Issue/Uitgawe 112

UPCOMING EVENTS

- HARVEST WEED CONTROL STRATEGIES WORKSHOPS WITH MICHAEL WALSH (AUS): FEBRUARY 2024
- 9TH WORLD CONGRESS ON CONSERVATION AGRICULTURE: 22-25 JULY 2024
- SSK WINTER CEREAL DAY RIVERSDALE: 21 AUGUST 2024
- SKOG FARMERS' DAY" 22 AUGUST 2024
- HOPEFIELD FARMERS' DAY: 30 AUGUST 2024

blwk - cawc

AUG/SEPT 2023

BLWK/nuusbrief CAWC/newsletter

Inhoud/Contents

VOORWOORD/PREFACE

Hallo almal,

Dit was wragties 'n besige tyd die afgelope maand in die Wes-Kaap. Augustus het afgeskop met die 11de BLWK Jack Human konferensie en verskeie boeredae het gevolg. RiVersdal, SKOG en Hopefield se boeredae is gekenmerk deur uitstekende bywoning syfers en ons is baie dankbaar vir almal wat tyd gemaak het om al die dae by te woon. Die samewerking tussen die Departement en industrie tydens die dae is 'n riem onder die hart.

Ons sien nou uit na oestyd en na aanleiding van hoe die gewasse daar buite tans lyk kan dit 'n goeie een wees.

Groete van huis tot huis.

Hello everyone,

Wow, what a mad dash over the last month. August is really jampacked with numerous events showcasing CA trials and talks about local agriculture. Starting with the 11th CAWC Jack Human Conference and farmers' days at Riversdale, SKOG and Hopefield. We are really thankful for all the support. All the events were well attended. The collaboration of the Department and Industry roleplayers at all these events is remarkable.

We can now look forward to harvest and driving around the production area it looks really promising.

All the best!

Dr Johann Strauss

EDITOR

LINKS OF THE MONTH

02

CLICK ON THE BUTTON TO VISIT THE WEBSITE. PLEASE NOTE YOU WILL NEED AN INTERNET CONNECTION.

Regenerative agriculture - will it provide a way forward for increased carbon? Prof Gerry Boyle writes that fluffy claims are not good enough, and robust scientific data is needed to assess the power of regenerative agriculture.

Canadian innovation beats EU precaution in agriculture sustainability: Stuart Smyth for Inside Policy

How to write a winning cover letter for a job application. #phd #phdlife #academia #postdoc

13 Nations Agree to Abolish Farming in order to 'Save the Planet'

PLEASE HELP

My name is Bernard ESSAMA, and I am currently conducting research for my Honours project on the drivers and barriers of precision agriculture within the South African grain industry. I am writing to kindly request your assistance, as an industry professional, to fill out a questionnaire for this study. The questionnaire is designed to gather insights from individuals involved in grain farming, including farmers, industry professionals and stakeholders. Your response as an industry professional will provide valuable data that will be anonymized and used solely for research purposes.

I understand that your time is valuable, and I truly appreciate your consideration in assisting with filling out the questionnaire. Your support will be instrumental in ensuring a diverse and comprehensive range of perspectives are represented in the research findings.

Here is the questionnaire link to be distributed to farmers: https://forms.gle/cyEu81DvNjGkMjcj6

Here is the questionnaire link for you as an industry professional ("experts"): https://forms.gle/jDrP8HrGZJca69o26

If you have any questions or require additional information about the research or the questionnaire, please do not hesitate to contact me at s217196950@mandela.ac.za or my supervisor Johan Jordaan at Johan.Jordaan@mandela.ac.za

Thank you in advance for your support and cooperation. Your involvement will contribute to advancing our understanding of precision agriculture adoption in the South African grain industry.

Best regards.

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A STEP CLOSER TO NEW NITROGEN-FIXING CROPS

The transfer of genes that allow nitrogen to be fixed from the atmosphere into PHOTOSYNTHESIZING CYANOBACTERIA could one day lead to similarly engineered crops.

Plants need nitrogen-rich soils to thrive, but there are a limited number of plants able to extract nitrogen gas from the atmosphere and fix it in a useful form in the soil. However, new kinds of crops capable of nitrogen fixation may soon be possible, after Japanese scientists successfully transferred nitrogen-fixing genes into a photosynthetic organism.

Nitrogen fixation is a process that chemically converts molecular nitrogen to ammonia, a nitrogen compound plants can use, explains Yuichi Fujita, a biochemist at Nagoya University, which is about 300 km west of Tokyo, Japan.

Much of the world's farming is currently supported by nitrogen-containing chemical fertilizers, but they are energy-intensive to produce and can lead to algal blooms when runoff pollutes waterbodies.

Many of the plants capable of nitrogen fixation are legumes, members of the bean family, but it would be game changing to have a wider variety of crops with this capacity, says Fujita.

His research is part of the COI-NEXT project, a bioplastic's project led by Kanazawa University and the Japan Science and Technology Agency. Fujita's research is focussed on the efficient production of crops that could be used as feedstock for bioplastics.

FRESH FIX

Legumes fix nitrogen through nodules that develop on their roots and host nitrogen-fixing bacteria, but conventional plant breeding, or even genetic engineering, hasn't yet succeeded at transferring the ability for nitrogen fixation via symbiosis with bacteria to other crops.

Fujita's team are instead exploring how to genetically engineer this ability, and have started with cyanobacteria, which can draw energy from the sun through photosynthesis, as plants can. Cyanobacteria are microorganisms that are either a single-cell or composed of single connected 'filamentous' cells. These microorganisms bear similarities to chloroplasts, the organelles responsible for photosynthesis within plant cells.

Passing the ability to fix nitrogen on to new crops has been challenging. This is largely because the process is driven by an enzyme called nitrogenase, which breaks down easily in the presence of molecular oxygen, a compound abundant in plant cells and the atmosphere.

"Since plants generate oxygen through photosynthesis, nitrogenase needs to be protected not only from atmospheric oxygen, but also from the oxygen produced within the plant cell," says Fujita.

As a first step, his team has engineered the genes for nitrogen fixation into certain cyanobacteria. This was an easier proposition than plants, because there were already cyanobacteria which produce nitrogenase.

The researchers identified 50 genes that code for nitrogenase and its closely related enzymes and proteins in a nitrogen-fixing cyanobacterium called *Leptolyngbya boryana*. They then introduced some of these genes into the genome of another strain of cyanobacteria which didn't have this ability, *Synechocystis* sp. PCC 6803, which subsequently was able to produce small amounts of the enzyme.

▲ **Nagoya University researchers have engineered nitrogen-fixing genes from a cyanobacterium (*Leptolyngbya boryana*, pictured) that already creates a key enzyme into one that does not.**

FUTURE FIXATIONS

The achievement is exciting, but such small quantities of nitrogenase can't "support nitrogen-fixing growth in cyanobacteria," says Fujita, "so we are trying to introduce other genes to enhance nitrogenase activity."

The team's cyanobacteria success is only a first step, and there are many hurdles to overcome before nitrogenase genes might be engineered into crops such as sugar beet, rice and maize.

Fujita says protecting nitrogenase from oxygen generated in plants cells might require engineering its production to only happen at night, while photosynthesis is paused; or for it to occur in the roots, where photosynthesis does not take place. ■

NAGOYA UNIVERSITY

https://en.nagoya-u.ac.jp/

Research at Agriculture Canada has made strides toward a stable canola plant that consistently exhibits about 800 plant hairs per leaf. | Adeline Panamaroff photo

HAIRY CANOLA RESEARCH EMBARKS ON LONG AND WINDING ROAD

By Adeline Panamaroff, frelance writer

Scientist takes research in a different direction as efforts continue to breed canola with plant hairs to fend off flea beetles

Plant hairs may provide better natural pest control than insecticides. The knowledge that plants with plant hairs, called trichomes, are unpleasant to insects and animals is not new but using it to make canola undesirable to flea beetles remains an ongoing challenge.

Varieties of hairy canola have been in development for more than 20 years. Development is slow going because gene crossing has been tricky. Dwayne Hegedus, research scientist at Agriculture Canada, sees the light at the end of the tunnel, however.

The research began with Margaret Gruber and Julie Soroka, who created the original “hairy canola” from a cross of canola varieties like Westar and Arabidopsis thaliana, a close plant relative.

The plant cross had hairy leaves but it proved unstable a few generations later, with some plants reverting to hairless. There was also another issue.

Hegedus said Texas A&M University owns a patent on the Arabidopsis GL3 gene and a licence is required to use the gene in canola.

The research was also hindered by the industry itself, Hegedus added. Several chemical and seed companies expressed interest in the idea of hairy canola, but also knew that a natural insect defence could affect insecticide sales. Seed or pesticide companies were reluctant to fund it, he said.

A big component of the research project has been procuring a steady supply of flea beetles. | Adeline Panamaroff photo

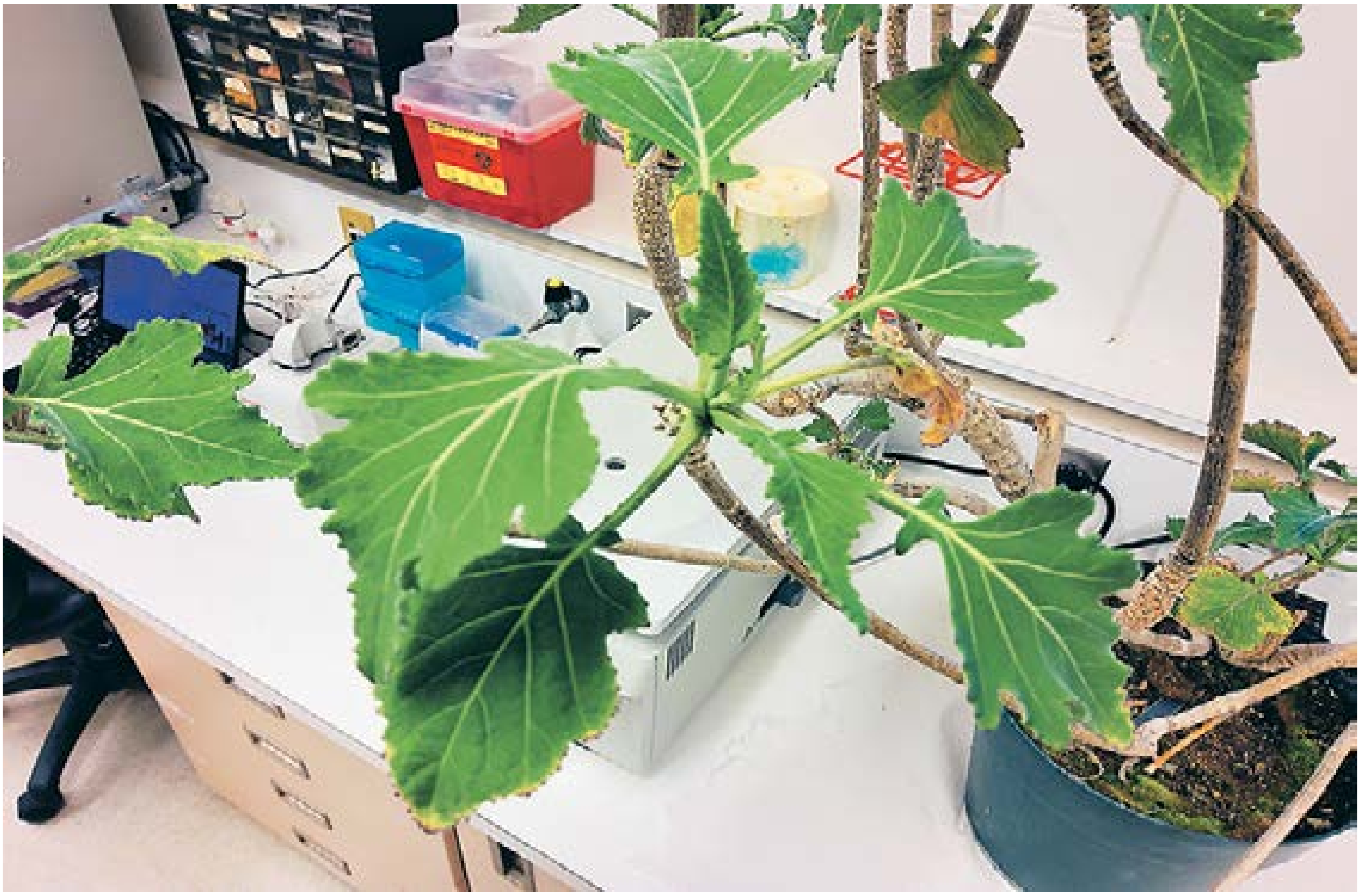
Renewed interest emerged after the European Union banned neonicotinoid seed treatments, which has made it near impossible to grow canola in much of Europe. Meanwhile, the push for biofuels has led to increased interest in crops like canola that are suitable for biofuels.

When Hegedus joined the team in about 2018, he took the research in a different direction. He looked at Brassica villosa, a closer relative of canola, and thought it showed a lot of promise with its velvety leaves. The work focused on transferring the hairy and waxy leaf trait.

The research has experienced many ups and downs and progress has been slow. Conventional breeding takes time, and putting promising new lines through trials takes years.

A big component was also procuring a steady supply of flea beetles. After all, the point of the research was to see how they react to the presence of plant hairs on the leaves of their favourite meal.

Hegedus said entomologists from other universities have stepped up to help.



When Agriculture Canada scientist Dwayne Hegedus began researching hairy canola, he took a look at Brassica villosa, a closer relative of canola, and thought it showed promise because of its velvety leaves. His work focused on transferring the hairy and waxy leaf trait. | Adeline Panamaroff photo

"After about 20 years of work… we finally have been able to establish a colony of flea beetles here at the centre. That means we can actively propagate flea beetles in the colony."

Until six months ago, researchers had to collect both striped and crucifer flea beetles during a small window of time once a year and then hurriedly carry out experiments before the supply was depleted.

Plant hairs deter flea beetles because they follow several steps before they feed. The hairs disrupt the process, causing beetles to leave the plant. The added waxy trait that has also come out of Hegedus's research has similar effects as the hairs, interrupting the steps the beetle needs to do before feeding.

The research, funded by the Canola Council of Canada, Agriculture Canada, the Canola AgriScience Cluster, and previously by the Manitoba, Saskatchewan and Alberta canola groups and other provincial government fund matching programs, has made strides toward a stable plant that consistently exhibits about 800 plant hairs per leaf.

The Rothamsted Experience By Rothamsted Research

Read Bio
Published: July 12th, 2023

There can be few sites in the world that have witnessed more soil monitoring than Rothamsted in Hertfordshire, UK.

For 180 years scientists have been collecting and analysing soil samples from the same field where different crop plots are given varying fertiliser treatments. This makes the Broadbalk site at Rothamsted the longest running field experiment in the world.

Through astonishing foresight, the founders of Rothamsted, the Victorian philanthropist John Bennet Lawes and the chemist Henry Gilbert, kept soil and plant samples from nearly every plot they tested. The Sample Archive at Rothamsted now has almost a third of a million items, representing a continuous data set unmatched anywhere else.

This gives Rothamsted's scientists a priceless resource with which to study how soil quality changes over time. Old samples are now being analysed with modern techniques to provide new insights into the effects of continuous fertiliser use on soil structure and biology.

A SOLID LEGACY

Lawes and Gilbert were systematic in how they set up the experimental plots and in analysing the samples collected. A control strip with no applications at all has been maintained throughout the duration of the experiment.

Likewise, an "organic" strip that has only had additions of farm-yard manure has been continuously present. Other plots have had differing applications of nitrogen, phosphorous, magnesium and potassium in an attempt to better understand the nutritional needs of plants.

Some of the long-term findings from these efforts have been highly influential in modern thinking about soil health and security. Whilst there is currently a lively current debate about how to protect and boost levels of soil organic carbon, Lawes and Gilbert's studies have revealed that the carbon content of some soils in the experiment has changed little in more than a century after they were first measured in 1865.

Some-of-the-nearly-300000-soil-and-plant-samples-in-the-archive-at-Rothamsted-UK-dating-back-180-years

Other experiments have been used to respond to contemporary challenges in agriculture such as nitrate pollution and climate change. For instance, detailed work on nitrogen cycling has been carried out using a stable isotope of nitrogen applied to microplots within the experiments. Likewise other studies have focussed on the soil's ability to act as a sink for methane, an important greenhouse gas.

A WORLD-WIDE NETWORK

The experiments at Rothamsted have inspired similar studies elsewhere. The Morrow plots at the University of Illinois, for instance, were started in 1876. Other research institutes have followed suit.

This global proliferation led to the creation of the Global Long-Term Agricultural Experiment Network (GLTEN) in 20191, which brings together long-running experiments that span nearly two centuries and six continents, as well as representing numerous climates, environments, crop types, farming practices and land-management regimes.

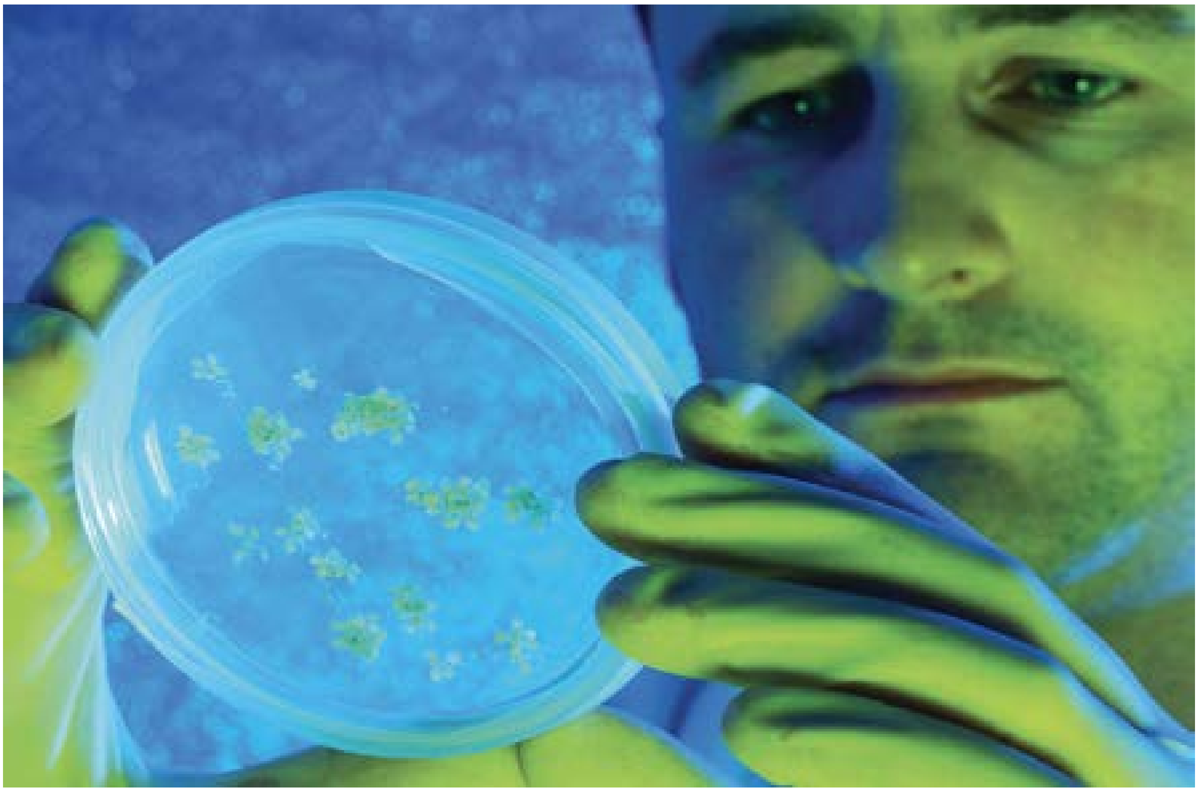
The researchers responsible for these long-term experiments – defined as experiments running for at least a decade – have made their information openly available on the network's website to help other scientists discover their studies and foster further collaborative work.

GLTEN represents a potential treasure trove of information – over 1750 years' worth of data in total – that will help researchers and policymakers design "the farms of the future". The 65 sites span the globe, with about 20 in the Americas, a dozen or so in Africa, more than 10 in Europe and several others across both Asia and Australasia.

"these long-term experiments are a really important global resource for informing future farming"

"The hope is that lessons learnt in one country might improve practices elsewhere – resulting in natural resources being used more efficiently, and in a way that produces a food supply that delivers a nutritionally balanced diet," says Rothamsted Dr Jonathan Storkey, who helped set up the Network.

Installing-soil-monitorng-cables-at-Rothamted



Investigating-the-soil-mircobiome-is-a-vital-elemnet-of-monitoring-overall-soil-health

"We also hope this initiative will help us uncover 'hidden' long-term experiments that we didn't know about, enabling us to mine and analyse their datasets and insights.

A good example of the value of long-term experiments is our understanding the effects of man-made fertiliser use, a practice that began in Europe during the Victorian era. Fertiliser experiments that started in the UK in the 1800s have helped chart the long-term impacts of this switch not just on crop yields, but also soils, water, wildlife, human-health and climate.

"These long-term experiments are a really important global resource for informing future farming," says Storkey. "Agriculture will face the massive challenges of feeding a growing world population without relying on the conversion of remaining natural habitats to agriculture, and all the while, reducing other impacts on the environment including the release of greenhouse gases and losses of biodiversity."

FROM CHEMISTRY TO BIOLOGY

Much of Lawes and Gilbert's global influence derives from their early studies focused on the chemistry of fertilisers and its relationship to plant health. However, more recently scientists have increasingly begun to realise that biology of the soil also plays a critical role. Fortunately, genetic information retained in Rothamsted samples that are now decades old can still be easily analysed and sequenced, providing new information on how the microbiome under our feet is changing.

One recent study has led to a radical new way of thinking about why adding organic material like manure to soils improves flood and drought resilience, climate control and crop yields – universal 'ecosystem services' that are widely recognised as worth billions to the global economy.

Sampling-for-soil-organic-matter-fractions-at-Rothamsted

Using over 50 years' worth of data from the long-term field experiments, researchers have demonstrated that common farming practices drain the soil of carbon, altering the structure of soils' microscopic habitat and, remarkably, the genetics of microbes living within it.

The team of microbiologists and physicists considered almost 9,000 genes and used X-ray imaging to look at soil pores smaller than the width of a human hair, and in concert with previous work, have started forming what they envisage will be a universal 'Theory of Soil'.

In healthy soils, relatively low nitrogen levels limit microbes' ability to utilise carbon compounds, so they excrete them as polymers which act as a kind of 'glue' – creating a porous, interconnected structure in the soil which allows water, air, and nutrients to circulate.

The study team believe that the Victorian-era switch from manure to ammonia and phosphorous based fertilisers has caused microbes to metabolise more carbon, excrete less polymers and fundamentally alter the properties of farmland soils when compared to their original grassland state.

Lead researcher Professor Andrew Neal says: "We noticed that as carbon is lost from soil, the pores within it become smaller and less connected. This results in fundamental changes in the flow of water, nutrients and oxygen through soil and forces several significant changes to microbial behaviour and metabolism. Low carbon, poorly connected soils are much less efficient at supporting growth and recycling nutrients."

"low carbon, poorly connected soils are much less efficient at supporting growth and recycling nutrients"

The closed soil structure also means microbes need to expend more energy on activities such as searching out and degrading less easily accessible organic matter for nutrients.

Conversely, in carbon-rich soil there is an extensive network of pores which allow for greater circulation of air, nutrients and retention of water.

"Manure is high in carbon and nitrogen, whereas ammonia-based fertilisers are devoid of carbon. Decades of such inputs – and soil processes typically act over decades – have changed the way soil microbes get their energy and nutrients, and how they respire."

TURF WARS

The team followed up this study with a deeper dive into the traces of the microbial ecosystem preserved in the historic samples. They likened the impact of arable farming on soil ecosystems to creating a "gangsters' paradise" for certain soil organisms.

This new study showed that common farming practices such as ploughing, fertilising and adding pesticide to fields results in a chaotic new (microbial) world order where nitrogen stealing archaea and killer fungi have muscled their way in at the expense of many plant beneficial fungi.

Measuring-compaction-with-a-soil-penetrometer-at-Rothamsted-UK-edited

The research also found the more 'nutritionally monotonous' arable soil environment has led many bacteria to 'reduce their running costs' by jettisoning more than 600 of the genes usually needed when faced with the diverse range of food sources found in grasslands or pastures.

This means that typical measures of soil biodiversity aren't adequately explaining what is going on in soil – as farming not only changes the number and relatedness of the species present, but also the genetic complement of the community as a whole.

Using soil samples from a long running Rothamsted plot experiment, the team together with the US Department of Energy's Pacific Northwest National Laboratory compared arable soils with their original grassland state, as well as bare soils that have been left fallow for over 50 years.

According to Professor Neal, when grassland is converted to arable, the richness of species doesn't change very much, but new species move in, and they don't necessarily fill the same ecological roles.

Compared to their original grassland state, arable soils had fewer, but more varied, species of fungi. Mycorrhizal fungi, those that form mutual beneficial associations with plants and play important roles in plant nutrition, are reduced in favour of pathogenic fungi that survive by attacking insects, plants and lichen.

__The researchers also saw a greater variety of bacteria in arable soil, whilst the total number of species of archaea – a group of single cell organisms members of which generate the greenhouse gas nitrous oxide as a by-product of ammonia oxidation – also increased in response to fertilisation.

The results also show that the responses of these three different types of organisms varied markedly depending on the physical and chemical challenge presented by farmers.

"Farming practices cause physical disruption and alter the nutritional inputs, which means less diverse plant materials and more readily available nitrogen to soil," says Prof Neal. "As a result, some species lose out allowing new ones – often with very different ways of making a living – to thrive. Even those that survive have had to change the way they live their lives."

The move from grassland to either bare soil or arable land impacted the genomes of bacteria and archaea, with organisms in arable soil having approximately 650 fewer, and those in bare soil having about 1,300 fewer genes, compared to organisms in grasslands.

"Bacteria have a habit of losing genes if there is not a good reason to keep them," says Neal. "It's a 'use it or lose it' situation. What we think is happening here is they no longer need the functions these genes code for, and the genome length is reduced as a consequence."

SIGNALS IN THE SOIL

Ultimately it is not the biology, chemistry or structure of soil alone that determines its viability and performance, but the interaction of all three. As Professor Neal likes to put it, "soil is a process". So, measuring multiple facets of a given soil in-situ will be critical to our future understanding of soil health and sustainability.

"when buried optical-fibre cables are stretched or compressed which enables detection of the changes in strain and temperature"

The-Broadbalk-Long-Term-Experiment-on-winter-wheat-at-Rothamsted-UK

Consequently, Rothamsted has been fast developing its monitoring capacity across a range of soil attributes. One initiative is to develop sensor systems that measure gas concentrations in the ground and match these with strain, moisture, temperature and suction readings at different scales. This will enable scientists to provide data on the dynamics of gas flux and soil structure.

The monitoring systems deploy new technologies in innovative ways. A good example is a distributed fibre optic sensor (DFOS) system. Originally developed for measuring strain in built structures, it can be adapted for soils and provide measurements over several metres – potentially even kilometres.

When buried optical-fibre cables are stretched or compressed by surrounding soils, local anomalies are created in the fibre which enables detection of the changes in strain and temperature in the surrounding environment.

The technology is currently being further developed at UC Berkeley in California, who are a partner in the monitoring project, their team have been trialling the sensor systems in the unique wind tunnel-soil facility available at the Colorado School of Mines (CSM). An experimental set up has also been installed at Rothamsted.

The experiment will manipulate soil moisture fluctuations by balancing water introduction through rainfall and losses to evaporation and evapotranspiration as controlled by atmospheric factors such as temperature, wind speed, and relative humidity. This will allow the team to make more informed predictions of soil structure changes and greenhouse gas emissions under changing climate conditions.

Once the set-up has been fully tested the researchers will be able improve the predictive understanding of how changes in atmospheric carbon are affected by soil structure changes.

The proposed sensor development and experimental research will lead to a substantial improvement of soil carbon models such as the RothC model developed at Rothamsted in the 1990s.

LOW TECH SOLUTIONS

High tech soil monitoring will undoubtedly be an important tool in the development of high yield, low input future farming systems. But in the shorter term more accessible and easier to use measuring systems will be needed.

A good example is a rapid soil-phosphate measurement toolkit developed by Rothamsted.

Phosphorus application represents a particular challenge for modern agriculture. Whilst vital for healthy plant growth, globally phosphate sources are limited. Moreover, if phosphate is poorly applied it can end up polluting watercourses causing significant environmental damage.

And it is costly. Current instability in agricultural input markets saw phosphate fertiliser prices increased by as much as 130% in 2022, according to the UK's AHDB.

So more precise application would benefit farmers hugely. Moving from prophylactic over-use to more precise, targeted applications of phosphate would reduce the volumes and avoid unnecessary depletion of this finite natural resource. And a more measured approach would directly benefit farmers: cheaper, more frequent and accurate soil-testing would mean that they use fertiliser only where and when needed, resulting in increased yields, less work and lower costs.

Rothamsted Research produced a prototype rapid soil-phosphate measurement toolkit called Phosfield. This will enable cheaper, more frequent testing as well as more precise fertiliser applications, maximising yields and reducing pollution.

Funded by the ERDF's Agri-Tech Cornwall programme, the test kit provides precise results within just 20 minutes – a massive improvement on the several-day turnaround by laboratories.

'Most farmers test their soils for phosphate every three to five years,' explains Dr Susan Tandy, who until recently was a soil scientist at Rothamsted Research. 'They usually take several samples from across the field and amalgamate them to get an average reading.'

The level of phosphate varies across fields, and more accurate GPS-located testing would enable farmers to apply fertiliser at variable rates allowing them to achieve more consistent yields.

More importantly, phosphate availability can change over time and depends on the soil type, so by testing more frequently and knowing the soil type, farmers can be even more accurate in their fertiliser application. The test has been three years in development, and has been trialled in Ghana, where it could have significant benefits.

'The technique would be extremely useful in developing countries as they have limited lab access to test their soils, meaning the application of expensive fertiliser is both financially risky and may not match crop requirement,' explains Tandy.

Having nailed down the scientific process using Cornish soil samples, the researchers worked with product design and development firm Vital Spark Creative to produce an analytical kit that would be relatively easy to use in the field.

While precision farming techniques like soil and crop scanning sand conductivity tests enable variable rate nitrogen applications, analysing phosphate will likely always require a physical soil sample to be taken, says Tandy.

The test is also extremely cost effective, according to developers. Once the kit is acquired, each test costs pence rather than pounds for a laboratory analysis.

Although the tool is not yet commercially available, the Phosfield team are seeking additional funding to bring it to market and hope to undertake further research to produce tailored fertiliser recommendations for different crops and soil types.

FARMING FEEDS BILLIONS BUT CLIMATE IMPACTS NEED FIXING

Michael Barnard

Sep 11, 2023

Many of us hold romantic ideas about farming. We imagine wise stewards of the land who preserve soil for future generations. We think of gentle nurturers of livestock who ruefully cull it for food for the world. We think of farms as bucolic and climate friendly places.

Most of that is utter nonsense.

To start with, about 10% of total greenhouse gas emissions come from agriculture, which is why changing how we do it is on the short list of climate actions that will work.

Agriculture and animal husbandry have been transformed in the past 100 years, and especially since the start of the Green Revolution in the 1940s in Mexico. Norman Borlaug developed new disease resistance high-yield varieties of wheat which combined with new mechanized agricultural technologies to massively increase agricultural productivity. Mexico transformed from importing half of its grain to being an exporter.

Specialized automation has been an ongoing source of efficiencies and frustrations, with John Deere's modern tractors featuring GPS, precision agricultural management technologies, stereos, air conditioners, many kilometers of wires, US$700,000 price tags and very limited ability of owners to fix them should something go wrong.

The current wave of automation is with drones. Approaching 100% of American farms now survey fields and crops with the tiny unmanned craft most of us think of as toys. Those expensive tractors as well as crop-dusting helicopters and small airplanes are being left increasingly idle as massive, 3.5 meter span, electric hexacopters carrying up to 90 kilograms of herbicides, pesticides, fungicides or fertilizer at a time apply it precisely to crops. "Farmers" spend time in their offices integrating sensor data and using laptops to plot routes for drones to follow and how much of what product to drop where.

Tractors are now electrifying as well, with multiple vendors offering battery-powered electric vehicles to displace their diesel-gulping siblings.

The trend to electrification is positive, and the use of drones is even more positive. Burning electrons instead of diesel reduces climate and health impacting emissions. Soil compaction from farm equipment reduces crop yields by 9% to 55% per studies, and drones don't touch the soil, leading to yield increases. Precision drone spraying, per early data from a study pending publication, can reduce the amount of product sprayed by up to 50% with the same crop yields.

When people think of farms, they don't image high-tech automation with coordination of complex sensor data feeding pathway creation for autonomous flying drones and ground equipment. The romantic image of a young farm child learning to milk a cow is equally out of touch.

Dairy farms feature massive milking barns with automated milking attachments for hundreds or thousands of cows that feed into massive sterilized tanks for the product. The largest such farm, in China unsurprisingly, is the size of Portugal, has about 100,000 dairy cattle at any given point and produces 800,000 million liters of milk annually.

At one point, 95% of the population of countries like the USA were involved in agriculture, animal husbandry or agricultural product processing and distribution. Now it's under 3%.

But it wasn't just automation, of course. Another major part of the Green Revolution was interbreeding the plants themselves into the varieties we pluck off the shelves of grocery stores today. This has led to varieties with excellent caloric and nutritional yields that are very resistant to the most common plant diseases. A farmer from 1600 would barely recognize many or most of the plants sown and harvested today globally.

But with those high-yield, hardy varieties came monocultures. That they were resistant to many of the challenges plants faced did not mean that they were resistant to all of them. With the changes in plants came often tightly coupled changes in the chemicals we applied to crops to prevent fungi and insects from destroying them and weeds from strangling them.

Most importantly from a climate perspective is that globally there has been a massive increase in the use of ammonia-based fertilizers. Plants need nitrogen. That molecule is the most common in the air we breathe, about 78% of it. Nitrogen is 3-4% of most plants' mass. We used to rotate crops and use clover and other nitrogen fixing plants on fallow fields, but now we just apply ammonia-based fertilizers, as ammonia is nitrogen and hydrogen.

And here's the biggest climate problem. Ammonia-based fertilizers are made from natural gas or coal gas. Hydrogen is stripped off of the gas and combined with nitrogen from the air in a process that burns gas to create heat to turn water into steam. The carbon from the gas combines with oxygen from the air to make carbon dioxide, a greenhouse gas.

Every ton of hydrogen we create from natural gas comes with about eight tons of carbon dioxide we vent to the air. And natural gas and coal gas leak from point of extraction to point of use, producing even more climate heating.

Modern ammonia-based fertilizers are another fossil fuel, but for plants not cars. There's more. When we apply ammonia to fields, some of the nitrogen in the fertilizer binds with oxygen from the air to create nitrous oxides. One of those oxides is a very potent, long-lasting greenhouse gas, about 265 times more potent than carbon dioxide.

We will fix the manufacturing of ammonia with green hydrogen, eliminating that source of greenhouse gases. But we can't change the chemical reactions that turn it into a potent greenhouse gas when we apply it to fields.

We can, however, reduce our use of it. Remember those electron-sipping, high-precision drones? While they can't do the massive fertilizer application that occurs just after harvest, they can do the three to five additional fertilizer additions that occur during the growing season. They cut the amount of ammonia fertilizer required by up to 50%.

Is that all we can do? No. In parallel with plant genetics, there's a great deal of innovation and commercialization of nitrogen-fixing solutions that don't use ammonia at all. Pivot Bio's founders spent their PhDs in agricultural genetics looking at the problem. They unravelled the nitrogen-fixing capabilities of a common soil microbe, and were trying to figure out how to insert the genes into plants. Then they had their aha moment while walking to a coffee shop.

Soil microbes that fix nitrogen are as lazy as the rest of us. They live off sugars that the plant pushes out of its roots to feed the symbiotic ecosystems in the soil in the wild. When there isn't enough nitrogen in the soil, the microbes make it. When there is, they don't bother, just get fat and multiply on the sugars.

So Karsten Temme and his Pivot Bio co-founder decided to just get rid of the nitrogen sensor in the microbes. They now manufacture packages of the genetically altered microbes using standard yeast-based brewing techniques that any beer maker would understand that last on shelves for years. Farmers coat seeds with it before planting, or inject it with seeds while sowing, and the microbes happily provide a lot of the nitrogen the growing plants required.

When I spoke to Temme a couple of years ago, they already had a million acres of US corn growing with their product, and were reducing fertilizer requirements by 25%. Their stretch goal is 100% for wheat, corn and rice by 2030, and if their solution doesn't do it, there are a lot of other innovators working on the same problem globally.

Next up is low-tillage farming. Plants suck carbon out of the air and into the soil. Natural soil is a complex ecosystem that includes a lot of mushroom threads that slowly harvest carbon and lock it into long-lasting chemicals. When farmers plough the soil to break up that soil compaction problem, they destroy the sub-surface ecosystems. The carbon that was in the soil almost immediately returns to the air as carbon dioxide. The mushroom threads that were slowly drawing carbon into permanent storage are destroyed. And so, let's change a lot of our agriculture to get rid of ploughing.

The combination of precision agriculture, agrigenetics for nitrogen fixing and low-tillage farming means we can eliminate carbon emissions from modern farming in the coming decades.

But that's for industrial farming. Small hold farmers, romantic as they might be, aren't well enough capitalized by themselves. In Europe, they form co-ops to buy agricultural equipment that they can't afford individually, but still have to run it inefficiently on small fields, a compromise forced by culture, regulation and an unwillingness to change.

It's relatively easy to change the 600-800 biggest industrial agricultural giants globally. They are corporations with Boards and stakeholders, and respond rationally to carrots and sticks. There are a limited number of them. It's much harder to change the approaches of millions of small hold farmers, but possible. They need to compete and survive and they must embrace the advances or differentiate themselves with 'all-natural' approaches.

It's the last segment of farmers we also have to deal with, subsistence farmers. These are not the modern affluent hobby farmers who use their trust funds to grow many things that they consume and barter with slow food networks. These are the global deeply impoverished, the billion or so people living hand to mouth on the land. These are the calorie strippers, taking everything that they can from the land in a desperate attempt to keep their families fed and sheltered. These are the people with little education, no capital and little technology.

There is absolutely nothing romantic about the lives of these billion deeply poor people scraping food from semi-arable land or herding scrawny goats over rocky hills. They are merely the human beings we have still left behind. We need to assist them and their children to move to urban areas as much as possible. We need to free the land they are scraping bare to be used more productively, whether that's adding the most fertile portions to larger farms, putting wind or solar farms on it, planting trees on it or simply letting it rewild by itself.

Farming is not romantic. It's a complex, sophisticated business that's absolutely essential to feeding the billions of us who live and dream on this planet. And it's a big climate problem that we have solutions for. That's why fixing it is on the short list of climate actions that will work.

As a reminder, here's the short list of climate actions that will work:

- Electrify everything
- Overbuild renewable generation
- Build continent-scale electrical grids and markets
- Build pumped hydro and other storage
- Plant a lot of trees
- Change agricultural practices
- Fix concrete, steel and industrial processes
- Price carbon aggressively
- Shut down coal and gas generation aggressively
- Stop financing and subsidies for fossil fuel
- Eliminate HFCs in refrigeration
- Ignore distractions
- Pay attention to motivations

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