment (2006); Control+Recent: biochar applied after 8.2 y to the original Control plots; and Historical+Recent: biochar applied after 8.2 y to original Historical plots, i.e., two biochar applications (Supplementary Table 1). Otherwise, field plots were managed (sown with annual ryegrass, fertilized, and harvested) identically.

Our results showed that the SOC storage ceiling could be lifted through either single or multiple applications of biochar (Fig. 2a). The Control stored 35 (±1.3) Mg C ha^{-1} in the topsoil (0–75 mm), while the Historical plots stored 50 (± 1.1) Mg C ha^{-1} at 9.5 y after biochar addition (Fig. 2a). When biochar was added to the Control plots after 8.2 y (Control + Recent), the SOC storage capacity was raised to 44 (±0.7) Mg C ha^{-1} 1.3 y following biochar application. A second application of biochar after 8.2 y (Historical + Recent) raised the total SOC to 58 (± 0.2) Mg C ha^{-1} 1.3 y later. The total increase of 15 Mg C ha^{-1} after 9.5 y in Historical plots consisted of 5.7 Mg biochar-C ha^{-1} in the topsoil plus an additional 9.3 Mg C ha^{-1} from the enhanced SOC accumulation. Furthermore, this enhanced SOC accumulation could be increased by multiple applications of biochar—the total increase of 23 Mg C ha^{-1} in the Historical+Recent treatment after two biochar applications over 9.5 y consisted of 11.4 Mg biochar-C ha^{-1} and 11.6 Mg C ha^{-1} from enhanced SOC accumulation (1.01 Mg new SOC per Mg biochar-C). Thus, the second application of biochar in the Historical+Recent plots increased the SOC storage capacity by an additional 2.3 Mg new C ha^{-1} compared to the Historical soil with a single application of biochar, with this being a 25% increase in new SOC accumulation caused by the second application of biochar.

The increase in SOC storage was due to a decrease in net cumulative SOC mineralization (defined as negative priming). The Historical+Recent treatment lowered SOC mineralization in the presence of roots by 89 g CO_2-C m^{-2} over 1.3 y compared with Control+Recent soils, in which SOC mineralization dropped by 55 g CO_2-C m^{-2} ($P < 0.05$, Fig. 2b). Neither Historical+Recent nor Control+Recent soils exhibited changes in soil, soil+root, or root respiration compared to the Control soils ($P > 0.05$, Supplementary Figs. 2 and 3). As a portion of the total CO_2 flux, root respiration remained relatively consistent (27–36%) and was unaffected by treatments within each pulse labelling event ($P > 0.05$, Supplementary Table 2).

To further examine this decrease in SOC mineralization, we partitioned rhizodeposits (root C) from biochar C and SOC within aggregate size and density fractions. Historical+Recent soils had a similar proportion of total recovered ^{13}C (58 ± 5.7 %, Fig. 3a) as Historical soils (60 ± 9.8%), with this being around 18% greater than Control (42 ± 7.3%) and Control+Recent soils (45 ± 4.5%; Fig. 3b) after the pulse-labelling event at 9.5 y ($P < 0.05$; Supplementary Table 3). This increase in belowground ^{13}C retention could be largely explained by an increase in ^{13}C associated with mineral-protected soil organic matter (M-SOM), which increased by 14% in Historical+Recent compared with Control+Recent soils ($P < 0.05$, Supplementary Table 4). Initially, Historical+Recent soils nearly doubled the ^{13}C retention in the occluded particulate organic matter (O-POM) fractions of microaggregates (5 mg ^{13}C m^{-2}) and M-SOM fractions of macroaggregates (14 mg ^{13}C m^{-2}) at

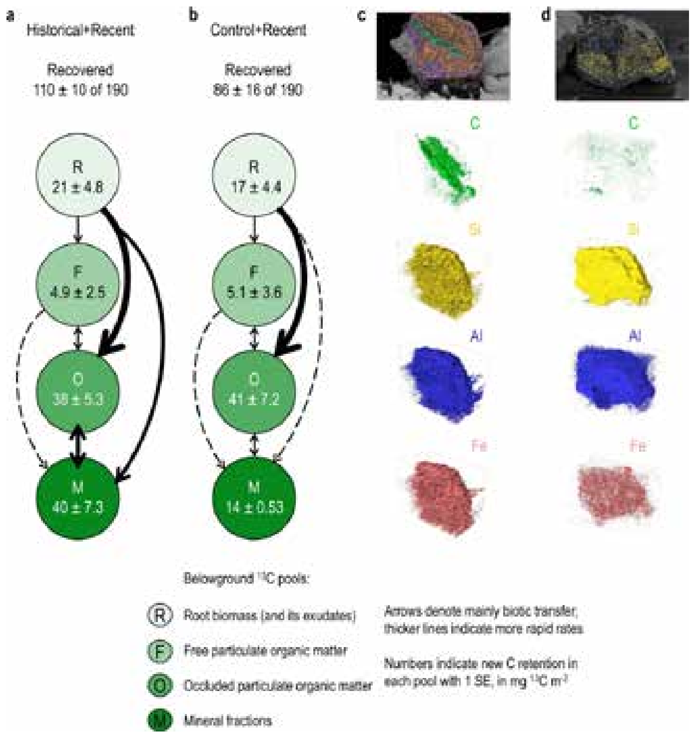


Fig. 3: Allocation and retention of rhizodeposits (^{13}C-enriched) and three-dimensional (3D) elemental distribution in a biochar-amended Ferralsol at 9.5 y.

New C retention in different belowground carbon pools from Historical+Recent **(a)** and Control+Recent **(b)** soil (n = 3). The total recovery of ^{13}C from ^{13}C-CO_2 pulse labelling (± SE) is given for soil + root respiration, root biomass, free and occluded particulate matter, and mineral fractions 15 days after labelling each plot with 190 mg 13C-CO_2 m−2. **c, d** Three-dimensional focused ion beam scanning electron microscopy energy dispersive spectroscopy (3D FIB-SEM-EDS) of an intact soil aggregate from a Historical+Recent biochar plot (**c,** 30 μm × 25 μm × 24 μm) or Control+Recent plot (**d,** 30 μm × 20 μm × 30 μm), showing distribution of carbon, silicon, aluminium, and iron.

8.9 y compared to Control+Recent soils (Supplementary Fig. 4a, b). The root-derived ^{13}C from rhizodeposition was gradually accumulated into O-POM and M-SOM in macroaggregates at 9.2 y (Supplementary Fig. 4c, d), which transformed into the M-SOM fraction in micro- and macroaggregates by 9.5 y (Supplementary Fig 4e, f).

Microbial contribution and responses to the retention of rhizodeposits

To determine the microbial contribution to this increased SOC storage capacity, we quantified catabolic enzyme activities, metabolic quotients of native SOC (bulk soil) and rhizodeposition (^{13}C content), and specific enzyme activity in Control+Recent and Historical+Recent soils. Microbial biomass increased by 8–12% in Control+Recent compared with Historical+Recent soils between 8.9 and 9.5 y (Supplementary Table 5), as a result of the stimulation of microbial co-metabolism[30] by the addition of biochar-C to a previously unamended soil, which also induced a small positive priming effect in Control+Recent soils (Fig. 2b). Historical+Recent soils increased substrate-induced respiration for citric, malic, and protocatechuic acids compared to Control+Recent soils, but no differences were detected for 12 other C substrates that are all common in agricultural soils (Supplementary Fig. 5).

This greater respiration induced by carboxylic and phenolic acids (common in root exudates) partially explained the higher metabolic quotient associated with bulk SOC in Control+Recent than Historical+Recent soils (Supplementary Table 5). Lower metabolic quotients indicate higher substrate-use efficiency, so the lower metabolic quotient observed in Historical+Recent soils supports the more rapid establishment of negative priming than in the Control+Recent soils 8.2 y after the biochar addition (Fig. 2b). This suggests that the microbial accessibility to SOC might be limited in the Historical+Recent plots, whereas in the Control+Recent biochar, the soil microorganisms had to adapt to a change in C-substrate type and availability[31].

The ratio of extracellular enzymes to microbial biomass (specific enzyme activity) can be used to indicate the C-turnover efficiency of the soil microbial community, and a low specific enzyme activity can retard the mineralization of native SOC[32]. Here, the ratio of enzyme activity-to-microbial biomass was similar in both Historical+Recent and Control+Recent soils compared to the Control soil (Supplementary Table 6) despite the reduced enzyme activities (Supplementary Table 7). This is consistent with decreased metabolic quotients/increased microbial C-use efficiency (Supplementary Table 5) for bulk SOC but not root-derived C in the amended soils, which indirectly contributes to negative priming (Fig. 2b). The presence of opportunistic microbes that meet their energy and nutrient demands by exploiting the catalytic activities of decomposers could lower the specific enzyme activity[32].

It is noted that sorption affinities of the fluorophore and/or the enzyme to biochar compared to other soil surfaces may lead to underestimating enzyme activities[33]. Here, we used matrix-matched standard curves to account for any potential binding (or quenching/excitation) of the fluorophore. The fluorescence response of standard curves constructed using the soil matrix with or without biochar were not significantly different (Supplementary Table 9), suggesting that fluorophore sorption, quenching, or excitation did not contribute to the observed differences in enzyme activities.

Spatial heterogeneity of SOC

Our study provides the first visual evidence of a mechanism by which biochar can accelerate the formation of organo-mineral and organic interfaces in soils to protect SOC from microbial degradation, summarized in Fig. 1. Biochar can sorb root-derived C (rhizodeposits) that forms biofilms on its surfaces (Figs. 1a and 3a). The very fine layer of soil minerals that accumulate on biochar as it ages in soil[30,34,35] protects rhizodeposits from microbial metabolism[36,37] over time. Microbial necromass is also incorporated into this coating of organo-mineral and organic interfaces and is protected from degradation[38,39,40,41,42,43,44] (Figs. 1b, c, 4, and 5). A coating can build on the biochar surfaces (Fig. 1d) and the processes repeat to build rhizodeposits in soil over time (Fig. 1e). Our spectroscopic data showed the formation of clay–organic complexes as one possible mechanism by which biochar promotes the accumulation of new biogenic SOC.

To visualize the retention of rhizodeposits and microbial-derived C, we undertook one-dimensional (1D) spectroscopic, two-dimensional (2D) microspectroscopic, and three-dimensional (3D) electron microscopic analyses of SOC spatial heterogeneity. We provided direct visual evidence of the spatial heterogeneity at the nano- to micro-scales. To better understand the process of negative priming following biochar application, we mapped the elemental composition within intact aggregates to determine whether the retention of rhizodeposits (and other forms of C) may be facilitated via protection by Fe and Al-rich soil minerals. The 3D distribution of C, Si, Al, and Fe was assessed using a focused ion beam (FIB) coupled with scanning electron microscopy (SEM) and elemental detection provided by energy-dispersive X-ray spectroscopy (FIB-SEM-EDS; Fig. 3c, d). These results illustrate how C (including rhizodeposits) can be retained through the formation of organo-mineral complexes with Fe oxides in the soil (Fig. 1b; Supplementary Movie 1).

We further examined biochar extracted from the Control+Recent soil on a nanometre scale by directly analyzing the chemical composition of the organo-mineral and organo-organic coatings on the biochar surface and in its pores. An image of the area where fungi were located inside a biochar pore shows a high concentration of irregular pores and a coating of organic material (Fig. 4a, b). Fungi can mine nutrients from minerals by exuding acids[45,46] that may cause the observed microporosity of organo–mineral–biochar interfaces (Figs. 4a–c, e, S6). Complex changes had occurred on the biochar surface over 1.3 y, revealed by EDS analysis (Figs. 4f, S6c–f). One possible mechanism is that positively-charged nanoparticulate minerals rich in Al, Si, Ca, P, and Fe can be attracted to the surface of the negatively-charged biochar. These positively-charged minerals subsequently attracted negatively-charged organic molecules with detectable concentrations of C=C, C–OH, C–N/C=N, C=O, COOH functional groups, quinone bonds, and anions, thus initiating a process whereby porous clusters were accumulated on the biochar surface (Fig. 4d, g, h; Supplementary Table 9). It is also noted that Fe-Al-oxyhydroxide minerals can have both positive and negative net surface charge depending on pH (i.e., they are variable charge minerals). Most biochars are dominated by neutral carboxyl or negative carboxylate groups (depending on pH), but some biochars may also have positively-charged oxonium groups. Using synchrotron-based soft X-ray (SXR) spectroscopy (Fig. 4i), we observed greater intensities of carboxyl COOH (288.6 eV) in the 9.5-y aged biochar (10.6%) compared with the 1.3-y aged biochar (6.1%; Supplementary Table 11). Similarly, exudates from plants and microorganisms can be deposited around minerals and attracted by cations onto biochar surfaces. Recent biochar application to the Historical plots would provide new unoccupied surfaces and pores in the soil to increase sorption capacity for root exudates[47] (Fig. 1a), which would then serve as binding agents to further enhance aggregation[48]. As these clusters build, they may also be detached from the biochar either through fluctuating redox conditions, interaction with microbes, or perturbation caused by soil invertebrates or human activities[34] (Fig. 1d). These results provide direct evidence of repeated cycles of formation of organo-mineral coatings on the biochar surfaces during aggregate turnover or in response to changes in soil conditions, with these processes accumulating rhizodeposits in soil over time.

These biochar micro-sites have a high concentration of free radicals with low-molecular-weight organic C and/or inorganics dissolved from the biochar (Supplementary Table 9). Colloidal biochar particles, leachates, dissolved native SOC, and rhizodeposits may be further retained separately or held together via cation bridging with Ca2+ or Al and Fe oxyhydroxides[49,50,51] and/or organic interactions at the nanoscale[52] (Fig. 4f, h). These processes may be encouraged by oxidation of the biochar surface as it ages in soil[39,40]. This hypothesis is supported by

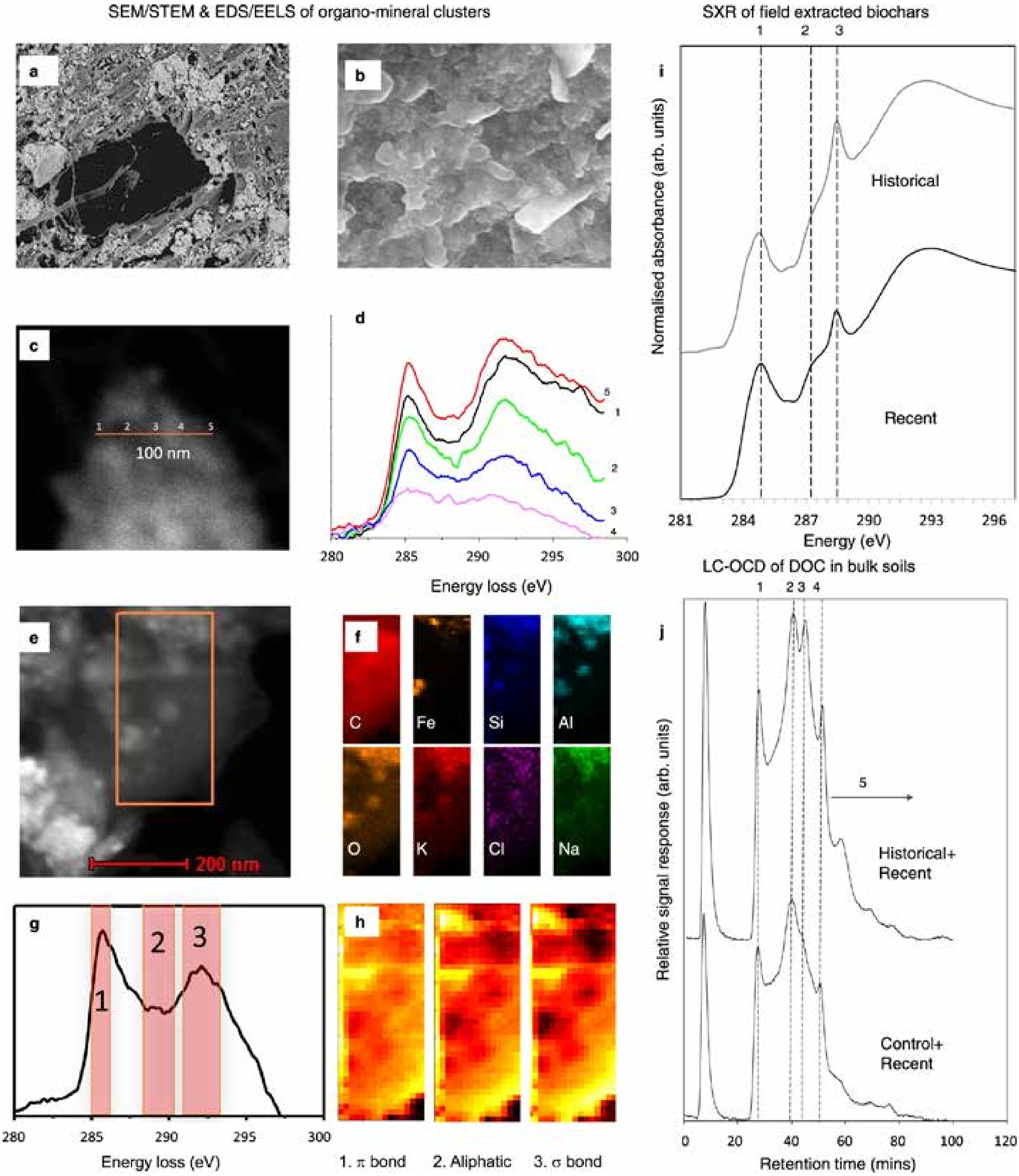


Fig. 4: In situ spectromicroscopic analysis of the organo-mineral coating on biochar surfaces and pores.
a A pore in biochar that was recovered from the Historical plots (scanning electron microscopy [SEM]). Bar, 50 µm. **b** Surface of the organo-mineral layer inside the biochar pore from Historical plots (SEM). Bar, 200 nm. **c** Organo-mineral clusters on a biochar surface from the Control+Recent plots (high-angle annular dark-field scanning transmission electron microscopy [HAADF-STEM]); **d** the electron energy loss spectra (EELS) at positions 1–5 of the clusters in **(c)**. **e** A deposit attached to the surface of biochar from the Historical plots (HAADF). **f** 2D elemental mapping of the boxed area in e (energy-dispersive spectroscopy [EDS]. g EELS of the boxed area in **(e).** **h** Mapping integration of EELS regions 1–3 in **(g)**. **i** Average soft X-ray (SXR) emission spectra of field-extracted Control+Recent (1-y) and Historical (9.5-y) biochars (n = 9, CV < 3%). **j** Dissolved organic content (DOC) of Historical+Recent and Control+Recent soils (liquid chromatography-organic carbon detection [LC-OCD]). The hydrophilic fraction is further sub-divided into five categories: biopolymers, persistent C, building blocks, low molecular weight acids, and low molecular weight neutral molecules.

liquid chromatography-organic carbon detection (LC-OCD), which reveals that total dissolved organic C, hydrophobic C fractions, and building blocks (oxidized persistent C including polyaromatic acids and polyphenols) were higher in Historical+Recent than in Control+Recent soils (Fig. 4j; Supplementary Table 10). The analysis of the surface of the 9.5-y aged biochar by C-edge energy electron loss spectroscopy (EELS) and X-ray photoelectron spectroscopy (XPS) indicated that most of the oxidized C species were formed in the organo-mineral coating (Fig. 4f–h). The concentrations of the different functional groups were influenced by the presence of nanophase Fe, Si, and Al oxides[52].We further validated the nanoscale observations of biochar surfaces in soil at the microscale. To differentiate the molecular diversity of organic compounds and their lateral arrangement with respect to organo-mineral interfaces, we conducted in situ spectromicroscopic analysis using SXR (Fig. 5a) and synchrotron-based infrared microspectroscopy (IRM; Figs. 5b, S7, S8). We examined intact water-stable microaggregates (53–250 µm) and the mineral fraction (<53 µm) from Historical+Recent and Control+Recent soils. SXR analyses revealed that the C functional groups in the microaggregates were dominated by quinones, aromatic C (1s-π* transitions of conjugated C=C), aliphatic C, and carboxylic C (Fig. 5a), which are derived from biochar and rhizodeposits. The relative proportion of functional groups was similar between Control+Recent and Historical+Recent soils (Supplementary Table 11). The mineral fraction was characterized by dominant peaks of aliphatic, amide, and carboxylic C, suggesting deposition of microbial metabolites or debris, exopolysaccharides, and root exudates onto mineral surfaces[27,53,54,55,56,57]. The proportion of aliphatic C nearly doubled in the Historical+Recent treatment (30.6%) compared with the Control+Recent treatment (15.6%; Supplementary Table 11). These data provide evidence of rhizodeposits and microbial necromass incorporation into SOC, with rhizodeposits predominantly in microaggregates rather than mineral fractions. This difference indicates that retention of rhizodeposits in SOC relies on forming complex organic and organo-mineral interfaces with microbial necromass and biochar, while microbial necromass can be protected by organo-mineral

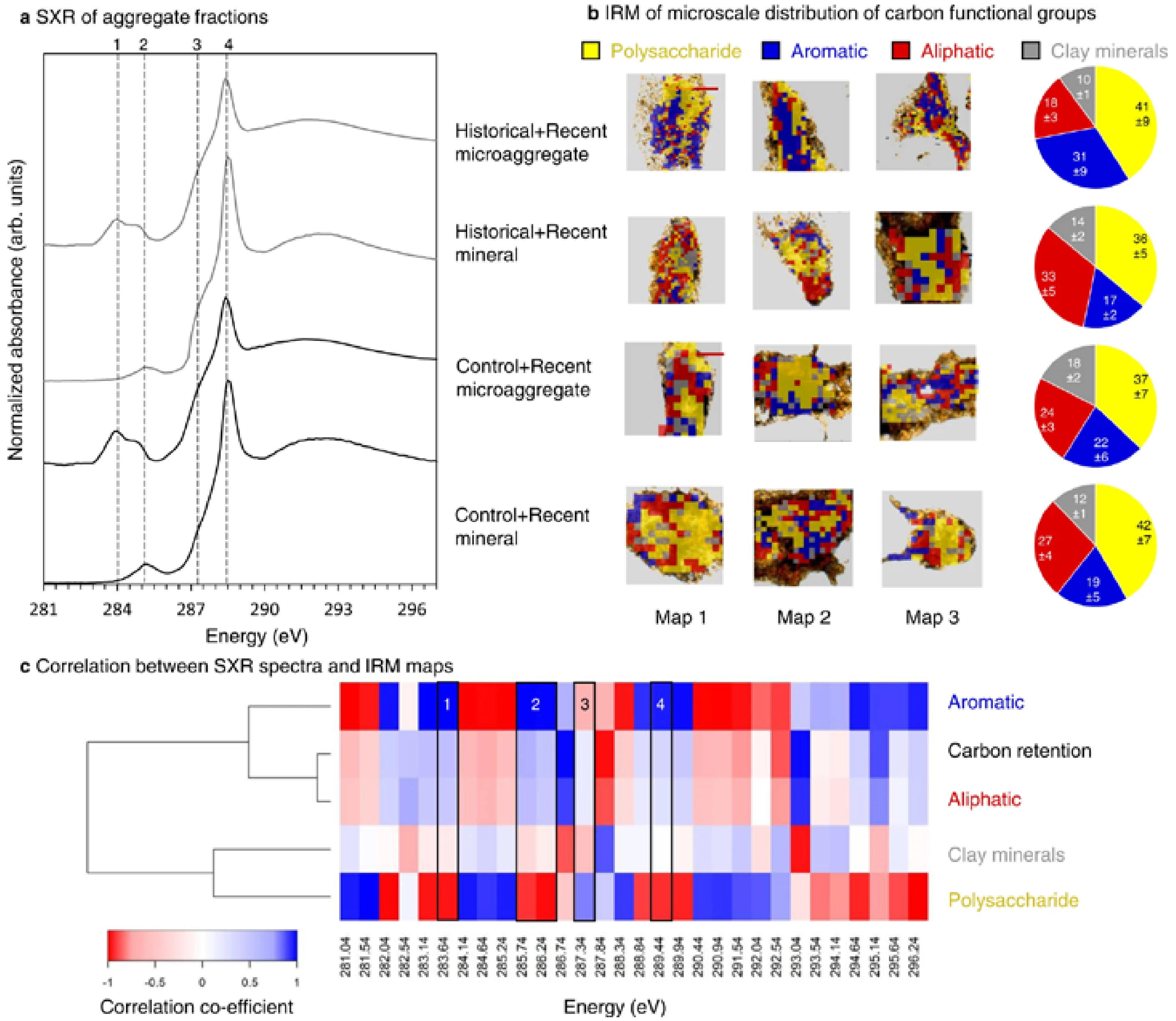


Fig. 5: Synchrotron-based spectromicroscopic analysis of microaggregates (53–250 µm) and mineral fractions (<53 µm) in Control+Recent and Historical+Recent soils.
a Average soft X-ray (SXR) spectra of microaggregates and mineral fractions from Historical+Recent and Control+Recent plots (n = 9, CV < 3%), featuring quinones, aromatic C, aliphatic C, and carboxylic C. **b** Semi-thin (200 nm) sections of free water-stable microaggregates and mineral fractions isolated from Historical+Recent and Control+Recent plots analyzed using synchrotron-based infrared-microspectroscopy (IRM). Spectral maps showing the distribution of polysaccharide-C (1035 cm−1), aromatic-C (1600 cm−1), aliphatic-C (2920 cm−1), and clay mineral-OH (3650 cm−1) obtained from 64 co-added scans, overlaid on optical micrographs of the semi-thin sections. Bars, 50 µm. Pie charts display normalized optical proportions of the four features analyzed by an image processing pipeline (Supplementary Fig. 10 and Supplementary Table 12). **c** Hierarchical clustering dendrogram indicating similarity relationships between C functional groups from SXR (first derivatives), and their distribution from IRM or belowground C retention (Fig. 3a, b) across biochar treatments.

interfaces in mineral fractions.

These SXR results also align with the micro-spatial maps produced from IRM analyses of sections taken from intact aggregates (Fig. 5c). The correlation between clay minerals and microbial metabolites (aliphatic-C) in the microaggregates was stronger in Historical+Recent soils than in Control+Recent microaggregates ($R2 = 0.96$ vs. 0.86, Supplementary Fig. 9). In contrast, the correlation of microbial-derived C with clay was similar for both mineral fractions ($R2 = 0.94$–0.95). The correlation between polysaccharide-C and clay was much greater in Historical+Recent than in Control+Recent microaggregates ($R2 = 0.83$ vs. 0.46, Supplementary Fig. 9). We developed an image processing pipeline to quantify the distribution of C forms in association with clay from IRM (Supplementary Fig. 10). For the microaggregates, a greater proportion of aromatic-C (31% of pixels across the intact section) was found in Historical+Recent soil compared with Control+Recent soil (22%) because of the biochar persisting in Historical soils from the original soil amendment at the trial establishment (Fig. 5b; Supplementary Table 12). The distribution of polysaccharide-C (36–42%), aromatic-C (17–19%), aliphatic C (27–33%), and clay (12–14%) was similar in the two mineral fractions (Fig. 5b; Supplementary Table 12). These observations agree with new C retention in belowground ^{13}C pools (Figs. 3a, b and 5c), highlighting the importance of clay minerals for protecting SOC from microbial mineralization.

Potential global impact of lifting the soil carbon ceiling

The elevation of the SOC ceiling observed in our trial has significant implications for the global efforts to build SOC[9,58,59]. We have estimated the magnitude of the potential CDR that could be delivered if the SOC increase demonstrated here is extrapolated to similar contexts globally. Based on global potential production of woody feedstock of 0.48–0.90 Pg C y^{-1}, assuming that this biochar is applied to Ferralsols under tropical pasture with the same response of about 1.01 Mg new SOC per Mg biochar-C over two applications applied, an additional soil C sink of 0.23–0.45 Pg C y^{-1} could be potentially achieved. This increase represents a substantial increase over the current contribution of grasslands of 0.04 Pg C to the global SOC pool[6].

In our study, we raised the SOC storage capacity in a subtropical soil with a strategic application of a *Eucalyptus saligna* biochar (550 °C) 8.2 y after the original biochar application. Of importance to building soil C stocks, a second application of biochar to previously amended soils resulted in 2.3 Mg new C ha^{-1} (i.e., microbial necromass and rhizodeposits) being stored as SOC (Historical + Recent vs. Historical, Fig. 2a). Our in situ spectromicroscopic analyses at the molecular to microaggregate scales showed accumulation of clay mineral-organic complexes in the soil. This spectroscopic evidence supports our proposed model (Fig. 1) for one possible mechanism by which biochar promotes the accumulation of new biogenic SOC. This mechanism, if found to apply in other tropical Ferralsols, could substantially increase the potential for CDR through the use of biochar.

METHODS

Field site details

The field experiment was situated at the Wollongbar Primary Industries Institute (28°49'S, 153°23'E, elevation: 140 m), Wollongbar, New South Wales, Australia. The classification and properties of the soil can be found in Weng *et al*[60].. Briefly, the soil is a Rhodic Ferralsol, a fine-textured and Fe-rich mineral soil dominated by kaolinite, gibbsite, and goethite. The 100 mm topsoil was pH_{CaCl2} 4.5, with 35 g kg^{-1} C, 84 g kg^{-1} Fe, and 67 g kg^{-1} Al.

Details of the initial field site establishment in 2006 are in Slavich *et al.*[61]. Each of the three replicate plots was treated either with biochar incorporated into the topsoil (0–100 mm) at 10 Mg ha^{-1} (1% w/w, 7.6 Mg biochar-C ha^{-1}, applied to 100 mm depth) plus nitrogen phosphorus potassium (NPK) fertilizer ('*Historical*'), or NPK only ('*Control*'). An annual ryegrass (*Lolium multiflorum*) was seeded each year at 35 kg seed ha^{-1}. Urea was applied at 46 kg N ha^{-1} six times each year (276 kg ha^{-1} total) in winter and spring following manual cutting of pasture grass to simulate grazing. Basal nutrients containing P and K were applied annually at sowing[61]. At 8.2 y after trial establishment (April 2014), each Historical and Control plot was superimposed with subplots (0.5 m × 0.5 m), and biochar added again at the same rate to subplots ('*Historical + Recent*' and '*Control + Recent*'). Field sites were maintained as previously described for a further 1.3 y.

The same biochar batch was added to the field site in 2006 and 2014. Biochar was derived from a single source of aboveground biomass of mature *Eucalyptus saligna*, pyrolyzed at 550 °C for 30 min (Pacific Pyrolysis, NSW, Australia), and sieved to <2 mm before application. The biochar density was 0.332 g cm^{-3} (following Quin *et al.*[62]), and its chemical properties are described in Slavich *et al.*[61]. For storage, biochar was air-dried and archived in sealed 200 L steel containers at room temperature. Biochar (10 Mg ha^{-1}) was mixed with 100 mm topsoil and repacked into plots to a bulk density of 1 g cm^{-3}; plots to which no biochar was added were also excavated and repacked to the same bulk density. The topsoil±biochar was weighed before repacking to determine soil bulk density for each treatment.

Soil and root respiration collars

Specialized respiration collars were used to isolate soil-only and soil+root respiration from shoot respiration[43,60] (Supplementary Fig. 1). A sand+root collar (50 mm diameter) packed with acid-washed sand and planted with ryegrass was installed in each Control subplot to measure root-only respiration. A similar sand+root collar was packed with a biochar–sand mixture (1% w/w) in each Historical+Recent subplot. NPK fertilizers were applied as described above to maintain root growth into the collars. Moisture content was maintained at 60–80% field capacity in the root collars to minimize C isotopic fractionation during photosynthesis caused by water stress[63].

Soil sampling

Soils were sampled at 8.9, 9.2, and 9.5 y after trial establishment. Intact soil cores (40 mm diameter) were sampled to 75 mm depth within each subplot, outside the respiration collars to reduce disturbance. Note that although 7.6 Mg biochar-C ha^{-1} was incorporated to 100 mm depth, soils were sampled to 75 mm depth because the trial originally started as an 'agronomic assessment of biochar' and the industry standard for pasture soil analysis was 0–75 mm sampling. Hence, the amount of biochar-C in the top 75 mm layer was estimated to be 5.7 Mg biochar-C ha^{-1} assuming no lateral movement of biochar. This may underestimate new SOC accumulation. Previously sampled areas were avoided in subsequent sampling events. Samples were mixed evenly and analyzed for pH, total SOC, and microbial biomass C (MBC). Total SOC was measured on an equivalent-mass basis using Dumas combustion[60], and converted to soil C density using the bulk density of each biochar treatment. Soil pH was measured on soil suspensions (1:5 w/w soil:water) using an IntelliCAL PHC101 pH probe on a Hach HQ40d portable metre (Loveland, Colorado, USA). The metabolic quotients of total C or rhizodeposits were then quantified as the ratio of respiration (native SOC or ^{13}C-labelled root respiration) over total MBC. The remaining soil was stored at −20 °C.

SOC priming in the plant–biochar–soil systems

To understand how plant–biochar–soil interactions affect SOC priming, the $\delta^{13}C$ signature of CO_2-C from soil-only, soil+root, and sand+root samples was measured before and after pulse labelling events (Supplementary Fig. 1). The C content and $\delta^{13}C$ signatures of bulk soil, aggregates, and fractions, were measured using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK), according to Weng *et al.*[60].Three pulse labelling campaigns were conducted on three occasions: 12 June 2014, 01 August 2014, and 30 July 2015. Each event applied 190 mg ^{13}C m^{-2} as the label and was analyzed as an independent experiment assuming no retention of ^{13}C from prior events. The excess of enriched ^{13}C-CO_2 from soil+root ($\delta^{13}C_{Total}$) and sand+root ($\delta^{13}C_{Biochar}+_{Root}$) respiration was measured 3, 5, 10, and 15 d after each pulse labelling event. Soil-only respiration was measured in Control plots with no pulse labelling ($\delta^{13}C_{Soil}$) and at 15 d after pulse labelling ($\delta^{13}C_{Total'}$). Biochars were recovered by hand from soil samples, thoroughly rinsed with distilled water on a 100 μm sieve, and oven-dried at 50 °C for 24 h. The $\delta^{13}C$ signatures of aged biochar (from Historical subplots) and new biochar (from Control+Recent subplots) were both −25.0 ± 0.1‰.

The rhizosphere priming of native SOC was quantified using a three-pool C partitioning model: biochar-C, root-C, and SOC. Any interactive effect of biochar and root on the $\delta^{13}C$ signature of soil would be surpassed by a greater level of $\delta^{13}C$ enrichment of the root component compared with any isotopic signature contribution from soil and biochar to the $\delta^{13}C$ signature of the total respiration.

The mineralization of native SOC (C_{Soil}) in the presence of plant roots was calculated by:

$$C_{Soil}\ (\%)=100\times(\delta^{13}C_{Total}-\delta^{13}C_{Biochar+Root})/(\delta^{13}C_{Soil}-\delta^{13}C_{Biochar+Root})$$

Similarly, the proportion of soil-derived CO_2-C in total respiration from plant-free soil (CSoil’) was determined by:

$$C_{Soil'}\ (\%)=100\times(\delta^{13}C_{Total'}-\delta^{13}C_{Biochar})/(\delta^{13}C_{Soil}-\delta^{13}C_{Biochar})$$

Rhizosphere priming of SOC in the biochar system was the difference in native SOC mineralization between the plant-containing and plant-lacking systems, partitioned from biochar endmembers:

$$Priming=(C_{Soil}(\%)\times C_{Total}-C_{Soil'}(\%)\times C_{Total'})/100$$

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BEE INFORMED

We are showcasing the six decades of research, development and extension (RD&E) projects that have contributed to the humble, yet vital honey bee and pollination industry.

Pollination is critical to the production of many of our favourite foods and Australia's food security, with 65% of horticultural and agricultural crops dependent on honey bees for pollination - making up one in every three mouthfuls of food we eat.

The industry has come a long way since 1962 when commercial beekeepers first contributed to an industry levy. There has been a 10-fold increase in recreational beekeeping, as well as major increases in commercial beekeeping, with approximately 530,000 commercially managed hives across Australia that are available to deliver paid pollination services. In 2019, the almond industry hired 180,000 hives for crop pollination.

> **"Without bees, fruits, seeds, nuts and vegetables would not make it from the paddock to our plates,"**
>
> **Annelies McGaw**

The growth and advancements in the honey bee and pollination industry can be attributed in part to the 60 years of RD&E projects funded through the honey bee levy, which was collated into a compendium of research earlier this year – Bee Informed.

AgriFutures Honey Bee and Pollination Program Manager, Annelies McGaw, said the development of Bee Informed was crucial to ensure that earlier work that was not digitised would not be lost.

"Collating the industry's years of research was critical to document what we know and what we need to learn to ensure the longevity of honey bees and pollination in Australia," Annelies said.

"Projects we are investing in today like the Optimisation and Evaluation of an External Trap as a Mass Trapping and Monitoring Device for Small Hive Beetles project have built upon the historic RD&E projects detailed in Bee Informed," Annelies said.

Bee Informed contains a whopping 280 projects investigating pollination and a range of other key topics relating to pests and disease, nutrition, genetic improvement, floral resources, off-farm issues, and communication and extension. The publication outlines the diversity, breadth and purpose of the research undertaken over the years, the outcomes of each project, the implications for the industry, and the key benefits for commercial apiarists.

"Without bees, fruits, seeds, nuts and vegetables would not make it from the paddock to our plates," Annelies said.

"We want to raise awareness about these unique pollinators so that we can secure the pollination of Australia's crops and continue to build a brighter future for our bees, and also celebrate the many years of research and collaborations that have helped to build the united and resilient industry we have today," Annelies said.

"This is especially important given the challenges the industry has faced over the past few years with bushfires, floods, and the recent incursion of Varroa mite having devastating impacts on hives, honey production and the nation's horticultural and agricultural sectors."

AgriFutures Honey Bee and Pollination Program is continuing to invest in research that reflects and responds to industry needs and concerns. Current focus areas of the program are:

- Nutrition best practice and disease interaction
- Effective pollination strategies
- Hive performance
- Industry capacity for research and leadership
- Benefits of honey and developing chain traceability
- The role of floral resources.

Bee Informed is free to download or available to purchase in hard copy from the AgriFutures Australia website here.

For more information on the Honey Bee and Pollination Program visit https://www.agrifutures.com.au/rural-industries/honey-bee-pollination/.


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