LINCOLN AGRITECH LTD

Science with Impact

ANNUAL REPORT 2022

LINCOLN AGRITECH LTD

MEASURE. MODEL. MANAGE.®

Engineering and Science for Agriculture, Industry and the Environment

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Who We Are

Values

TAKING A FUTURE FOCUSED APPROACH

We strive to create real-world solutions for tomorrow's challenges.

BEING ADAPTABLE

We are flexible and nimble in what we do and how we do it, finding the right approach and solutions at the right time.

OUR PEOPLE AND OUR ENVIRONMENT

We have passion for our people and environment, they are at the centre of everything we do and drive our success.

MAKING A DIFFERENCE

Our science and engineering solutions make a positive difference to New Zealand and the world.

INCLUSIVITY AND COLLABORATION

In our workplace everyone feels they belong and can make a meaningful contribution to our work.

DIVERSE PERSPECTIVES AND INSIGHTS

Our work is impactful through valuing diversity of thought, backgrounds and knowledge.

Our Vision

Trusted science & technology for a better world.

Our Mission

Empowering the primary sector and communities to thrive, while safeguarding our environment.

What We Do

We deliver the world-class research, science & engineering solutions you want.

Research groups

Lincoln Agritech is a multidisciplinary research and development company, and is a 100% subsidiary of Lincoln University. We have a long track record of delivering leading-edge science and engineering technologies for primary industries and the environmental sector.

Our research groups are:

- **Precision Agriculture:** We apply and support the development of sensing technologies, including remote sensing, to assess and understand the spatial and temporal variability of soils, crops, and animals. We study how such data can improve decision-making.
- **Biotechnology:** We provide microbial biotechnology and consulting to industry and agriculture, including biocontrol to manage disease and enhance plant growth systems for farming, horticulture, and forestry.
- **Environmental:** We provide water-related research, focused on understanding and measuring groundwater systems. We also supply tools to regional and central government, and water users, to manage groundwater quality, nitrogen impacts, and water allocation, enabling a sustainable future for water resources.
- **GreenTech:** We research engineering-based methane mitigation and CO_2 removal techniques to combat global warming and help New Zealand meet its contribution to greenhouse gas reduction.
- **Information Technology and IRRICAD™:** IRRICAD™, is a world-leading computer software system for designing pressurised irrigation systems, which sells in more than 90 countries, and is available in eight languages. It is used by the world's largest irrigation company, Netafim.
- **New Materials:** We develop new high-value materials from biological sources, including coarse wool and plant-derived cellulose. We partner with industry, including the Wool Research Organisation of New Zealand, and focus on commercial applications of new materials.
- **Sensing Technology:** We provide smart sensing technologies for the agricultural and industrial sectors that reduce costs, realise new revenue streams, and improve decision-making. Our capabilities include:
  - ***Electromagnetics:*** Electromagnetic sensing for precision measurements in agriculture, medical imaging, industrial processing, and civil engineering.
  - ***Machine Vision:*** Extracting and visualising actionable data from various sensors using machine learning, also known as artificial intelligence, or AI.

Chairman's Report

Lincoln Agritech Chairman, Bruce Gemmell.

It's an honour to present this Lincoln Agritech Annual Report for the first time in my role as Chair.

In February 2022, long-standing chair Ted Rogers stood down, at which point I took over the mantle. I want to thank Ted for all the years he has given to Lincoln Agritech, culminating in the Accelerated Growth Plan. Other changes to the board were the resignations of Phil O'Callaghan and John Hay, who we thank and acknowledge for their contribution. We also welcomed Lincoln University Vice Chancellor Grant Edwards in February.

The presence of both myself and Grant Edwards on the board shows the importance Lincoln University places on the relationship with Lincoln Agritech.

At the end of 2021 the Lincoln Agritech Board submitted to Lincoln University's Council, as part of our company's statement of corporate intent for 2022, a programme business case for accelerated growth. With the plan approved, in 2022 the board set about guiding the company on its new growth trajectory to double its revenue from $15m to $30m by 2026.

Lincoln Agritech's strategy is to continue to contribute to our shareholder's strategic goals. As well as actively pursuing partnerships and growth, we are also focused on cementing our reputation, and that of the university, for world-class research. You will read about much of that research in the pages that follow. These stories give just a glimpse into the national and global impact our research is having.

Through our growth plans, we are well-placed to continue, and grow, the research the primary sector needs to manage the production and environmental challenges our world is facing. By doubling in size we are aiming to more than double our impact.

It also enables us to actively contribute towards Lincoln University's strategic goal of focusing on meaningful partnership and facilitating growth.

As with the previous two years, the company had to negotiate significant Covid-related disruption, and I would like to thank management and staff for navigating it well and achieving positive results. Special mention should also go to Board member Julia Chambers who, as a resident of Auckland, had to endure significantly longer in lockdown than those of us based in Canterbury or other parts of the country.

I would like to thank the board for their support, advice and guidance through 2022 as we launched the company on its accelerated growth trajectory. I look forward to seeing it bear fruit over the next years.

Lincoln Agritech CEO, Peter Barrowclough.

CEO's Report

In 2022 we said goodbye to previous Chairman Ted Rogers. During the 13 years of his tenure our company grew from 35 to 85 staff, and turnover grew from $5.5 million to $15.7 m. I want to thank Ted for his leadership of the board and support for me during this time.

During 2022 staff numbers rose to 85, from 77 in 2021. We made several significant appointments, including a new Electromagnetic Sensing Team Leader, a new Biotechnology Team Leader, a General Manager for HydroMetrics, a new Business Development & Marketing Group Manager, a new Government Funding Programme Manager, and a new Hamilton-based Senior Scientist for our environmental group.

At the end of the year we also appointed our former Cultural Advisor Chaz Doherty as Kaiārahi Māori. In this role he will lead co-design of our company-wide Māori Partnerships strategy. You can read more about our new staff on page 26.

It was another challenging year for staff. As well as the continuing impact of Covid, several faced significant personal crises. I want to thank all those who supported their colleagues and those who faced adversity outside of work, but still carried on.

Meanwhile concerns about climate change, food security, and the environmental impact of farming, horticulture, and forestry grew, showing we need to redouble our research efforts to help stakeholders address these existential issues.

After several years of being unable to meet international colleagues and clients in person, we again began travelling internationally towards the end of the year.

In September HydroMetrics General Manager Andy Matheson and Application & Sales Engineer Darcy Aker attended the World Water Congress & Exhibition in Denmark. While in Europe they also made significant progress setting up international distributors to sell our optical nitrate sensors.

Our outreach also stepped up, with the launch of video podcast series Beyond Number 8, a Facebook page, and our own stand at Fieldays (previously we had a presence in Lincoln University's tent). These all helped us to reach new audiences and increase awareness of our science.

Trusted science is our mantra and we continue to undertake some amazing research. For example, Dr Adrian Tan is a key member of a University of Canterbury-led team that received a Marsden Award of almost $1 million to research new ways of measuring sea ice thickness. Their research also featured on a stamp – a Lincoln Agritech first!

Our research for Wool Source to find new uses for coarse wool continued to produce commercial outcomes. One of the most talked about was Karen Murrell's launch at Fieldays of a lipstick coloured with Wool Source pigments. We are expecting more exciting developments in this area this year.

In many ways, our experience of 2022 mirrors that of our 100% shareholder, Lincoln University. The University is also emerging from pandemic restrictions and growing, with the return of international students, a new Vice Chancellor, and impressive new buildings taking shape. We look forward to continuing working with our university colleagues, and all our collaborators, to find solutions for 21st century issues.

Science with Impact

Robotics research strengthens relationships to end-users

An interdisciplinary project to develop workforce robots for primary industries has led to new ways to work with end-users for the involved scientists.

In 2017 the project's first phase was funded for two years with a $2m grant from the Ministry of Business, Innovation and Employment's National Science Challenge Science for Technological Innovations (SfTI) project. It included scientists from Lincoln Agritech, Scion and the universities of Auckland, Canterbury, and Otago, as well as Massey University and Victoria University of Wellington.

Together with industry representatives, the researchers proposed developing components for self-learning robots to work in harsh outdoor environments such as agriculture and forestry. In general, such robots had to be able to detect and operate safely around human workers and navigate rough terrain.

In 2019 the project won a three-year extension (total of $3m), focused on forestry, and working with the Lake Taupō Forest Trust.

This national Robotic Spearhead was a science-led project with industry guidance. Individual teams worked on one aspect each before integrating their results into a full-fledged outdoor robot, says Armin Werner, Lincoln Agritech's Precision Agriculture Group Manager and the project's Principal Investigator.

The researchers were quite advanced in developing a robot they thought would be a self-guided platform to carry seedlings to the forestry workers planting them. Then, with additional SfTI support, the research approach turned on its head – from being science-led to industry-led.

"As scientists, we discuss our ideas and use academic arguments about why they will work, for example, for the forestry sector," says Armin. "But that strategy didn't work for achieving the SfTI programme's latest goals of creating measurable impact with the funding."

"We discussed our options with the forest industry and found an application they want," says Jaco Fourie, Lincoln Agritech's Machine Vision Senior Scientist and Team Leader. "We said, 'You've seen what technology we've developed and you've seen the ideas for it. We're not going to tell you what we think the next step is – what do you want it to do to make it useful for you?'

"The resulting self-guiding platform for clearing forest paths from dense understorey growth was even a better fit for what we were developing," says Jaco. "The industry was very receptive and invested much expertise and time into the project."

"We are now preparing the required modifications of our robot platform and plan to build a commercially viable product."

Lake Taupō Forestry Trust and Lake Rotoaira Forest Trust Manager Geoff Thorp says working with the project has been an opportunity to influence future research.

"We see some of the techniques they're starting to develop as things that we know we'll be able to use. It's been educational to see just how complex some challenges the researchers face regarding automation and robotics."

In 2022, the follow-up project was funded for 18 months to build and commercialise the manoeuvring control system for a robot that will, almost automatically, maintain forest tracks by shredding the understorey. This control system could later be modified for other outdoor robots.

Above: The prototype robot is put through its paces in a Taupō forest.

Promising trial to slash herbicide use

A project investigating precision weeding in vineyards could prevent thousands of litres of herbicide use – and save thousands of cubic metres of water – across New Zealand's viticulture and horticulture industries.

Six New Zealand vineyards have partnered with Lincoln Agritech and the Ministry for Primary Industries' (MPI's) Sustainable Food and Fibre Futures (SFF Futures) fund to trial high-pressure water weeding (also known as waterjet weeding).

Mark Eder, Manager of Waiata Vineyards in Waipara, North Canterbury, heard about high-pressure water weeding, or waterjet weeding, several years ago, before seeing it in action in Italy in 2018.

He realised it could drastically reduce Waiata's herbicide use. Not only does this fit with the vineyard's ethos of sustainability, but it's becoming increasingly important in a world demanding less pesticide use.

In April 2022 Waiata Vineyard joined forces with Cloudy Bay, Pernod Ricard, Indevin, Villa Maria, and Yealands vineyards, all in Marlborough, to import a second-hand Caffini Grasskiller from Australia and work with Lincoln Agritech to rationalise the water use.

The aim of the two-year project is to develop a smart sensing device and valve that integrate with the waterjet weeder so it activates only when it senses a weed – and turns off when it doesn't.

"The original machine uses about 1000-1500 litres per hectare," says Lincoln Agritech Agronomist Allister Holmes. "We intend to reduce this to less than 500 l/ha. That's actually less than the typical amount of water used when spraying herbicide, which is between 600 and 900 l/ha."

The first trials in North Canterbury and Marlborough are evaluating the Caffini Grasskiller against the standard practice of multiple herbicide applications per season.

"We've found that it's best to use it on an under-row area that doesn't have large, perennial weeds such as docks and mallows present, as it doesn't totally kill these weeds," says Allister.

For the next trial, the team is fitting optical sensors to the weed control heads that can distinguish between green and brown, so the weeder can turn water on and off, depending on whether it senses weeds.

"We expect this technology will allow water use to be reduced by 75%," says Allister.

Between them, the six vineyards in the trials cover nearly 5000 ha. If the technology works as expected, it will take more than 50,000 litres of herbicide a year out of their weed management programmes.

However, it could do even more. There are 40,000 ha of grapes grown in New Zealand and around 68,000 ha of perennial tree crops, which could also benefit from the technology, grown nationally.

"If just another 10% of the perennial tree crops in New Zealand took up this technology, and replaced herbicides at the same rate, there would be an additional 60,000 litres less agrichemicals used every year," says Allister.

The modified high-pressure water weeder operating in one of the trial vineyards.

Research shows how braided rivers work

New Zealand's braided rivers dominate our east coasts. But how do they affect the amount of water in our aquifers, which is available for human activity and nature?

Until recently, no one knew how braided rivers worked beneath the surface and interacted with regional aquifers. But through significant advances in how we use technology, we are finding answers.

Lincoln Agritech's Scott Wilson is leading a five-year project, funded by the Ministry of Business, Innovation & Employment to find out how braided rivers and regional aquifers interact to store and transport water.

The team has made some important discoveries, using a lot of technology in novel ways. This includes the novel use of fibre optic cables installed beneath the ground, horizontally under rivers and also vertically to analyse river-groundwater exchange under different flow conditions. "This is giving us really beautiful profile through the aquifer system, helping us to learn about aquifer structure," says Scott.

It also includes equipment never used before in New Zealand such as an APSU surface nuclear magnetic resonance system, which measures the porosity and water content of sediment non-invasively (and so doesn't alter the observation through the very act of measuring). That particular piece of equipment had to be imported into New Zealand, along with its specialist operator Mathias Vang from Aarhus University in Denmark.

The team has also used tTEM – an electromagnetic system that is dragged along the ground to produce detailed 3D geophysical and geological maps of the sub-surface – satellite imagery combined with flow recorders to accurately measure river losses, and radon tracing to measure river water loss.

"Because we are studying something that's never been studied before, we are applying methods that have never been used in New Zealand before," says Scott.

"We now know how braided rivers work in the sub-surface. We know specifically what controls how much our rivers recharge the regional aquifers.

"We now have a conceptual model of how they work, where we know that braided rivers create their own aquifer system."

Using a sonic drilling rig to look beneath the river bed for the depth where permeability decreases.

Comprised of gravel, reworked through floods, this "braid plain aquifer" extends far beyond where we can see water. The river uses this gravel reservoir to regulate its flow and temperature. But if human activity reduces the size of this aquifer too much, it affects how much the river can recharge the regional aquifer and sustain river flows and temperatures during dry seasons.

As changing climate and human activity make sustainable water management crucial, this research will help New Zealand councils quantify the environmental and economic benefits of different river management strategies.

"This will be an important step in helping councils meet the Government's National Policy Statement on Freshwater Management, and ensuring that competing needs for water can be met in the best way possible," says Scott.

Real-time sensor sheds light on nitrate footprint

A one-year project to study nitrate levels and dynamics has revealed invaluable data to farmers, consultants, and scientists.

The 672ha Wainono Dairy Farm is near Fairlie, Canterbury, bordering the Opihi River. It is in a high nitrogen concentration area, and must understand its nitrogen footprint.

With the help of the Our Land and Water Rural Professionals Fund and primary sector consultancy The AgriBusiness Group, Wainono has been evaluating real-time water-quality monitoring, using Lincoln Agritech's HydroMetrics nitrate sensors.

The findings have been shared with the local irrigation company, catchment groups, community stakeholders, industry representatives, rural professionals, and Te Rūnanga o Arowhenua – the local iwi.

John Wright, Managing Director of Wainono Dairy Farm Ltd, took quarterly water samples for 10 years, but that didn't provide the information needed to really understand what was happening to nitrate concentrations. "I didn't know if a spike or a dip was a one-off or part of a pattern," he says.

Wainono installed three nitrate sensors along the groundwater flow direction, to compare upper, middle, and lower farm nitrate levels and dynamics. The nitrate data uploads to a HydroMetrics-hosted portal and is available in real time.

"I access the data every three or four days, and always before and after a weather event" John says.

Within two months, John could see the power of real-time information. "Levels are going up and down quite a bit, as we suspected from the quarterly spot samples we took previously, but now we can go much further and identify trends. I can see the potential in terms of how we manage grazing and when and where we fertilise."

AgriBusiness Group consultant Charlotte Senior says the project identified where large nitrate spikes come from. "It was clear drainage from big rainfall events was the main driver behind nitrogen losses."

The sensors also showed high nitrate levels in the groundwater coming onto the property from upstream, and taking about two days to show up at the bottom of the farm.

John says the sensors have helped Wainono Dairy Farm identify groundwater problems, and probable causes. "We see this data as a way of informing any environmental measures we take, such as riparian planting. Over time, we will be able to see if our planting really does make a difference."

It also sets the farm up for any future regulatory requirements. "We are creating a rich baseline data set of nitrate levels over time prior to a regulator requiring the information for compliance purposes.

"We will have way more valuable data than that provided by spot grab sampling, and also a thorough understanding of the nitrate levels across our farm."

At the end of the project Wainono Farm purchased the sensors so it could keep collecting the data and help the local community gain further insight into what affects nitrate levels.

AgriBusiness Group consultant Charlotte Senior with one of the HydroMetrics nitrate sensors.

Key Research

New Materials Group

Wool Industry Research Limited, New Uses for Crossbred Wool programme

Why it matters: This programme aims to develop new uses for crossbred wool, an important product from the New Zealand agricultural sector, which has suffered significantly due to decreasing demand and prices.

Overview: The programme, jointly funded Wool Research Organisation of New Zealand (WRONZ) and the Ministry of Business, Innovation and Employment (MBIE), is in its seventh and final year.

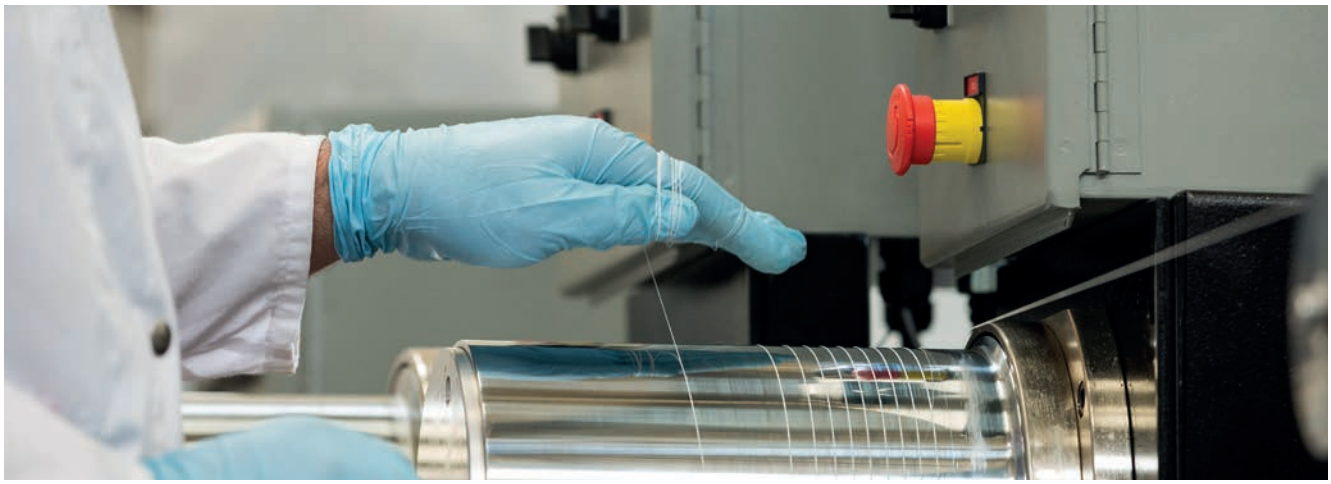
After a very successful period of research during the early part of the programme, activities are transitioning to market engagement and support for commercialisation efforts to establish the new products developed in global markets.

Commercialisation is undertaken by Wool Source Ltd, a company established by WRONZ to manage the commercial process and operate the pilot facility that produces these products.

Major outcomes/progress in 2022: We produced new product prototypes based on particle, powder and pigment technologies in the pilot plant, owned by Wool Source and operated by Lincoln Agritech. These were presented to partners in the print, personal care and other markets, both internationally and domestically. A strong positive response saw us supporting trade show activities in Asia and New Zealand and product launches by brand partners in personal care (Karen Murrell lipstick brand) and print (Mons Royale textile brand).

Products still under development include wool separated cell technology and regenerated fibres, both of which progressed substantially during 2022. A project focusing on additive and composite materials from wool separated cells developed several viable prototype materials in the filtration and coatings area and a new patent application was filed as a result.

We significantly scaled up our capability in extruded fibres and produced wool-based regenerated fibres with important textile and performance properties that support the value proposition for these novel fibres. This is expected to underpin the next stage of commercialisation for the New Uses for Crossbred Wool products.



We are continuing to develop our textile fibre extrusion capability.

Novel cellulose fibres from New Zealand plants for textile use

Why it matters: This programme has the transformative aim of creating a new industry producing added-value, extruded cellulose fibres from low-value plant material for use in high-value textiles. Such fibres are in demand internationally as the world seeks textiles that are low in environmental impact, as current textile fibres are either synthetic, or manufactured using an environmentally costly processes.

Overview: This five-year programme funded by MBIE is in its second year and includes collaborations with The Ferrier Institute, Victoria University of Wellington, SCION and AgResearch. The programme is supported by commercial partner WRONZ and has strong relationships with Ngāti Whare iwi.

Major outcomes/progress in 2022: One area of progress has been the extraction and characterisation of cellulose from tawa, a common and fast-growing tree in the Te Urewera and Whirinaki, as well as tī kōuka. Analysis shows tawa is a high-yielding source of cellulose, with specific beneficial characteristics, compared with radiata pine. The future looks promising for use of these native plant species as cellulose sources.

We are continuing to develop our textile fibre extrusion capability, scaling and enhancing the position of this unique in New Zealand facility. Ongoing contact with WRONZ and international textile companies support our commercial ambitions for implementation of this programme's outcomes.

Environmental Group

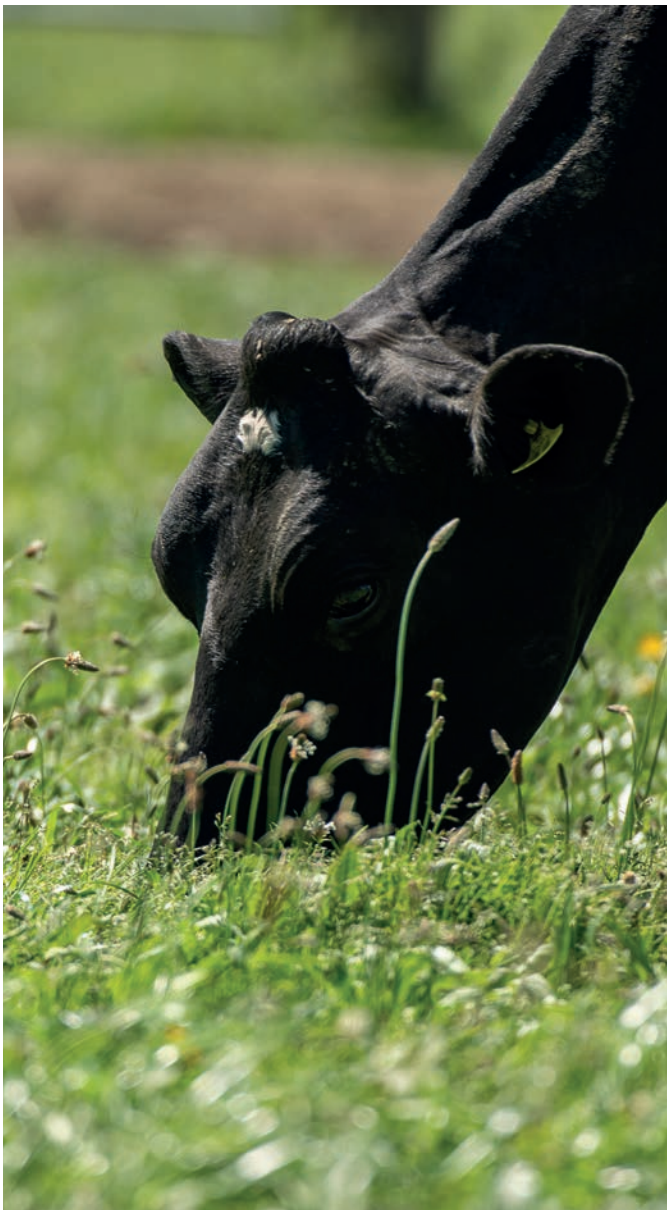
Plantain Potency and Practice programme

Why it matters: Nitrate leaching from dairy farms is a significant environmental issue for New Zealand's freshwater and groundwater. In many streams and rivers it causes eutrophication. Many farms need to reduce the amount of nitrate leaching from their land to meet regulatory and environmental standards.

Overview: This is a Sustainable Food and Fibres programme, led by DairyNZ. Lincoln Agritech is working with Lincoln University at the Lincoln University Research Dairy farm, to measure the amount of nitrates leaching from the dairy farm, comparing perennial ryegrass and clover pasture with ryegrass and clover with 30% plantain.

Major outcomes/progress in 2022: The 2022 drainage season was the first full season of the trial and results can be compared with a similar trial conducted by Massey University on heavier soils as part of the trial.

The first leaching results are emerging from the Lincoln University Research Farm experiment. They are showing similar trends to the Massey site, with a 38-50% reduction in cumulative nitrate leaching from 24% plantain pasture, compared with perennial ryegrass/clover for the season. These results are exciting. However, leaching was relatively low because dry conditions caused low average drainage, so the results need confirming with more data in coming seasons.



Credit: DairyNZ

Groundwater mitigations

Why it matters: This programme is also aimed at removing excess nitrates from the soil water to improve freshwater and groundwater quality.

Overview: We have been working with the National Institute of Water & Atmospheric research (NIWA) on a programme aimed at doubling the effectiveness of woodchip bioreactors. These are subsurface trenches or pits filled with woodchips, through which water flows and is denitrified by natural processes. In New Zealand, field-scale bioreactors have been installed to remove nitrates from agricultural surface or subsurface drainage, shallow groundwater, and effluent from glasshouses, domestic wastewater treatment systems, and dairy farm sheds.

Major outcomes/progress in 2022: In collaboration with Land and Water Research and the University of Waikato, we successfully conducted a lab-based column experiment to determine how modified woodchips enhance removal of nitrate and phosphorus from subsurface drainage water.

Preliminary results show that iron oxide effectively removes phosphorus (P) in drainage water and that the presence of manganese oxide (MnO_2) consistently enhances nitrate removal. Dr Aldrin Rivas, Lincoln Agritech's principal investigator for these projects, is providing guidance to a University of Waikato NIWA masters' student conducting research using our bioreactor columns.

Two journal papers and two conference papers we authored or co-authored have been published. We have submitted a manuscript on a novel method for quantifying nitrate removal rate in woodchip bioreactors to a journal, and are finalising a co-authored manuscript on P removal in bioreactor for submission. Our contract with NIWA ends in September 2023.

Critical Pathways research programme

Why it matters: Current groundwater models generally describe regional systems, with the dynamic local and intermediate flow systems not well represented. However, in some catchments, the majority of water (and nitrogen) fluxes are transported on these relatively shallow and short pathways, and so they need to be unravelled and adequately incorporated into models.

Overview: This programme is funded by the Ministry of Business, Innovation and Employment, in collaboration with Land and Water Research, Manaaki Whenua Landcare Research, Lincoln University, GNS Science, AgFirst and IK Associates. It has funding until September 2023. By the end of the programme, we will be able to defensibly describe and model sub-catchment scale water flows and nitrogen delivery to waterways, using data from two contrasting study catchments in the Waikato region.

Major outcomes/progress in 2022: We installed and sampled shallow groundwater wells (max 10 m deep) to gain an understanding of the lithology and nutrients in the groundwater system at the transect scale.

We have also installed our GW50 nitrate sensors in selected wells to gain high-resolution data (three-hourly) on nitrate dynamics in groundwater in our two study catchments.

We have also improved the deployment system of the nitrate sensors, which are located in five streams over the two catchments. They are now on a flotation device in the stream itself, compared with a PVC tube on the bank. This has resulted in improved data with less noise and less fouling, as well as showing that nitrate concentrations can be quite dynamic, particularly in early winter.

We have coded bore logs from all available sources in the Piako study catchment (shallow wells, soil pits, deep wells) for interpretation and matched them to SkyTEM and tTEM resistivity data, to try to ground truth the large-scale information these two survey methods have collected. Both catchments now have a SWAT-MODFLOW model, an integrated hydrological model that couples SWAT land surface processes with spatially-explicit groundwater flow processes. The Waiotapu model still requires final calibration.

Towed transient electromagnetic surveys (t-TEM) were carried out to provide finer detail/ greater resolution than the SkyTEM surveys in key locations across the Waiotapu stream catchment.

Sensing & Biotechnology Group

Snow radar project

Why it matters: Sea ice drives the world's weather by influencing major ocean currents as it forms and melts. Less ice means disrupted currents and weather, and a warmer world. Measuring the amount of sea ice is important for forecasting climate and weather. However, current measuring tools aren't accurate enough.

Overview: Lincoln Agritech is working with a team led by the University of Canterbury to develop a snow radar, one of three components of a device designed to measure sea ice thickness beneath the polar snow pack. Funded by The Deep South National Science Challenge, the team has deployed the snow radar on drones and a helicopter to monitor snow formations.

Major outcomes/progress in 2022: A 2022 Antarctica field campaign measured snow thickness from 15 m above the snow pack at a cruising speed of 30 m/s. This proved cheaper and faster than traditional probing – a 10 km transect was flown in six minutes – and much data was generated that accurately calculated the sea ice thickness.

The team subsequently won a Marsden grant to use their pioneering airborne technology to map and measure a vast stretch of Antarctic sea ice. The resulting data will be internationally significant in predicting sea ice trends and understanding the vital role complex coastal sea ice plays in global warming.

Above: The snow radar has been deployed on a helicopter to measure snow thickness in Antarctica.

Host-specificity of root microbiomes in emerging New Zealand crops

Why it matters: *Cannabis sativa* (medicinal cannabis) and *Humulus lupulus* (hops) are closely related genera of the Cannabaceae family and are two crops with strong growth potential in New Zealand and globally. Research suggests that the microbial community (microbiome) associated with these plants may impact THC/CBD levels for cannabis and flavour profiles for hops.

Our research aimed to obtain preliminary data on these plants' root-associated microbiomes, to better understand the microbes that interact with them in New Zealand soils and whether any microbes are specific to certain varieties.

Overview: We collected soil and root samples from *C. sativa* and *H. lupulus* varieties and profiled bacterial microbiomes by amplifying and sequencing a specific region of the 16S marker gene. Analysing the sequencing data has allowed us to identify the various bacterial species present and determine the relative abundance of particular bacterial isolates in each sample.

Major outcomes/progress in 2022: Our microbiome analysis indicates some varietal-specificity in the bacterial communities found on the roots of *C. sativa* and *H. lupulus*, particularly among the five *H. lupulus* varieties. We are now determining what effect location has on the microbial associations and investigating whether these affect THC/CBD levels or flavour profiles.

Automated knot and bark recognition project (Machine Vision)

Why it matters: All logs exported from New Zealand must meet phyto-sanitary debarking standards. The entire shipment can be refused if it fails to meet this standard, potentially costing millions in lost revenue. This project aims to automate the quality control process of checking logs to ensure they meet the required export phyto-sanitary debarking standard.

Overview: Funded by Forest Growers Research, Lincoln Agritech is collaborating with Applied Teleoperation Ltd to develop a system that uses machine vision and image processing tools to automatically recognise bark and knots on logs during debarking at a sawmill. It uses multiple cameras to assess logs in real-time and measure the amount of bark remaining after debarking. The system will report debarking quality as an estimate of the percentage of bark remaining, with the location of the bark and knots visualised on a console screen. Our goal is a functional prototype that can be installed on-site for assessing bark and knots.

Major outcomes/progress in 2022: We have trained an object detection model to find and identify bark of unknown and varying shapes and sizes on logs as they move past the camera on the debarker. Our model successfully processed each frame of the video feed at 20 milliseconds per frame with acceptable bark detection accuracy.

Methane mitigation project

Why it matters: Rumen-generated methane emissions are a problem for New Zealand. Methane constitutes 44% of the country's gross greenhouse gas emissions, of which 89% derive from agriculture. Reducing methane will help to rapidly mitigate short- to mid-term climate change. The UN Climate and Clean Air Coalition estimates a 45% methane reduction by 2030 would avoid 0.3°C warming by 2040. New Zealand has legislated to cut biogenic methane emissions by 10% of 2017 levels by 2030, and 24-47% by 2050.

Overview: GreenTech is a high-growth area that is attracting substantial interest from government and private investors. Lincoln Agritech's new GreenTech team is applying a novel engineering approach to reducing and/or mitigating greenhouse gas at a global scale using a highly selective process. This project is investigating low-energy (and low-cost) electrochemical solutions to remove or reduce the methane produced by ruminant animals.

Major outcomes/progress in 2022: Our research has successfully trialled methods and electrodes to oxidise low concentrations of methane. Having successfully completed Phase 1 of the work supported by New Zealand Agricultural Greenhouse Gas Centre, we are now moving into Phase 2.

Precision Agriculture Group

Optical N-sensing of dairy pastures

Why it matters: Managing plant nutrients on grazed dairy pastures is challenging as it requires optimal nutrient supply for optimal plant growth and environmental objectives. Spatial variability and nitrogen (N) demand of pasture growth can be detected with optical sensors, available overseas for arable crops, now mounted on fertiliser trucks in New Zealand. This is known as sensor-based Variable Rate Application of Nitrogen (VRA-N) for pastures.

Overview: A group of dairy farmers, consultants, contractors and service companies in South Canterbury initiated a Sustainable Food and Fibre Futures (SFFF) project to pilot the N-sensing technology on pastures. Lincoln Agritech, with AgResearch and Plant & Food Research, introduced commercially available optical sensors on six commercial farms to assess their value in N-fertilisation.

Major outcomes/progress in 2022: The project demonstrated under farming conditions that optical N sensing of pasture canopies is an important piece in dairy farmers' toolbox for N-fertilisation of pastures.

Spatial differences of pasture biomass within the Canterbury dairy farm paddocks showed 35%, and even more, variation (the to-be-grazed dry matter biomass).

It has been shown that using VRA-N via optical sensors on fertiliser spreaders improves grazed pasture production from the same amount of N applied. In some situations, higher yields between 500 kg DM/ha pa and 800 kg DM/ha pa were measured when fertiliser was applied using optical sensor-based VRA-N. No significant yield losses were observed using optical VRA-N.

The participating farmers confirmed that what they learned from the project led to changes in their farming operations and that they will continue using the technology.

RTK-GPS was used to meaure and map pasture sampling points within 2 cm accuracy.

Counting leaf-occluded apple fruitlets on trees

Why it matters: Counting the number of apples on individual trees is crucial in decision-making about crop management during apple growth. It is a time-consuming exercise, and done repeatedly throughout the season. With the advancement of camera technology and AI-based computer vision algorithms, it is possible to count apple fruits in an image accurately. However, the accuracy of the apple counts is often hindered by leaf occlusion, that is, fruits that are hidden by leaves and other canopy structures. Growers are interested in the number of apples in the canopy, not the number of apples in a picture!

Overview: In the 'MaaraTech' project, funded by the Ministry of Business, Innovation and Employment and led by the University of Auckland (Prof Bruce MacDonald), Lincoln Agritech's imaging team worked with the Precision Agriculture group on using deliberate airflow to flutter leaves and reveal the hidden fruits.

Major outcomes/progress in 2022: We developed a leaf-moving fruit-counting system consisting of an orchard sprayer, action cameras and AI-based algorithms. This system captures multiple image frames (of the same canopy) while the sprayer fan is turned on and the sprayer moves down the row. Each captured image frame contains a different set of apples as the leaves fluttered.

These images are then analysed with AI-based machine vision models to identify and track fruits accurately. Results from the 2021-2022 season suggest an accuracy improvement of 20%-30% with leaf moving. Also, utilising the sprayer, an existing orchard vehicle capable of providing deliberate airflow, would make this solution more cost-effective for growers.

The prototype leaf-moving fruit counting system.

Finding the right time to harvest high-quality fibre of hemp

Why it matters: Two types of fibres grow in hemp stalks: high-quality primary fibre, used in textiles, and a low-quality secondary fibre that can reduce the overall quality of the primary fibre. In-field detecting the onset and increase in the growth of secondary fibres is crucial for hemp harvesting and processing.

Overview: In a study funded by Agmardt, we developed a new method to analyse the fibre composition of hemp stalks using Raman spectroscopy (RS) and hyperspectral imaging (HSI). With partners AgResearch, Lincoln University and Carrfields Ltd, we aimed to identify methods for an in-field high throughput phenotyping strategy to evaluate the fibre content and quality.

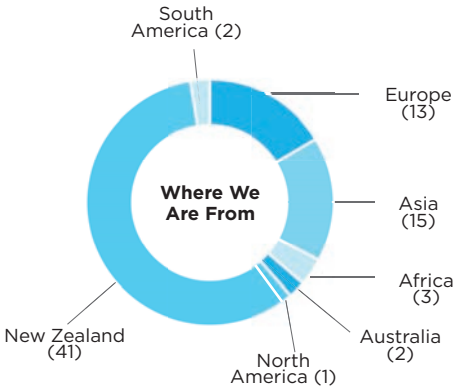
Major outcomes/progress in 2022: We used RS and HSI to assess the fibre composition of hemp stalks during growth, which we calibrated with microscopic inspection of the fibres in stalk cross-sections. The team demonstrated that hemp fibre has a distinctive Raman signature, which can be used to quantify and qualify the primary fibre.

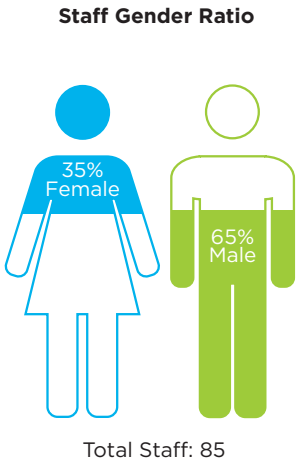
Using chemometric and data-analytical techniques, we developed RS and HSI models that could predict the existence of secondary fibre at any part of the stalk and during different times of the growth. The HSI model could also perform well, however, its specificity dropped at later stages of growth, while the RS model had consistent accuracy during the hemp growth period.

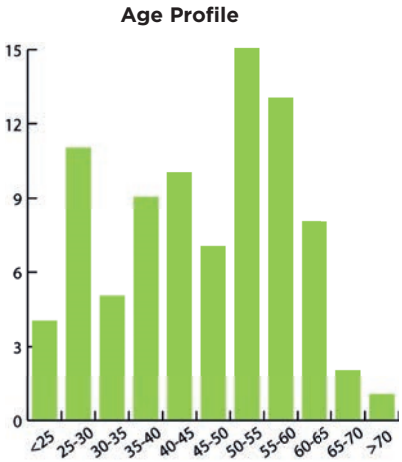
Our People

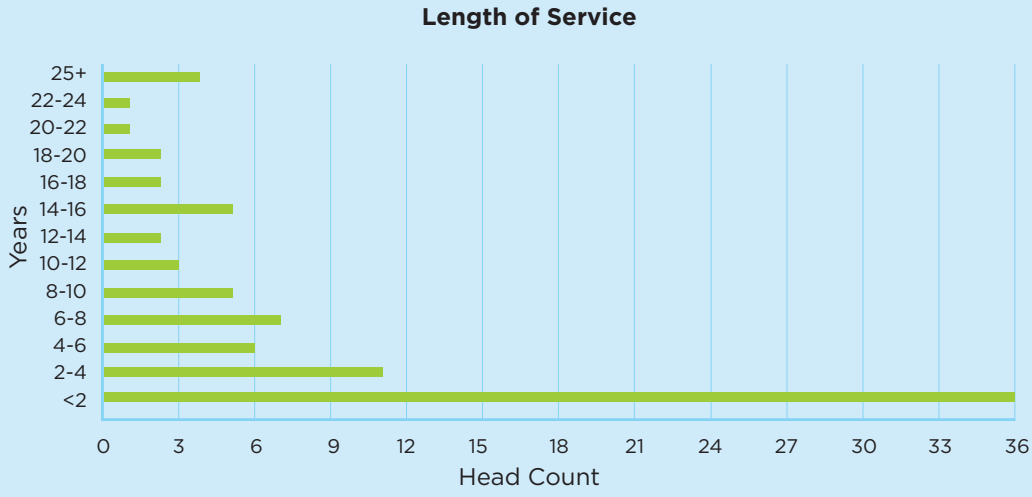
What We Look Like

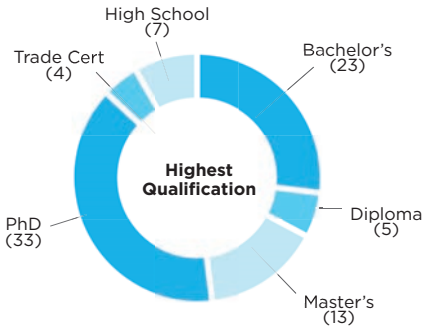
LAL Staff Profile as at the 31st December 2022

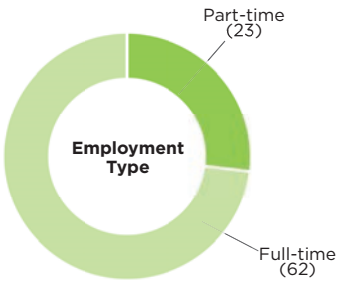


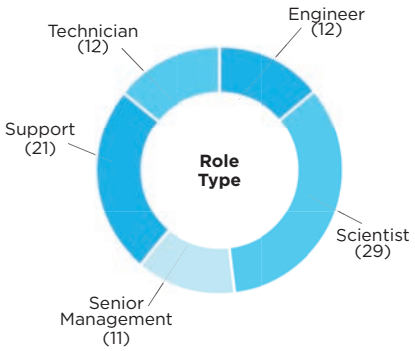












NB: Short fixed-term, casuals, and students removed.


Marc Fraser
PARAFILM
M

Senior Leadership

Peter Barrowclough
Chief Executive

Peter has more than 30 years of experience at the interface of science and business. He joined Lincoln Agritech in 2009, after holding governance and management roles in organisations as diverse as the Canterbury Development Corporation Ltd, PGG Wrightson, Crop and Food Research, and NZ Food Innovation South Island Ltd. He also founded a company exporting wasabi to Japan in the 1990s. He has an honours degree in horticultural science from Lincoln University and is passionate about the role of science and technology in increasing the nation's wealth. Agriculture is in his blood, and he lives on a small lifestyle block just outside Christchurch city where he also grows 3000 hazelnut trees.

Andrea Loubser
Financial Controller

Andrea is a chartered accountant and completed an MBA in 2019. Her career in finance spans more than 20 years across industries such as financial services, food processing and healthcare. Before joining Lincoln Agritech, Andrea served as the Business Manager at St Georges Hospital for 10 years. In 2022 Andrea led the company's finance operations and facilities management, ensuring appropriate policies, procedures and practices are developed and maintained. Andrea resigned in early 2023 for family reasons.

Andy Matheson
General Manager, HydroMetrics

Andy joined Lincoln Agritech in 2022 to take up the new role of General Manager, HydroMetrics. Andy has 25 years' experience in technology business development and senior private equity and venture capital. He particularly enjoys taking new technology ventures to the global stage. Most recently, he led the international expansion of an advanced surface materials venture spun out of Auckland University as Executive Director and Vice-President of Global Business Development.

Anya Hornsey
Group Manager, Business Development & Marketing

Anya Hornsey has an academic background in intellectual property and business administration, with a Master of Laws in Intellectual Property from Queensland University of Technology and a Postgraduate Diploma in Business Administration from Massey University. Anya has a long history in research and technology, working with researchers and innovators to secure funding and commercialise technology across a range of sectors. She has been CEO of a start-up and has governance experience in technology company roles.

Armin Werner
Group Manager, Precision Agriculture

Armin has a background in agronomy, crop modelling and sustainable development of land use. He gained his PhD at the University of Bonn and worked as Postdoc at Michigan State University. Before joining Lincoln Agritech, Armin was Director of the Institute of Land Use Systems (ZALF) in Germany. Armin specialises in novel agricultural production systems with a strong focus on precision agriculture, exploring the impacts of new technologies for primary industries and land use.

Blair Miller
Group Manager, Environmental Research

Blair grew up on a mixed cropping and dairy farm on the Taieri Plains south of Dunedin. His academic background includes a Bachelor of Science majoring in physical geography from the University of Otago, focusing on hill slope hydrological processes, and a PhD in environmental physics at Lincoln University, where he developed water balance models for agro-forestry farming systems. In 2009, he completed his MBA degree at Canterbury University to complement his scientific training. Blair has more than 20 years' experience in solving environmental management issues for the mining, forestry, agriculture, and tourism sectors.

Ian Woodhead
Chief Scientist

With more than 40 years' experience in sensor development, Ian's main research interests are measuring the broadband dielectric properties of composite materials, including water content, physical measurements using microwave and mm waves, and high-speed electronics. He is a member of the Institute of Electrical and Electronics Engineers (IEEE); the Antennas and Propagation, portfolio leader and management team member for the National Science Challenge – Science for Technological Innovation; Chair of New Zealand Electronics Institute Canterbury; board member of Lincoln University's Centre for Soil and Environmental Quality; and editorial board member of Biosystems Engineering (Elsevier). Ian was awarded the Royal Society Te Aparangi's Scott Medal in 2017.

Joanne Hay

Group Manager, Sensing & Biotechnology

Jo received a PhD from the University of Canterbury, specialising in molecular biology, plant viruses and crop resistance. She has several years' post-doctoral experience in the United Kingdom and New Zealand. As well as leading the biotechnology team, she plays a pivotal role in Lincoln Agritech's responses to major Government investment rounds and has been active in several commercialisation projects.

Kirsty Macdonald
Human Resources Manager

Kirsty has a Bachelor in Business Management, with a major in employment relations. She has extensive human resource management experience in New Zealand and the United Kingdom. She has worked in a wide range of sectors including the aviation, financial and legal services, marketing, transportation, and dairy industries.

Phil Dewar
Group Manager, IT

Phil has more than 30 years' experience in designing and developing specialised engineering software. He has extensive irrigation industry knowledge and is an expert in theoretical and practical irrigation solutions. Phil manages the development of IRRICAD™, the global leader in irrigation design software. Phil has worked at Lincoln Agritech since its inception and led the IT Group. He also develops software for other engineering applications, including spray drift modelling, water resources modelling, fertiliser application, soil moisture measurement, and resource management.

Rob Kelly
Group Manager, New Materials

Rob Kelly studied chemistry at the University of Cambridge (UK), completed a PhD at the University of Otago and then a postdoctoral fellowship at Lincoln University. He has managed R&D teams in New Zealand science institutes, including the Wool Research Organisation of New Zealand and Canesis Network Ltd, and has been involved in the establishment of new export businesses based on new materials developments with Keratec Ltd and Keraplast Technologies Ltd.

New Arrivals

Adam Hartland
Senior Scientist

In 2022 Adam joined Lincoln Agritech's team as a Senior Scientist based in Hamilton. Previously an Associate Professor at the University of Waikato, Adam formed and led the Waikato Environmental Geochemistry group. His research addresses the impact of climate change on soils and freshwater systems. With more than 50 publications in leading international journals and a network of national and international collaborators, Adam is well positioned to advance soil, water, and climate science in Aotearoa New Zealand. Adam aims to leverage practical science, engineering and technology to increase the resilience of our communities and primary sector, as we adapt to a more extreme and unstable climate.

Eva Anton
Electromagnetic Sensing Senior Scientist & Team Leader

Eva joined Lincoln Agritech in 2022 as Senior Scientist and Electromagnetic Sensing Team Leader. She gained her masters and doctorate degrees in Materials Science at Technical University of Darmstadt in Germany, and has since done research at KU Leuven in Belgium and Victoria University of Wellington. Eva's research is driven by her passion for new materials, curiosity about their properties and the goal to use their enhanced functionalities to improve existing applications or to develop new device concepts. Her current research uses microwaves in smart sensing and imaging tools for medical and agricultural applications.

Katrina Wilke
Government Funding Programme Manager

As Government Funding Programme Manager Katrina is responsible for identifying new funding opportunities and helping researchers to secure and manage government- and industry-funded programmes. She manages Lincoln Agritech's MBIE-contestable rounds and reporting activities. Katrina has held numerous collaborative roles in the science and agricultural sectors, enabling time-critical processes, and ranging from the funding, contracting and support of multi-year research programmes to the development and launch of agri-products. Katrina's academic background includes a Bachelor of Science in plant science, with graduate diplomas in teaching, business management and marketing.

Simon Kelly
Biotechnology Senior Scientist & Team Leader

Simon joined Lincoln Agritech in January 2022 as a Biotechnology Senior Scientist & Team Leader. He completed his Masters and PhD studies in microbiology at the University of Otago, where his research focused on soil bacteria and molecules they produce during beneficial interactions with plants. He continued his plant-microbe interaction research for eight years as a Postdoc/Assistant Professor in a plant molecular biology group at Aarhus University, Denmark. Simon is passionate about harnessing the potential of microbes to sustainably support agricultural practices and develop new biotechnology applications.

Andy Matheson
General Manager, HydroMetrics

Andy joined Lincoln Agritech as General Manager, HydroMetrics. Andy is an experienced technology business development executive and senior private equity and venture capital manager, with 25 years' experience (see Senior Leadership Team, p24).

Anya Hornsey
Group Manager, Business Development & Marketing

Anya joined Lincoln Agritech to lead the Business Development and Marketing teams. Anya has a background in intellectual property and business administration, and a long history in research and technology in Christchurch (see Senior Leadership Team, p24).

Other new arrivals in 2022

Cameron Breading – IT Support Technician

Conor Thomas – Reception/Office Administrator

Erica van Meer – Laboratory Technician

Hamish Scott – Laboratory Technician

Lachlan McKenzie – Postdoctoral Scientist

Lucille Ness – Health & Safety Advisor

Matthew Sullivan – Process Engineering Technician

Scott Berghan – IRRICAD Sales Engineer

Thai Tran – Geospatial Research Assistant

Awards & Achievements

Health and safety have always been important to Lincoln Agritech – and in 2022 we showed our commitment by receiving SiteWise accreditation with Gold status.

SiteWise accreditation is a prequalification system run by SiteSafe that grades a contractor's health and safety practices and capability. It then publishes that grade in a database so main contractors and principal organisations can view all contractor health and safety performance data in one place, before hiring.

Gold grading means Lincoln Agritech has achieved 90% or more of its annual assessment, showing "high quality health and safety systems".

Kim Eccleston was lead author on the paper that won the 2022 IEEE Industrial Engineering Paper Award on Antenna Measurements and Applications, from the IEEE Antennas and Propagation Society. Kim presented the paper "Multipixel Metamaterial Lens Imaging System" remotely to the IEEE Conference on Antenna Measurements and Applications. His co-authors were all Lincoln Agritech scientists. A second Lincoln Agritech paper was also nominated for the award. Yiwen Zhou was lead author of "Additive Manufacturing of Human Torso Phantom for Microwave Imaging", and his co-authors also included several Lincoln Agritech staff.

In 2022 Lincoln Agritech's Dr Adrian Tan's work was recognised in three ways.

First his work – as part of a team led by Prof Wolfgang Rack of the University of Canterbury – was featured on one of the stamps in the 2022 Ross Dependency Science on Ice, released by NZ Post in November.

Secondly, the same team was awarded $929,000 by the Marsden Fund to devise new ways of measuring sea ice. Their project will measure the largest stretches of Antarctic sea ice in history and shed light on its role in a warming climate.

The same team also won third prize in the 2022 Christchurch Aerospace Challenge for their plan to develop a lightweight snow radar mounted on a drone that could measure, for example, how much snow was on a slope above a ski field access road, and therefore determine the avalanche risk.

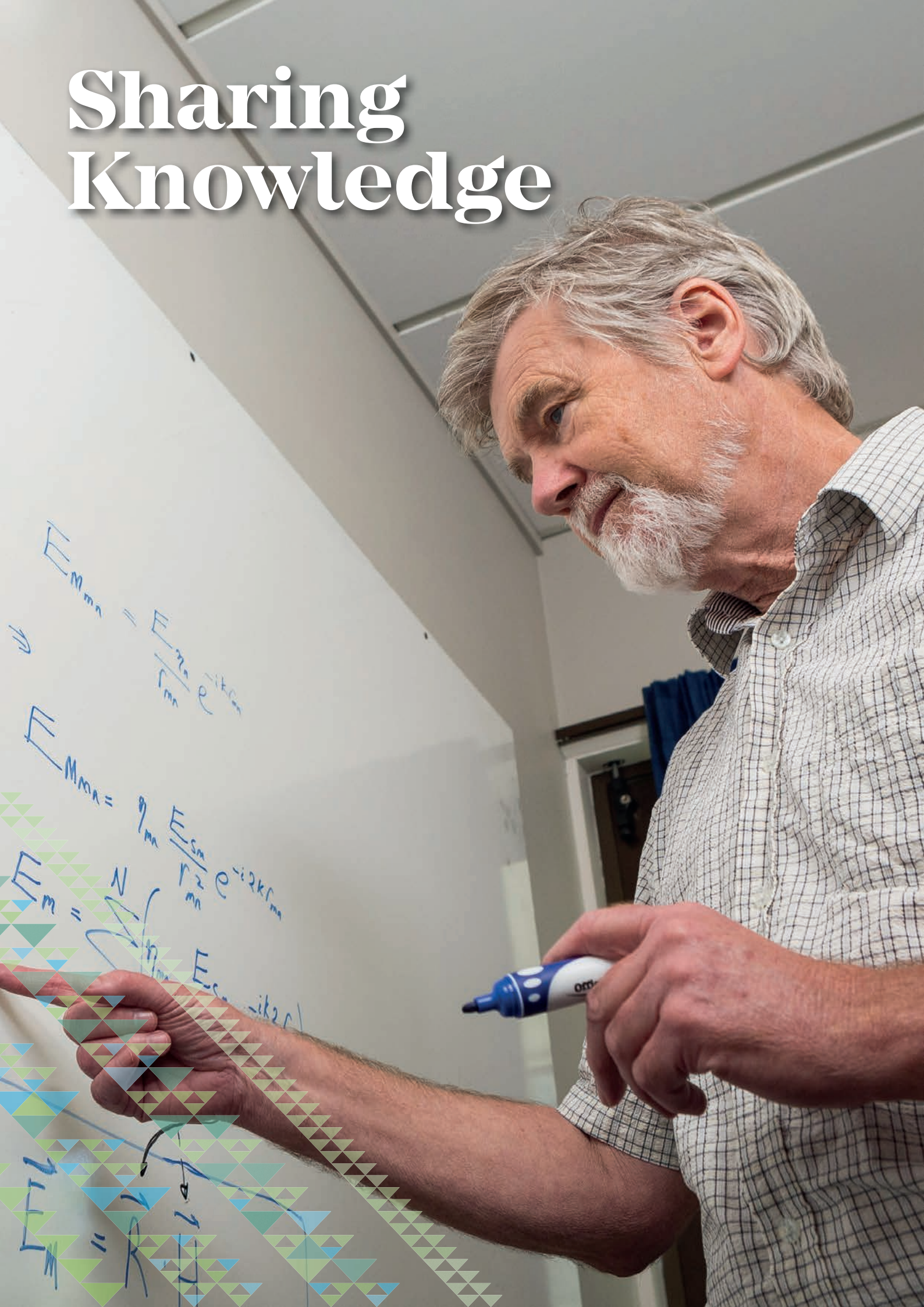
In 2022 Lincoln Agritech Research Scientist Ting Wu has was chosen to attend the Global Young Scientists Summit (GYSS) in Singapore in January 2023.

The summit is an annual multi-disciplinary summit hosted by the National Research Foundation of Singapore. Ting was nominated by Lincoln Agritech and the Ministry of Business, Innovation and Employment, and then selected as a participant by the hosts in Singapore.

Ting was also chosen and supported by the Royal Society of New Zealand to attend the 14th HOPE meeting in Japan, also held in early 2023.

Just three months after joining Lincoln Agritech, Biotechnology Senior Scientist & Team Leader Simon Kelly was appointed member of the BioTech New Zealand Executive Council. His expertise in harnessing microbes to sustainably support agricultural practices is invaluable for understanding the opportunities biotech offers New Zealand.

Sharing Knowledge



Non-Financial Highlights

53

Popular Press & Trade Journals

(excluding social media)

6

Podcasts

28

Conference Contributions

53

Client Reports

17

Journal Publications

Publications & Media

LINCOLN AGRITECH LTD

Twitter

2022: 1184 followers

7.4% increase

LinkedIn

2022: 2599 followers

48% increase

Facebook

2022: 103 followers

100% increase

Newsletter Circulation

2022: 1306 subscribers, 42% open rate

4.7% increase

IRRICAD™ IRRIGATION DESIGN SOFTWARE

LinkedIn

2022: 3669 followers

40% increase

HydroMetrics

LinkedIn

2022: 503 followers

47% increase

Facebook

2021: 163 followers

14.8% increase

Publications & Presentations 2022

Journal papers

Banks, E. W., Morgan, L. K., Sai Louie, A. J., Dempsey, D., Wilson, S. R. Active distributed temperature sensing to assess surface water–groundwater interaction and river loss in braided river systems, *Journal of Hydrology*, Volume 615, Part A, 2022, 128667, https://doi.org/10.1016/j.jhydrol.2022.128667.

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Cruickshank, A., Krsinic, G., Clark, C., Kelly, R. Wool Powder and Pigments for Pollution Protection – A Proposal, *Cosmetics and Toiletries*, Vol.137, No.4, April 2022

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Clark, C. Kelly, R., Krsinic, G., Cruickshank, A., MacDonald, S., Carnaby, G. Novel Wool Powders, Pigments and Particles for Personal Care. ASCC Conference, Melbourne, Australia, May 2022.

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Agriculture Minister Damien O'Connor helps to publicise a lipstick made with Wool Source pigments, developed under contract by Lincoln Agritech.

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P +64 3 325 3700
E info@lincolnagritech.co.nz
W lincolnagritech.co.nz

Throughout this publication the use of geometrical patterns represents the borders or edges of domains. The patterns indicate movement where spaces cross over and go back and forth – a space held to meet and greet, a space to navigate and negotiate. For us this pattern is symbolic of the fusion of cultures that seeks to develop and evolve, to grow its critical thinking, its shared learning systems. It supports a culture of science/mātauranga unique to this part of the world.