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GRDC

GROUNDCOVER SUPPLEMENT

NUTRIENT MANAGEMENT FOR ENDURING PROFITABILITY

GRDC BOOSTS NUTRIENT KNOWLEDGE

Fertilisers are one of the major costs for Australian grain growers and GRDC is on a quest to optimise these inputs

By Dr Kaara Klepper, Dr Stephen Loss and Dr Rowan Maddern

■ By recruiting novel technologies to learn more about soil function, GRDC is seeking a step change to maximise crop nutrient use efficiency across the country. GRDC has invested in synchrotron scanning techniques to provide insights into interactions between roots, water and nutrients. Micro-computed tomography and nanoscale secondary ion mass spectrometry are also enhancing insights into soil structure and nutrient supply. These innovative technologies and foundational research will provide insights to improve nutrient use in the medium term. Meanwhile, GRDC continues to invest in better soil sampling strategies, updated fertiliser recommendations, application methods, flexible pulse and pasture legume species, and harnessing soil biology to reduce nutrient input costs.

IMPROVED SOIL SAMPLING

Understanding nutrient reserves through soil analysis is fundamental to developing a cost-effective fertiliser strategy. Soil variability within a paddock is common, which can affect nutrient supplies and, in turn, crop yield. More intensive soil testing from each production zone can help growers identify areas where variable fertiliser rates could translate into higher profits.

NEW FERTILISER RECOMMENDATIONS

Changing climate and farming systems, together with greater diversity of crop and pasture species, mean fertiliser recommendations need to be reviewed. Acknowledging regional differences in farming systems, GRDC is investing in fertiliser recommendations that are better tailored to specific soil types, changes brought about by soil amelioration, and the integration of better-adapted crops and pastures in farm systems.

When maximising nutrient use efficiency it is important to consider soil nutrient cycling processes and long-term productivity.

Photo: Nicole Baxter

FERTILISER APPLICATION METHODS

Phosphorus and potassium are less mobile than nitrogen and need to be placed in the root zone, especially in no-till systems. But as nutrient export has increased through higher yields and cropping frequency, soil nutrient reserves are depleted and increased amounts of fertiliser are being applied in deep bands, affecting nutrient dynamics and crop rooting patterns. Research is unravelling these issues to improve fertiliser application methods.

SOIL BIOTA

Soil is not simply an inert medium to grow plants – it is a living ecosystem. Soil biology influences the physical structure of the soil, its chemistry and the supply of many nutrients. Microbes are particularly important for nitrogen cycling, supply and symbiotic fixation within farming systems. GRDC investments are supporting the development of new pasture legumes and regionally adapted rhizobia strains and inoculation practices for pulses.

Ultimately, GRDC is endeavouring to ensure growers understand their options to increase nutrient availability and crop uptake. This will occur through enhanced nutrient cycling, nitrogen fixation and improved soil management practices, which will lead to improved profitability and sustainability. □

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GROUNDCOVER™ SUPPLEMENT edited by Dr Sue Knights

COVER IMAGE: Investigation of wheat root-soil interfaces using non-destructive techniques provides new insights into crop nutrient management.

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Cutting-edge technology to investigate root behaviour

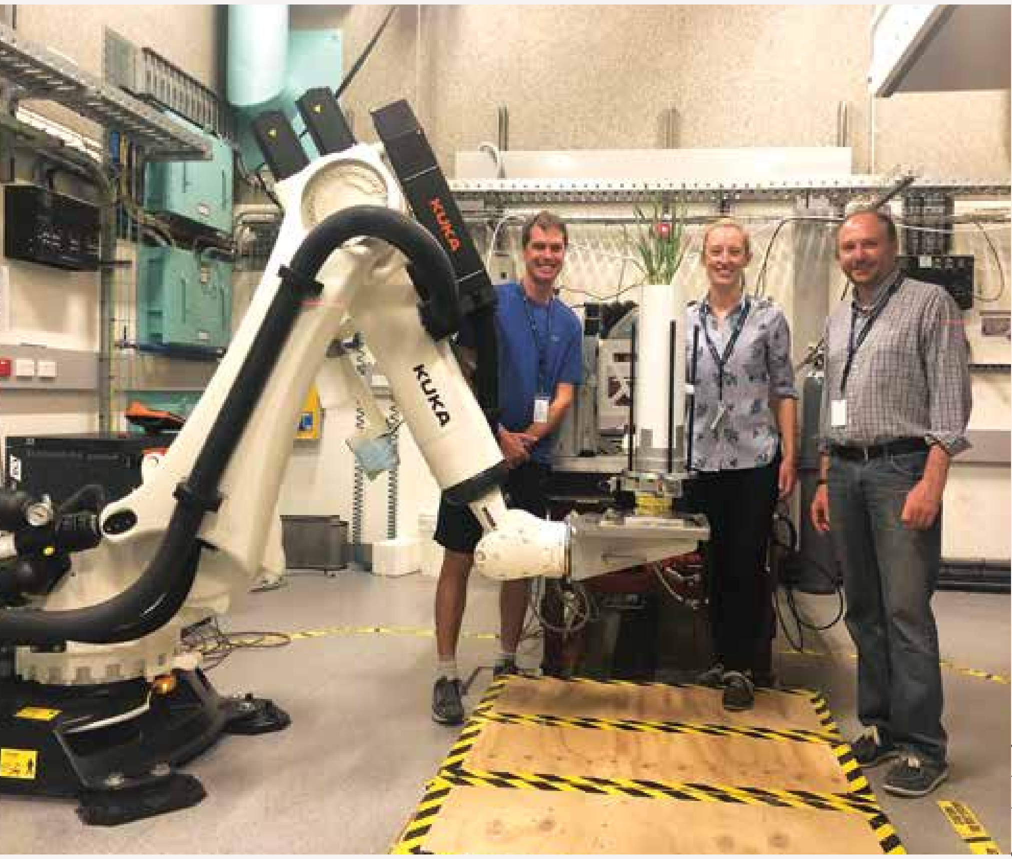

Photo: Yunyun (Allie) Zheng

Dr Peter Kopittke, Dr Casey Doolette and Professor Enzo Lombi scanning a soil core at the Australian Synchotron's IMBL beamline (Melbourne) to determine how root distribution is influenced by soil properties.

The hidden relationship between soils and plant roots is set to be exposed by researchers using the Australian Synchrotron to inform nutrient use efficiency

By Dr Peter Kopittke, Professor Enzo Lombi, Professor Richard Bell, Dr Casey Doolette, Dr Helen Hou and Dr Han Weng

■ Root distribution within soils is critical to plant growth and yield due to its regulation of water and nutrient uptake. However, roots are often referred to as "the hidden half" as they are difficult to study, being concealed in the soil.

For soils with constraints, such as sodic soils or nutrient-depleted soils, root distribution is especially important. For instance, in a bid to close the yield gap, growers on clay soils in eastern Australia are turning to deep banding of fertilisers such as phosphorus and potassium to address declining soil nutrient reserves in subsoil layers.

However, results in the field can be variable, ranging from substantial yield increases to no observable response, depending on soil type and fertiliser source. This variability is likely related, at least in part, to the ability of roots to explore and utilise the phosphorus. Until now, examining root behaviour in these and other soils has been difficult.

With investment from GRDC and in collaboration with the Australian Nuclear Science and Technology Organisation (ANSTO), several Australian universities are developing new approaches to examine root behaviour in soils using the Australian Synchrotron in Melbourne. Using this leading-edge technology, root distribution information will be simultaneously related to soil properties and nutrient availability.

ABOUT THE SYNCHROTRON

A synchrotron accelerates electrons to almost the speed of light, producing radiation, including X-rays, with special properties. These X-rays can be used to examine the three-dimensional distribution of roots within soils without disturbing the soils and without removing the roots.

Although this has been possible using conventional X-rays in typical laboratories, a new faster and more sensitive approach at the Australian Synchrotron can examine roots in soil cores up to 20 centimetres in diameter – 10 times larger than previously possible – and down to considerable depths (50 to 100cm). Being able to examine root distribution in large soil cores allows more realistic and informative analysis.

INTACT SOIL CORES

Collecting soil cores from the field and relating root distribution to nutrient availability and organic matter will provide information critical for understanding how to close the yield gap in constrained soils, including sodic soils (where roots are unable to access subsoil water) and nutrient-depleted soils (where roots are unable to access nutrients at the correct time and place within the soil).

This work commenced in late 2020 but is already well advanced. It is hoped the techniques will be fully developed in the next year, after which work will commence with researchers around Australia to value-add to existing GRDC investments.

Access to the synchrotron facility has taken research forward in a way that would not have been possible if traditional methods had to be relied upon. Given how widespread soil constraints are across Australia, using this machine to understand how root distribution can be improved in these soils will inform nutrient management decisions and help close the yield gap for growers. □

GRDC Codes UOQ1910-002, USA1910-001, UOQ1910-003

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Gravel soils are being investigated by stable isotope tracers that are imaged using nanoscale secondary ion mass spectrometry (nanoSIMS) to determine the extent of movement of nitrogen and phosphorus. Photo: Jeremy Bougoure, CMCA

Probe into ironstone gravel soils

New technology is being employed in a quest to understand the nutrient dynamics of gravel soils

KEY MESSAGE

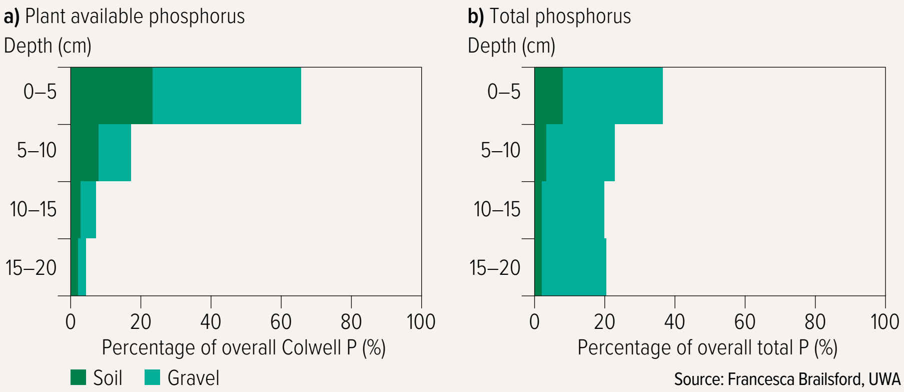
Cutting-edge tools and adapted standard soil analysis protocols are being used to learn more about nutrient use efficiency of ironstone gravel soils to better inform their management.

By Dr Francesca Brailsford and Professor Daniel Murphy

■ Ironstone gravel soils are common across Australia's southern cropping regions. Yet, while they may receive sufficient rainfall, their nutrient use efficiency is typically low.

However, detailed research is underway at SoilsWest at the University of Western Australia (UWA), with GRDC investment, to examine these soils' properties. This will provide new base knowledge of the interactions between the landscape, chemical and physical properties of ironstone gravel soils, and insights into their role in soil water and nutrient retention. Ultimately the findings will support improved nutrient management decisions for cropping.

Figure 1: An iron-dominated gravel with aluminium as a secondary element in loamy-sand soil has the majority of phosphorus bound to the gravel fraction.



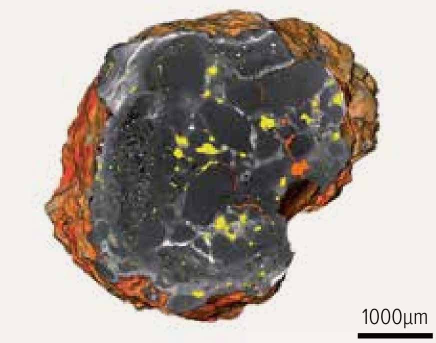
Source: Francesca Brailsford, UWA

ANALYSIS

Conventional soil analysis involves sieving to two millimetres, which excludes gravel, therefore the gravel composition and its impacts on nutrient (phosphorus, nitrogen) and water movement through soils are largely unknown.

To enhance our understanding of nutrient use efficiency of gravel soils, gravels are being processed using

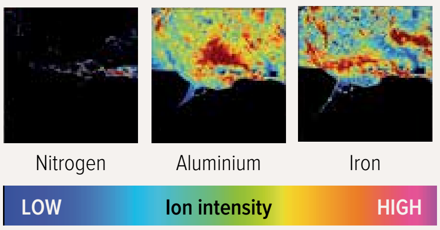
Figure 2: Micro-CT tomography scan of an internal silica-dominated gravel structure. Orange pores are surface-connected, while yellow pores are internal pores with no connection to the surface.



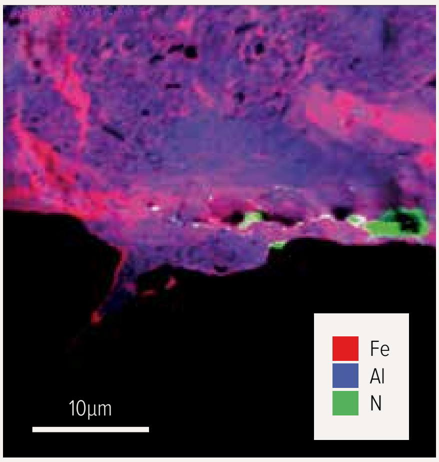
Source: Jeremy Shaw, CMCA

Figure 3: Nanoscale secondary ion mass spectrometry (nanoSIMS) output from a 40 x 40 µm section of gravel cross section edge.

a) Individual heat maps of nitrogen, aluminium and iron ion intensity.



b) Composite image combining nitrogen, aluminium and iron images highlighting the interactions of all three.



Source: Jeremy Bougoure, CMCA

IN A PADDOCK HISTORICALLY USED FOR CROPPING, MORE THAN 90 PER CENT OF PHOSPHORUS INPUTS REMAINED IN THE TOP 20 CENTIMETRES OF THE SOIL.

adapted protocols for standard soil analyses, combined with advanced research. This includes 'mineralogical powder diffraction analysis' using the Australian Synchrotron in Melbourne, and a range of imaging and microanalysis techniques at the Centre for Microscopy, Characterisation and Analysis (CMCA) at UWA.

Chemical analyses of gravel soils from a range of sites in WA, South Australia and Victoria have highlighted key differences between different gravel types (iron, aluminium or silica dominated). Increasing gravel iron content is associated with higher phosphorus content, while for increasing silica content, lower phosphorus.

Mineralogical data from the powder diffraction beamline at the Australian Synchrotron has shown that haematite – a common iron oxide – content, in particular, is associated with higher gravel phosphorus content.

Further elemental analysis of a gravel soil profile has revealed that even though there was no change in gravel composition with depth, gravel appears to restrict phosphorus movement down through the soil profile.

In a paddock historically used for cropping, more than 90 per cent of phosphorus inputs remained in the top 20 centimetres of the soil.

Despite gravels being less than one per cent of the total below-ground surface area available for nutrient binding, 60 per cent Colwell phosphorus (that is plant-available phosphorus) and 84 per cent total phosphorus was found to be associated with gravels (Figure 1a and b).

This finding confirms that gravels have the potential to bind phosphorus and other nutrients within the soil.

NEW TECHNIQUES

To understand these nutrient dynamics further, the UWA team is developing methods to quantify the capacity for predicting nutrient binding of both nitrogen and phosphorus to the gravels.

Three-dimensional X-ray scans of gravel structure using micro-computed tomography have demonstrated that gravel surface area is generally predictable from gravel mass or diameter, allowing the prediction of the surface area available for nutrient binding.

However, the gravel scans have also highlighted the presence of pore networks within the gravels, some of which are connected to the surface, providing opportunities for water, nutrients and microbes to enter (Figure 2).

A method to quantify the additional internal surface area available for binding is being developed at CMCA.

The extent of movement of nitrogen and phosphorus into the gravel can be measured using stable isotope tracers that are imaged using nanoscale secondary ion mass spectrometry (nanoSIMS, Figure 3). This information provides new insights into the extent of microbial and plant availability of the nutrients inside the gravel nodules of differing chemical compositions.

In conjunction with nanoSIMS, experiments to quantify bulk gravel nutrient and water-holding capacities are currently being run on a range of gravel types.

A combination of radioisotope and nutrient tracer techniques quantifying nitrogen and phosphorus binding capacities under a range of conditions are being jointly conducted at UWA and Bangor University, Wales.

INSIGHTS FOR GROWERS

Researchers are combining the gravel structural relationships from micro-CT tomography with nitrogen and phosphorus binding data in order to determine nitrogen/phosphorus binding capacities for different gravel types.

With this information, measuring nitrogen and phosphorus concentrations within a paddock should indicate whether a gravel soil is near to its nitrogen/phosphorus binding capacity and thus whether future nutrient additions will be bound by gravels or remain available to plants.

This will help inform more targeted management of different gravel soils in the future. □

GRDC Code UWA 1906-008

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Optimum soil sampling strategies for the west

By Dr Sue Knights

■ Determining an appropriate soil sampling strategy is challenging for Western Australia, given its soils are highly variable and, in places, might have been reconstructed using diverse amelioration techniques. Dr Yvette Oliver, a senior research scientist at CSIRO, is addressing this issue. With GRDC investment, she is leading a multi-disciplinary team from the University of Western Australia, Murdoch University, CSBP Ltd, Summit Fertilizers and the Department of Primary Industries and Regional Development.

The research value-adds to a suite of nutrient projects, including focus paddocks, precision agriculture, Yield Prophet, subsoil constraints and soil water. It is another testament to the collaborative capabilities of the SoilsWest venture and will provide insights from a large dataset covering the variable WA soils and management practices.

"Specifically, we are focusing on sampling strategies that address the microspatial variation caused by previous crop row stubble, or application of nutrients in the crop row, as well as the soil-mixing processes of amelioration," Dr Oliver says.

"Growers need to keep their goal in mind when they are considering an appropriate soil sampling strategy and ask questions: How accurate do you need to be? Do you want to monitor trends over time or just have a point-in-time reference to assess the nutrient status?" she says.

This will determine how many cores are required to meet this accuracy, depending on the variability of the paddocks.

WESTERN SOILS

Many WA soils suffer from one or more production constraints, including acidity, sodicity and poor soil structure; compaction and high soil strength; water repellence and low water holding capacity; and nutrient deficiency and stratification. This has driven the adoption of a wide range of amelioration techniques to reconstruct soils, using techniques such as deep ripping, spading and mouldboard ploughs.

"This customised approach to soil reconstruction means there is no one-size-fits-all recommendation when it comes to soil sampling for WA," Dr Oliver says.

KEY LESSONS

Over or under-fertilising is an issue for highly variable soils and a carefully considered sampling strategy can help resolve this.

"For example, if the soil test is returned with an average 10 milligrams per kilogram value for phosphorus, the actual value may be much higher or lower, as the range is determined by how variable the soils are across a paddock and how many samples were taken," Dr Oliver says.

If fewer cores were taken, then the range of likely phosphorus values is high and the likely economic loss from over-fertilising or under-fertilising is also high (Figure 1a and 1b). If the variability is low (Figure 1a), then there is a similar chance of financial loss at taking 14 cores as there is at 40 cores. But if the variability is high (Figure 1b), then about 30 cores are required to reduce economic loss.

There was no definable trend for difference in on-row and off-row nutrients, so sampling can remain random unless there is precision sowing.

Deeper nutrients to 30 to 40 centimetres are accessible by the crops. In many cases it was found that nitrate-nitrogen and potassium to 30cm, or phosphorus and sulfur to 20cm, can be estimated from the zero to 10cm test in WA soils and low-to-medium-rainfall farming systems. ☐

GRDC Code CSP1801-004

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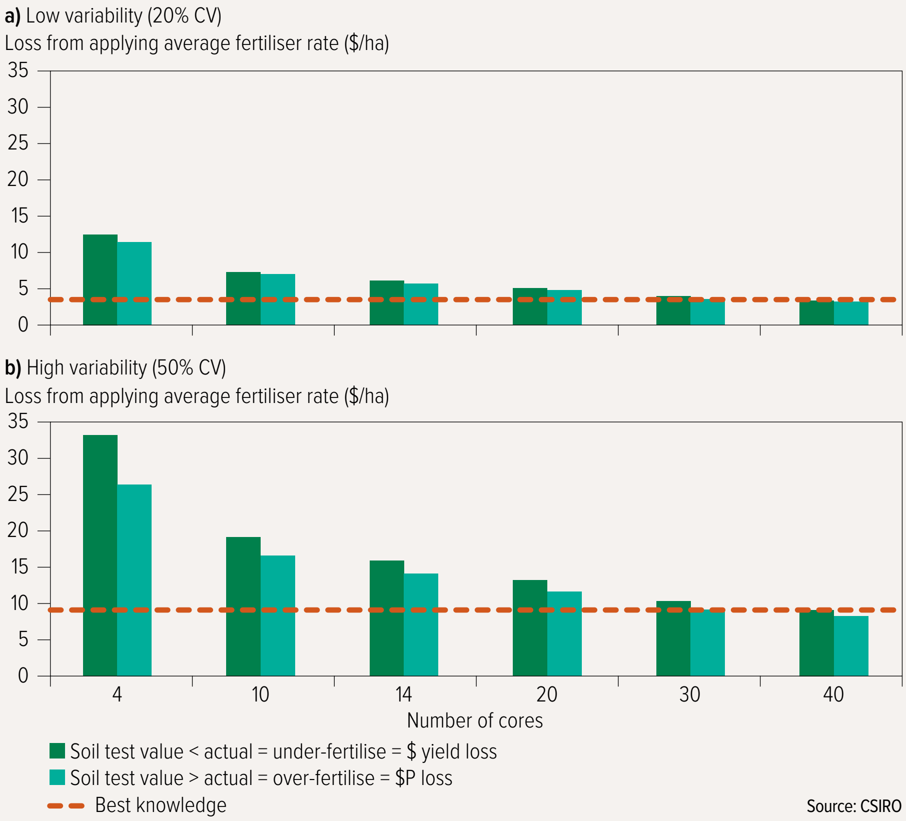
Figure 1: Loss ($/ha) from applying an average phosphorus fertiliser rate of 10mg/kg across soils with phosphorus values lower or higher than the average test value. Calculation based on (a) paddock with low soil variability (coefficient of variation, CV of 20 per cent) or (b) high variability (CV of 50 per cent) across a range of bulked soil cores ranging from four to 40.



Source: CSIRO

Intensive testing key to lifting fertiliser returns

More intensive zone soil sampling has the potential to boost nutrient investments on variable soils

By Dr Harm van Rees, Dr Sean Mason, Dan Bell, Dr Therese McBeath, Jackie Ouzman and Dr Rick Llewellyn

KEY POINTS

- **In-paddock variability can have a substantial impact on soil nutrient status and yield potential**
- **By taking soil tests from each production zone, growers can better identify areas where variable rates of fertiliser may translate into higher profits**

■ With fertilisers often the largest single variable expense for growers, money spent on soil testing will help maximise the return on that investment by optimising those inputs and crop yields. Yet in paddocks with variable soil types, testing can often be insufficient to understand the variability and identify potential gains.

To demonstrate how intensive soil and plant testing can improve fertiliser decisions and maximise returns for growers, GRDC has invested in research in the southern region. The project, which started in 2018, is led by Agronomy Solutions in partnership with Nutrien Ag Solutions, AgCommunicators, Australian Precision Ag Laboratory and CSIRO.

PADDOCK DEMONSTRATIONS

Working with growers in South Australia and Victoria, researchers identified more than 300 paddocks with variable productivity and intensively sampled soil for nutrient analysis in two different one-hectare production zones prior to sowing in 2019. Of these, 150 paddocks were selected to trial different fertiliser rates applied as strips across the full width of the paddock, including the intensively sampled zones.

At sowing, the growers applied phosphorus at zero, their standard rate and double their standard rate. If soil tests indicated phosphorus levels were already high, an additional half rate was included. At other sites, nitrogen strips were also top-dressed as required, but are not reported in this article.

By comparing wheat yield map data, dry matter and plant tissue analysis with the soil test results and fertiliser rates, researchers were able to better understand the variable responses in the different production zones.

VARIABILITY

In 2019, the soil nutrient status was highly variable across many of the paddocks tested in the project. For example, in a paddock in the Victorian Southern Mallee, soil tests indicated marginal soil phosphorus in Production Zone 1 and the DGT P results predicted a deficiency in Zone 2. While deficiency was not predicted by Colwell P, the higher phosphorus buffering index observed in Zone 2 is typically associated with higher critical Colwell P targets.

In this paddock, phosphorus was applied in double-seeder-width strips at zero, half rate (4.4 kilograms of phosphorus per hectare), standard (8.8kg P/ha) and double (17.6kg P/ha). The yield results showed just how variable the productivity was across the full width of the paddock (see Figure 1). There were significant yield improvements observed in the phosphorus-deficient Zone 2 for the double rate compared with the standard rate, and no significant differences between any of the rates in Zone 1.

The results for this and other paddocks demonstrate that growers need to increase sampling intensity and sample more than one soil type or production zone in each paddock.

These grower demonstrations were continued in 2020 and researchers are also investigating the potential for large-scale grower-replicated trials (100 metres long and three seeder-widths wide) to help overcome the influence of paddock variability on interpreting the response to different rates of phosphorus fertiliser. □

GRDC Code 9176604

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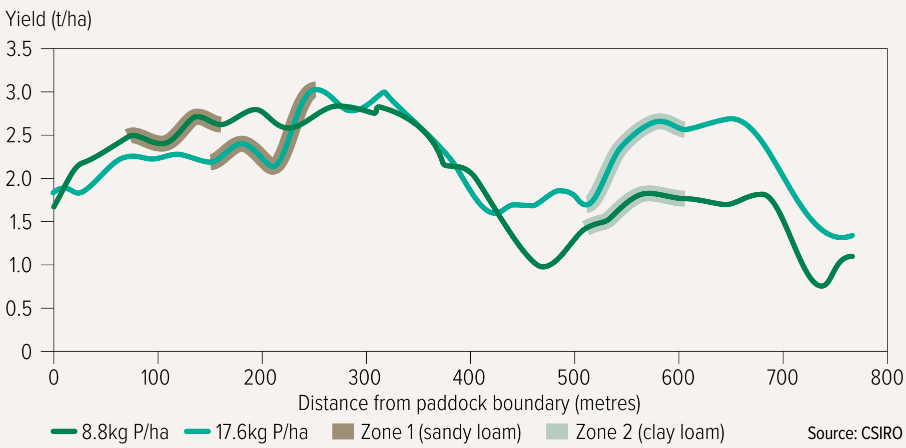
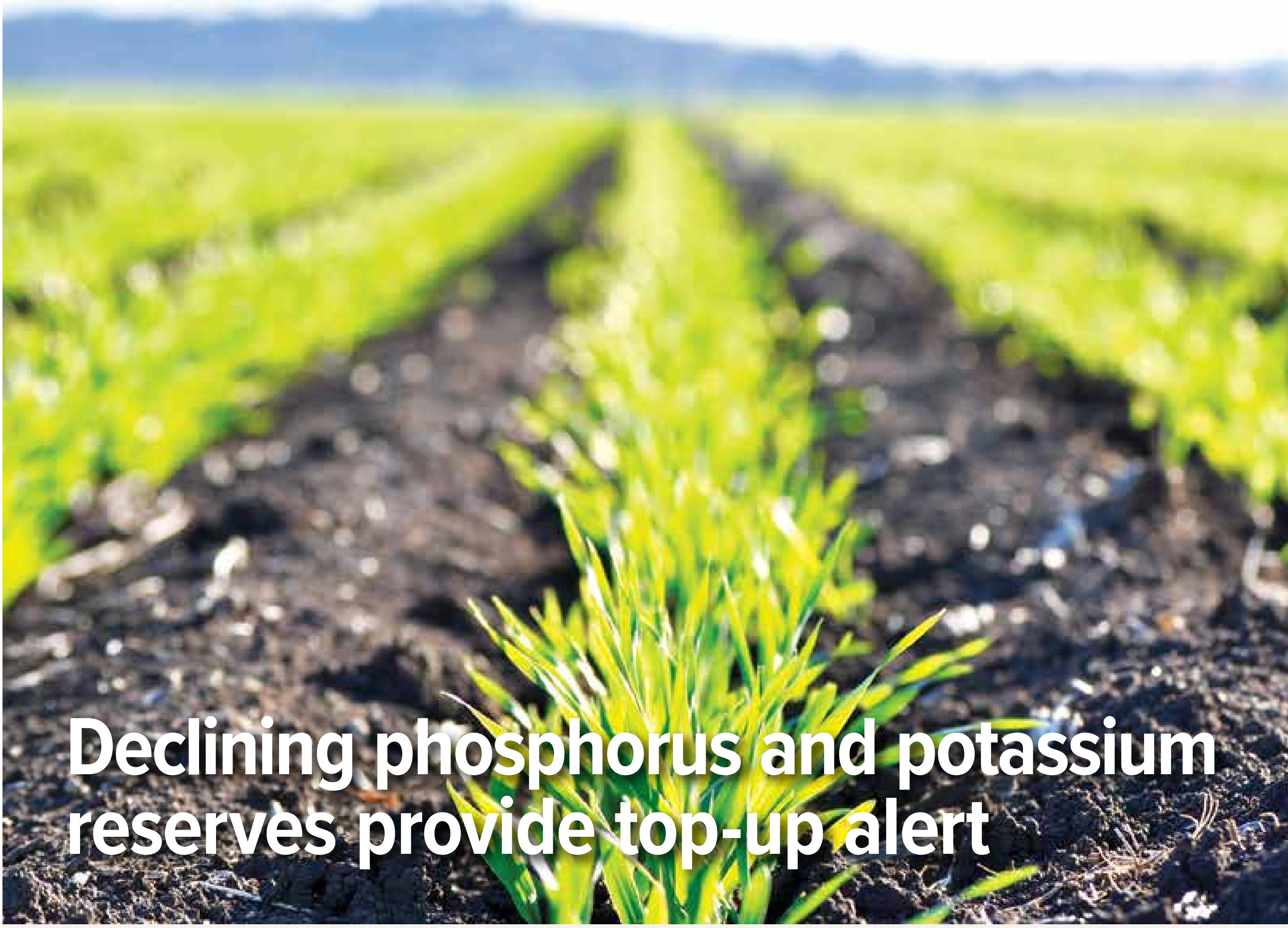
THE RESULTS FOR THIS AND OTHER PADDOCKS DEMONSTRATE THAT GROWERS NEED TO INCREASE SAMPLING INTENSITY AND SAMPLE MORE THAN ONE SOIL TYPE OR PRODUCTION ZONE IN EACH PADDOCK.

Figure 1: Harvest yield data strips across the full paddock width demonstrate the variability across the paddock. The double rate of phosphorus (17.6kg P/ha) has significantly improved yield compared with the standard rate (8.8kg P/ha) in Zone 2, where intensive soil testing identified a phosphorus deficiency. Zone 1 was not considered deficient and there was no significant difference between phosphorus treatments.



Source: CSIRO



Declining phosphorus and potassium reserves provide top-up alert

Improving access to phosphorus and potassium is essential to optimising grain production. Photo: Richard Flavel

While measuring available phosphorus and potassium is essential for seasonal fertiliser decisions, reserves can provide an early warning for future declines

By Associate Professor Chris Guppy, Associate Professor Matt Tighe and Dr Phil Moody*

KEY POINTS

- Reserves of phosphorus and potassium vary widely in soils of the northern grains region but can be an important early warning signal to guide fertiliser decisions
- There are no district-wide indicators of reserve phosphorus and potassium status
- We recommend growers and advisers assess reserve phosphorus and potassium every 10 years at surface and subsoil depths

Declining soil fertility in the northern grains region has led to novel fertiliser application and placement strategies and, importantly, an awareness of the changes in phosphorus and potassium availability that are needed to increase grain production and optimise fertiliser recovery.

Large reserves of phosphorus and potassium exist in some of these soils, but to date we have had limited understanding of how to quantify them and over what timeframe – and to what extent – they can supplement existing available sources.

A three-year GRDC investment in research at the University of New England and the Queensland Department of Environment and Science has shed some light on the nature of phosphorus and potassium reserves. In particular, it has improved understanding of their distribution across the region, measurement, availability to crop roots, and whether landscape changes (such as periodic flooding) or varying crop rotation (including more pulses) could increase crop availability.

The results show it is not possible to provide district-wide indicators of reserve phosphorus and potassium status, as cropping history and management result in wide variation in these nutrient pools. However, there is also no evidence that either episodic flooding or increased pulse rotations can accelerate the release of phosphorus or potassium from soil reserves into labile soil pools.

MEASURING RESERVES

Monitoring available phosphorus and potassium in the surface (zero to 10 centimetres) and subsoil (10 to 30cm) is essential for providing seasonal fertiliser recommendations (see Table 1). We recommend growers and advisers also assess reserve phosphorus and potassium every 10 years at surface and subsoil depths to provide early warning of declining soil nutrient reserves. However, predicting the likely contribution of these reserves to crop nutrient requirements remains problematic, and seasonal fertiliser recommendations should not be adjusted for reserve phosphorus and potassium status.

The key measures of these reserves in soils of the northern grains region were identified as the BSES-P soil phosphorus test (extractant: 0.005 molar sulfuric acid) and a one-hour tetraphenylborate extraction for potassium (TB-K). These are readily available through commercial and institutional labs, although TB-K is not undertaken as regularly as BSES-P. Preliminary evidence suggests mid-infrared spectroscopy (MIR) can produce a rapid and cost-effective estimate of reserve phosphorus and potassium, and further research may improve this diagnostic capability.

Adjusting fertiliser recommendations on the basis of BSES-P or TB-K results is not recommended, but periodic measurement of these pools will determine the size of the buffer that is slowing the decline in plant-available phosphorus and potassium pools.

ADJUSTMENT FACTORS

We suggest PBI (corrected with Colwell P) and cation exchange capacity (CEC) should be factored into the critical ranges for Colwell P and exchangeable potassium.

Most northern grains region soils (except ferrosols) have PBI values of 150 to 250, meaning applied phosphorus remains available to crops through the season and unused phosphorus is likely to be available the following season. Responsive Colwell P levels in soils (less than 25 milligrams Colwell P per kilogram for most circumstances) need not be adjusted unless PBI values are above approximately 250.

Responsive exchangeable potassium levels increase with CEC because it takes an increasing amount of exchangeable potassium to maintain an adequate soil solution concentration as CEC increases. We suspect that while critical potassium values increase with CEC, they may not increase linearly above a CEC of 40 centimoles of positive charge per kilogram of soil.

Because we found little evidence that northern grain region soils 'fix' applied potassium, it is concluded that they do not contain appreciable amounts of potassium-fixing clay minerals such as illites or vermiculites. Regular potassium applications that replace the amount of potassium removed each year in harvested products should, therefore, be sufficient to maintain adequate levels.

Overall, this project has identified that reserve pools are important sources of phosphorus and potassium in some of the region's soils, thereby buffering the plant-available pools.

However, in making fertiliser recommendations, advisers should focus on the plant-available fractions of soil phosphorus and potassium, taking into account the relevant buffer capacity measures of PBI and CEC respectively. □

**Dr Phil Moody passed away on 30 June 2020.*

Table 1: Soil testing recommendations for phosphorus and potassium in the northern grains region. Test both the surface (0–10cm) and subsoil (10–30cm).

Soil test timing	Phosphorus testing strategy	Potassium testing strategy
<2 yearly	Available (Colwell P) Adjust critical value if PBI>250	Available (Exchangeable K) Adjust critical value if CEC>20 and/or sodic
<10 yearly	Reserve (BSES-P minus Colwell P) Consider replacement strategy if <1.5x Colwell P	Reserve (TBK minus Exchangeable K) Consider replacement strategy if <1.3x Exchangeable K

Source: Chris Guppy

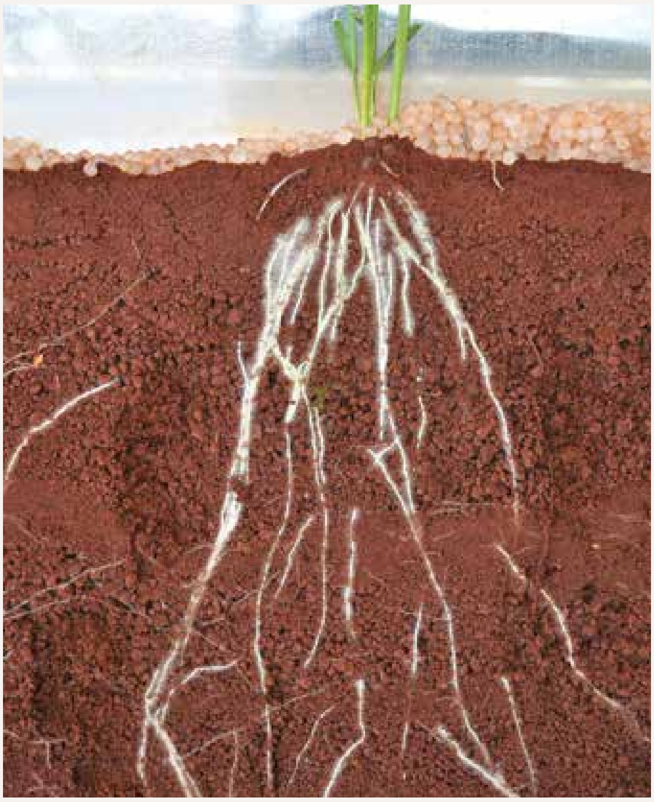


Photo: Richard Flavel

Measuring reserve phosphorus and potassium will help understand the size of the buffer that is slowing the decline in plant-available pools.

THE RESULTS SHOW IT IS NOT POSSIBLE TO PROVIDE DISTRICT-WIDE INDICATORS OF RESERVE PHOSPHORUS AND POTASSIUM STATUS, AS CROPPING HISTORY AND MANAGEMENT RESULT IN WIDE VARIATION IN THESE NUTRIENT POOLS.

GRDC Code UNE00022

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Big three nutrients under rigorous study

A multi-institutional research program is underway to further unravel the complex and ever-changing nitrogen, phosphorus and potassium dynamics in Western Australia

By Dr Craig Scanlan, Professor Daniel Murphy, Professor Zed Rengel and Professor Richard Bell

KEY POINTS

- Due to the combined effects of changing farming practices and climate, nutrient management strategies need to be continually updated
- Soil biota play a vital and complex role in nutrient cycles that is challenging to unravel
- Detailed insights into nitrogen, phosphorus and potassium dynamics will be used to deliver improved fertiliser management strategies by the end of 2022

■ Long-term changes to cropping systems – together with changing climate – are driving the need to update the knowledge base used to guide nitrogen, phosphorus and potassium fertiliser decisions for the western region.

Using knowledge from a research program supported by GRDC, a SoilsWest team from the University of Western Australia (UWA), Murdoch University and the Department of Primary Industries and Regional Development will assess economic responses to management strategies for these macronutrients, update nutrient decision guidelines and roll out findings to the western grains industry.

NITROGEN INSIGHTS

Work at UWA is focused on soil nitrogen processes that have the greatest impact on profit from fertilisers. Laboratory and glasshouse experiments are delivering an improved understanding of soil nitrogen supply by unravelling the interactions between climate, management and biological pathways in soil.

For example, Figure 1 shows how soil nitrogen storage (total soil nitrogen) is greater at low soil pH (in $CaCl_2$). Acidity causes soil organic matter (which includes organic nitrogen) to accumulate as the soil biota have a lower efficiency for soil organic matter cycling at low pH. This means the soil organic nitrogen store builds up instead of being released by the soil biota to become plant-available (Figure 1a). At optimal pH values (more than 5.5), soil biota are more active. This leads to faster soil organic matter cycling and greater release of plant-available soil nitrogen (Figure 1b).

PHOSPHORUS INSIGHTS

To better inform phosphorus management, there is a need to: (i) re-examine which soil properties are the best predictors of grain yield response to fertiliser phosphorus; (ii) establish whether small amounts of starter phosphorus fertiliser would allow crops to unlock soil phosphorus; (iii) test various options for optimising phosphorus fertility down the soil profile; and (iv) quantify the impact of crop sequence on soil phosphorus supply.

Nuclear magnetic resonance phosphorus spectroscopy was used at UWA to characterise phosphorus forms in a range of soils. While the majority of phosphorus present in soil was in the inorganic phosphate form, organic phosphorus represented about 30 per cent of the total in cropping soils.

Work on phosphorus fertiliser placement suggests subsoil phosphorus supply is important. At a field trial near Tammin, where topsoil phosphorus levels were adequate but the subsoil was low (less than 10 milligrams per kilogram of Colwell phosphorus), there was no response to phosphorus drilled below seed. However, the wheat yield was almost 20 per cent higher in the ripped treatment (50 centimetres). with phosphorus placements at 20 and 40cm compared with ripping alone.

Long-term phosphorus-cycling trials are providing some insight into the effect of crop sequence on crop response to fertiliser phosphorus. In the second year (2019), wheat following wheat showed a greater yield response to phosphorus

Photo: UWA

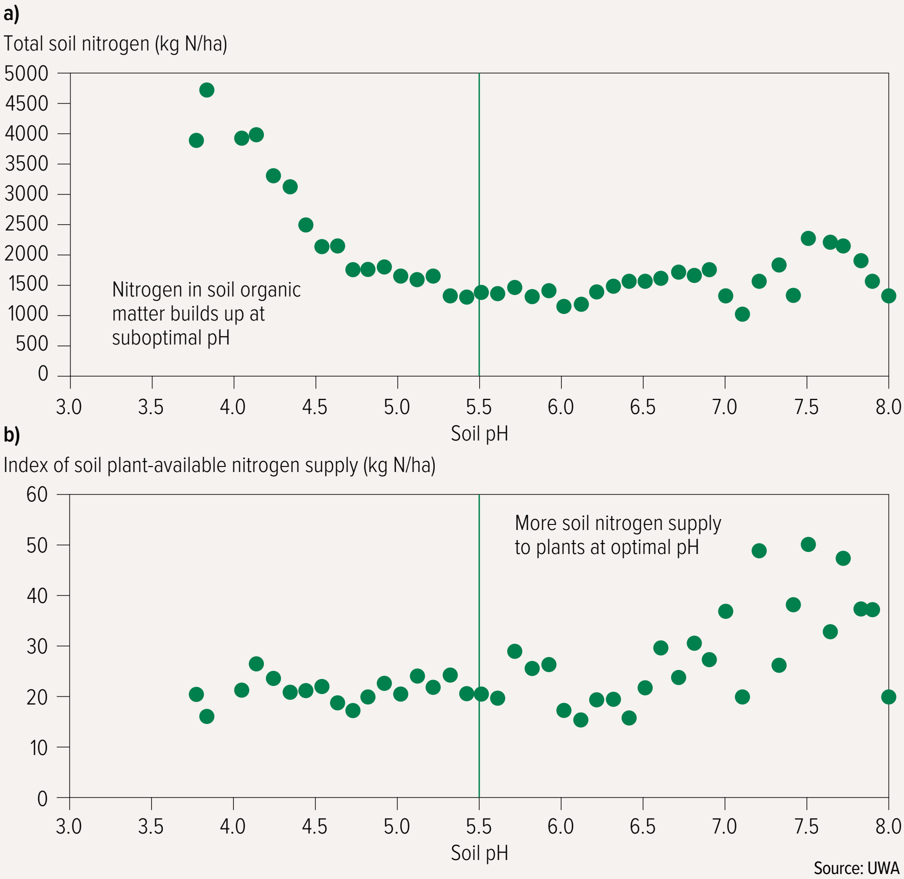
The research team examining root growth responses to deep-placed phosphorus at a trial site at South Tammin, Western Australia.

fertiliser than wheat following lupins at the Esperance site. These four-year trials will provide knowledge on how the cumulative effects of crop sequence and phosphorus fertiliser management influence plant-available phosphorus and grain yield.

POTASSIUM INSIGHTS

To better inform potassium fertiliser decisions, long-term field experiments are testing the effects of potassium fertiliser strategies and crop rotation on potassium availability and leaching.

Figure 1: Relationship between soil pH and (a) total soil nitrogen and (b) plant-available soil nitrogen in WA cropping soils. Note: the index of plant-available soil nitrogen supply is determined by a laboratory incubation.



Source: UWA

Leaching of potassium was detected after the first year at the Mingenew site.

Four grower case studies were investigated based on observations of windrow effects in crops in 2019 and 2020 on loam-textured soils (Figure 3a). Soil and plant testing on and off the windrow demonstrated the difference in growth was most likely due to potassium deficiency at three of the case studies. In 2020, strips of muriate of potash applied across the windrow showed a 30 per cent increase in oat yield in the inter-row (Figure 3a and b).

Ultimately, the research will determine whether a higher level of soil potassium is required in loamy soils to avoid potassium deficiency, compared with sandy soils. The forms of potassium in WA soils and the ability of different soil test methods to predict plant-available potassium are also being examined. Soil has been collected from 21 soil types across the region, ranging from grey sands to red clay loams.

By the end of 2022, the team expects to deliver new recommendations to growers on nitrogen, phosphorus and potassium soil testing for loam-textured soils and appropriate fertiliser management strategies. ☐

GRDC Code UWA1801-002

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Figure 2: Soil pits opened to take soil and root samples from the phosphorus placement trial at Tammin.

Photo: Gustavo Boitt, UWA

Figure 3a: Windrow effects in wheat crop at Meckering 2019, which was attributed to differences in soil potassium level.

Source: Murdoch University

Figure 3b: Cross strips of potassium chloride showing oat crop response to potassium supply between last year's windrows.

Source: Murdoch University

Time for fertiliser calculation reboot

Changing farming systems and a broader range of crops mean new data is needed to determine critical concentrations of soil nutrients

Canola grown in a field trial at Minnipa, South Australia, in the 2020 growing season demonstrates the impact on biomass of contrasting concentrations of soil phosphorus. Photo: Nigel Wilhelm

By Professor Mike Bell, Dr Nigel Wilhelm, Dr Roger Armstrong, Dr Ehsan Tavakkoli, Dr David Lester and Sjaan Davey

KEY POINTS

- Fertiliser recommendations need to be updated to better reflect changing farming systems and a broader range of crop species
- Seasonal conditions can have a profound effect on nutrient availability, particularly as no-till systems mean immobile nutrients such as phosphorus and potassium are likely to be concentrated in the often-dry top few centimetres

■ Growers rely on soil test interpretations to identify whether fertiliser is needed and how much is required to achieve the water-limited yield potential.

Soil test values are compared to the target ‘critical nutrient concentration ranges’ needed for a crop to achieve 90 per cent of the nutrient-unlimited yield.

The ranges reflect the uncertainty around crop responses under different seasonal conditions and management systems, and are based on extensive research into nitrogen, phosphorus, potassium and sulfur requirements specific to each crop species.

CHANGING LAND MANAGEMENT

However, most historical fertiliser trials have been with winter cereals (wheat and barley) and focused on nitrogen and phosphorus. Research into responses of pulses, oilseeds and coarse grains such as sorghum has been limited, as has research into other nutrients such as sulfur and potassium.

Historical trials were typically conducted in fields with full cultivation, so nutrients were well-distributed in the plough layer rather than concentrated in the top few centimetres, as tends to happen with no-till.

Much of the existing research was also conducted more than 30 years ago, when cropping systems were quite different and soil fertility reserves were either higher (in the northern vertosols) or lower (in some of the lighter-textured soils in the south and west).

To address these limitations, GRDC invested in a field program conducted at 18 to 20 research sites between 2017 and 2020. Led by the University of Queensland, the team – which includes the South Australian Research and Development Institute (SARDI), NSW

Department of Primary Industries and the Department of Agriculture and Fisheries Queensland – has measured nutrient responses by 40 to 50 crops in each of the four years.

At each site, a 'reference crop' of wheat or sorghum was used to assess the 'relative responsiveness' of winter and summer pulses, oilseeds or coarse grains to increasing concentrations of the nutrient being studied (see example in Figure 1).

Relative differences were then extrapolated to a wider range of sites and soil types, using the more extensive trial datasets that already exist for the reference species.

The research has focused on identifying the responsiveness and critical soil test ranges of important pulses, oilseeds and coarse grains to differing soil concentrations of all four key nutrients to improve fertiliser recommendations.

Many of the trial sites experienced dry seasons prior to 2020, with results highlighting the consequences of estimating critical nutrient concentrations under those conditions.

DRY CONDITIONS

Dry seasonal conditions prior to 2020 limited yields and nutrient demand by crops and reduced the ability of roots to forage in topsoil layers where less-mobile nutrients, such as phosphorus and potassium, can be concentrated. This has meant a number of site-years were either unresponsive or showed only small yield increases, even with high soil nutrient concentrations.

An example of the latter is a trial at Roseworthy in SA that found critical concentration ranges for phosphorus in wheat were two to three times the accepted concentrations. These were greatest in the 2018 crop (late sowing, water stress), but were also marked in the better-performing but still water-limited 2019. These seasonal differences were opposite what was expected on the basis of crop demand, suggesting a very inefficient nutrient uptake in drier conditions.

There have also been apparent differences in critical concentrations of nutrients between the reference crop and the other species (such as in Figure 1), but some of these differences may be due to seasonal conditions and not fundamental nutrient requirements.

For example, pulse and oilseed yields have often been less responsive to increasing phosphorus availability than wheat. However, we believe this apparent lack of response reflects the fact that our trials were conducted in dry seasons and often with a sharp finish. Pulses and oilseeds typically have a lower tolerance to stress and suffer a greater yield penalty than cereals. While you do not need much nutrient to grow a low-yielding crop, you cannot capitalise on a good season without nutrients. The wetter 2020 season is providing a welcome opportunity to better test this hypothesis.

The project data will be added to the existing bank of soil testing data and will also generate guidelines about how much fertiliser is required to change soil nutrient concentrations and how quickly those concentrations decline after fertiliser application. □

GRDC Code UQ00082

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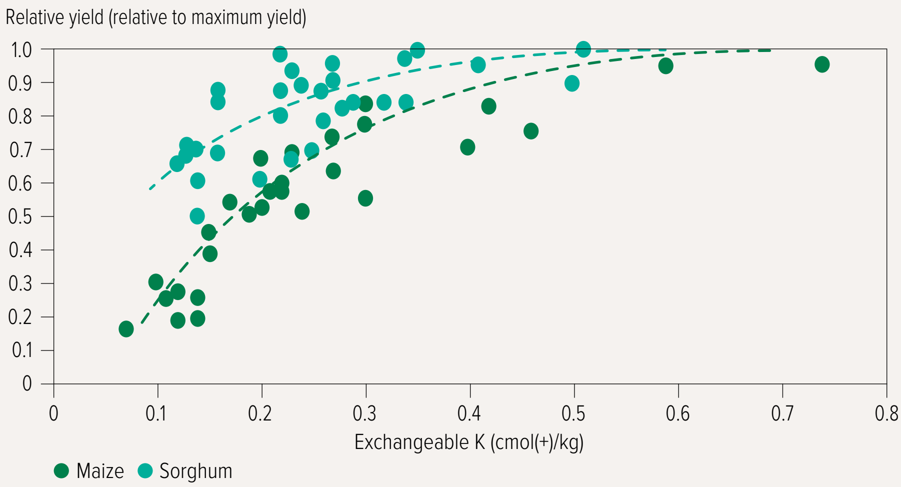
Photo: Mike Bell

A four-year study is examining fertiliser responses for a broad range of crops including sorghum, here showing potassium deficiency.

Professor Mike Bell.

Figure 1: Contrasting relative yield responses of sorghum and maize to increasing soil potassium on a ferrosol soil near Kingaroy, Queensland. Maximum yields in this 2018-19 season were 7.1t/ha for maize and 5.6t/ha for sorghum, with maize requiring higher exchangeable potassium to approach these target yields.



Source: Mike Bell

Fertiliser guides planned for ameliorated soils

Mechanical amelioration of soil constraints can lead to improved crop performance, but do growers need to change their nutrient management to reach their new yield potential?

By Dr Craig Scanlan, Professor Daniel Murphy and Associate Professor Frances Hoyle

KEY POINTS

- Mechanical amelioration of constrained soil generally leads to improved crop performance, but little is known about the soil's changed nutrient status
- Research is underway to develop fertiliser guidelines for these ameliorated soils
- Preliminary results show that ameliorating water-repellent soil is improving potassium availability

■ Although mechanical soil amelioration is successfully alleviating multiple soil constraints across Western Australia, some significant knowledge gaps have emerged.

An integrated research program, supported by GRDC and led by the Department of Primary Industries and Regional Development (DPIRD), is set to fill these gaps and update guidelines for fertiliser recommendations for these ameliorated soils by 2022.

DPIRD is working with the University of Western Australia, Curtin University and CSIRO through the SoilsWest Alliance, bringing together expertise in field crop nutrition, soil nitrogen processes, geostatistics and geophysics. This broad skills base will allow the team to gain an understanding of how soil amelioration is changing soil nutrient supply and demand at the plot and paddock scale.

QUESTIONS BEING ADDRESSED

Mechanical soil amelioration is undertaken with mouldboard ploughs, rotary spaders, disc ploughs and deep rippers. All of these mechanical approaches introduce spatial variation in soil properties – most likely changing soil nutrient supply and root growth – and change crop demand, which raises some important questions:

1. **How do different implements redistribute soil nutrients within their working depth?**
2. **How do we sample an ameliorated soil so as to best predict fertiliser requirements?**
3. **Does a change in spatial distribution of nutrients actually lead to a difference in plant availability of these nutrients and how do we predict this?**
4. **What is the amount of soil organic matter decomposed in the short term (less than two years) and how does this influence soil nitrogen supply in response to soil amelioration?**
5. **How does mechanical soil amelioration change the yield response to applied nutrients?**

PRELIMINARY RESULTS

Research is showing that ameliorating soil water repellence is improving the availability of soil potassium. Weekly measurements of shoot growth and nutrient concentration at a trial in Gibson showed shoot potassium concentration was well above critical levels in the ameliorated soil in early growth stages, but was close to critical levels in the untreated soil at all sampling times (Figure 1). Higher uptake of soil potassium has also been observed at other sites where amelioration of soil water repellence has been undertaken.

Deep ripping has changed the yield response to surface-applied nutrients. On a compacted grey deep sandy duplex, deep ripping increased the response to nitrogen in the second year after deep ripping. On a compacted deep grey sand with very low soil potassium levels, deep ripping alone did not increase wheat grain yield but deep ripping combined with applied potassium did.

Field trials with deep placement of nutrients have revealed some interesting results. The effect of deep-placed nutrients is linked to subsoil nutrient levels; the largest response (17 per cent) to deep-placed phosphorus was at a site where subsoil Colwell phosphorus levels were less than five milligrams per kilogram below 30-centimetre depth. However, at two sites were there was no significant yield response to deep placement of nutrients, there was an increase in grain protein. These trials are continuing and the ongoing effects will be monitored. □

GRDC Code DAW1801-001

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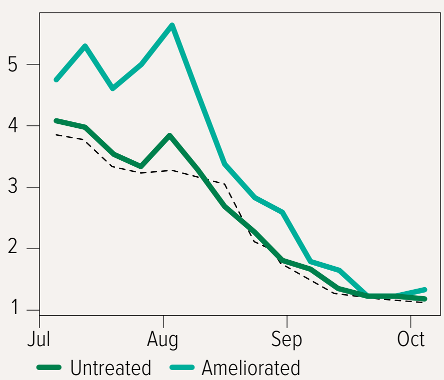
Photo: Evan Collis

Deep rippers are commonly used to ameliorate compacted soils in particular to improve moisture penetration but, as yet, their effect on soil nutrients is not well known.

Figure 1: Shoot potassium concentration in a wheat field trial, Gibson, WA, 2019. Dashed line shows the critical level for the growth stage observed in each measurement.



Source: DPIRD

Overcoming constraints on highly calcareous soils

Highly calcareous soils are very difficult to farm and the keys to improving their productivity are far from clear

By Dr Nigel Wilhelm, Amanda Cook, Dr Therese McBeath, Dr Ehsan Tavakkoli, Dr Gupta Vadakattu and Dr Lukas Van Zwieten

KEY POINTS

- Highly calcareous soils severely restrict crop growth and yield in multiple ways
- New research aims to tackle the complex range of issues, which include low water use efficiency and phosphorus availability

Calcarosols occupy about 60 per cent of the cropping soils in south-eastern Australia, with more than 1.1 million hectares of South Australia's cropping area highly calcareous. Highly calcareous soils limit the effectiveness of improved agronomic practices, with poor early crop vigour and low water use efficiency.

Constraints include low phosphorus status, poor nitrogen cycling, severe fertiliser toxicity during germination, low water-holding capacity, high burden of Rhizoctonia and, at depth, extreme pH, sodicity, bicarbonate toxicity and salinity.

GRDC has commissioned two partner projects, one led by the Cooperative Research Centre for High Performance Soils (the Soil CRC) and the other by CSIRO, to improve the understanding of these soils, with the aim of increasing water use efficiency and farm profitability.

They will bring together a multidisciplinary team from Primary Industries and Regions South Australia, the NSW Department of Primary Industries, CSIRO, Agricultural Innovation & Research Eyre Peninsula and MacKillop Farm Management Group.

TACKLING THE ISSUES

The studies will investigate topsoil issues such as nutrient deficiencies and toxicities, Rhizoctonia and problems with dry seeding, as well as how the common but not well understood subsoil issues of extremely high pH, sodicity, boron toxicity and salinity affect crop production.

Phosphorus nutrition is a particular issue on these soils because the nutrient is rapidly converted to insoluble forms. Fluid phosphorus is more effective than granular fertiliser in these soils but is not commonly used due to price and added logistical issues. Understanding how fertiliser phosphorus supply is influenced by wetting and drying and the presence of multiple constraints in these unique soils will help to identify new management options, including the potential value of novel products and whether granular phosphorus can be used more effectively.

The majority of the field work will be conducted on the Upper Eyre Peninsula with two major field sites on highly calcareous grey sandy soils (typical of these extreme soils) and one on a moderately calcareous soil (more representative of the rest of calcareous soils on the Eyre Peninsula and the SA and Victorian Mallee regions). A satellite site in south-eastern SA will contrast the behaviour of a calcareous soil in a higher-rainfall environment.

A demonstration site to showcase the type of work these projects will undertake was set up in 2020 on the Upper Eyre Peninsula at Poochera.

It showed that deep ripping with inclusion plates improved barley growth substantially, which was a surprise because previous deep ripping attempts have shown little benefit on these soils – albeit without inclusion plates. Extra fertiliser in the seed row caused little damage in the trial despite very low soil moisture at seeding, even though this is often a severe problem under these conditions. Strategies to control Rhizoctonia with a seed dressing and extra fertiliser also had little benefit, although deep ripping itself reduced Rhizoctonia.

This demonstration has highlighted that these highly calcareous soils are very difficult to farm and the keys to improving their productivity are far from clear. ☐

GRDC Codes HPS2006-001O, CSP2009-003

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Photos: David Davenport

A demonstration plot at Poochera on the Upper Eyre Peninsula shows improvements are possible. The plot on the left was managed with inputs typical for the district, while the one on the right was deep-ripped with inclusion plates prior to seeding. Patches in the plot on the left are caused by Rhizoctonia. Photos taken mid-season 2020.

Fertiliser band dynamics affect nutrient recovery

Improving phosphorus uptake from deep bands is not as simple as increasing the rate in the band

By Professor Mike Bell, Associate Professor Peter Kopittke, Dr Gregor Meyer and Dr Chelsea Janke

KEY MESSAGE

Increasing the rate of phosphorus in deep bands can reduce the efficiency of crop nutrient recovery.

Banding fertiliser is not new, especially in no-till cropping where retaining stubble cover is paramount. However, as cropping systems intensify and rates of nutrient removal rise, growers are increasingly reliant on fertiliser nutrients to meet plant demand. This is driving higher nutrient application rates, including higher in-band fertiliser concentrations, which can impact on the crop's ability to access those nutrients.

The most extreme examples of high in-band fertiliser concentrations are in crops such as sorghum, cotton, maize and sugarcane, where high application rates are combined with row and fertiliser-band spacing that can be as wide as 100 to 150 centimetres. Likewise, on clay soils in the northern grains region, bands of less mobile nutrients such as phosphorus and potassium are applied into subsoils at rates high enough to provide four to five years of residual benefit.

While these practices commonly deliver agronomic benefits, they are often characterised by inefficient crop nutrient recovery. Possible reasons vary but may include:

- the small volume of soil treated;
- root systems that are unable to respond to a nutrient-rich soil patch;
- roots that respond too well and rapidly dry out the band environment; and
- chemical changes in the band environment (the 'fertosphere') that slow or prevent root access or reduce the availability of the applied nutrients.

EARLY FINDINGS

Building on data from the More Profit from Crop Nutrition initiative, GRDC invested in a University of Queensland study exploring fertosphere dynamics associated with the application of different forms of granular phosphorus fertiliser – with or without co-applied potassium fertiliser applied as muriate of potash (Figure 1). Preliminary findings still require confirmation, but include some interesting, and unexpected, observations.

The form of phosphorus fertiliser used in the highly concentrated band appears to be important, with DAP seemingly having a higher availability within these bands than MAP or superphosphate across a wide range of soil types.

The pH of the fertosphere is a critical driver of this. Further work is underway to confirm these findings and to determine whether the form of phosphorus fertiliser used will influence the efficiency of plant utilisation in the bands.

Despite concern that the co-application of potassium with phosphorus can cause a decrease in phosphorus availability, findings so far indicate this effect is comparatively modest and relatively less important than the form of phosphorus fertiliser used.

BANDING PHOSPHORUS IN CALCAREOUS SOILS IS LIKELY TO BE PROBLEMATIC, AS IT IS RAPIDLY CONVERTED TO FORMS THAT ARE NOT AVAILABLE TO PLANTS.

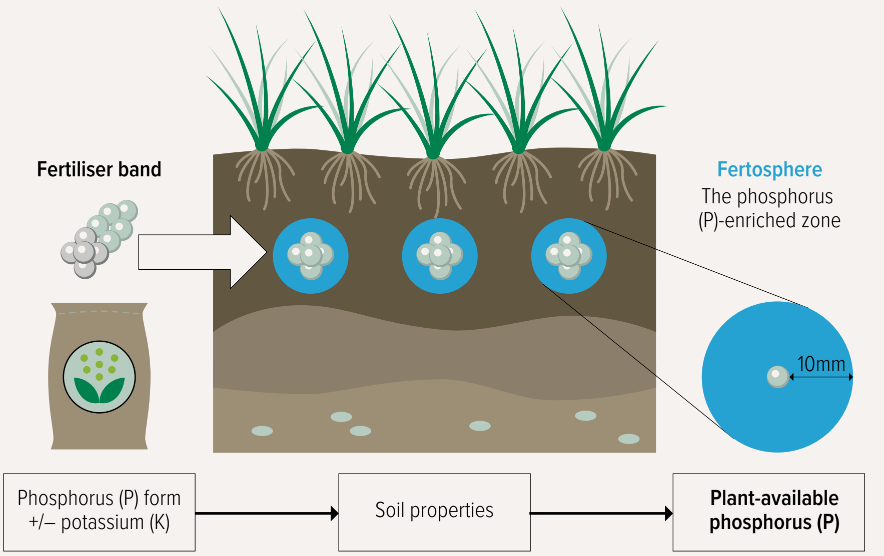
Finally, phosphorus availability within the band is influenced by the interaction of the fertiliser with inherent soil properties. Banding phosphorus in calcareous soils is likely to be problematic, as it is rapidly converted to forms that are not available to plants.

In other soils, availability is highest for soils where the fertosphere pH remains near-neutral and decreases in soils where the fertosphere pH is more acidic.

Soils with a high clay content potentially cause a slight decrease in phosphorus availability within the band, although initial data suggests this decrease is smaller than that caused by low pH in the fertosphere.

Further studies are exploring the short and long-term availability of fertosphere phosphorus reaction products to plant root acquisition. ☐

Figure 1: The fertosphere around bands of phosphorus fertiliser. The properties of the fertilisers themselves, in interaction with the surrounding soil matrix, will influence the availability of the applied nutrients for crop uptake.



Source: Dr Gregor Meyer

GRDC Codes UQ00086, UQ00078, UQ00063

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Deep-banding conundrum for deep-rooting traits

Water or food – an increasingly tough choice for a plant's root system

By Dr Frederik van der Bom, Dr Alwyn Williams and Professor Mike Bell

Productivity of grain systems in the northern region is governed by efficient water use. Breeders have recently started targeting deep-rooting traits (narrow root angles) meant to improve access to deep soil moisture.

However, declining soil fertility is increasingly preventing crops from attaining their water-limited yield potential. This is particularly the case with less mobile nutrients such as phosphorus and potassium, which are increasingly concentrated in surface soil layers due to several factors – extraction from the subsoil, shallow fertiliser applications, residue returns to the soil surface and limited tillage.

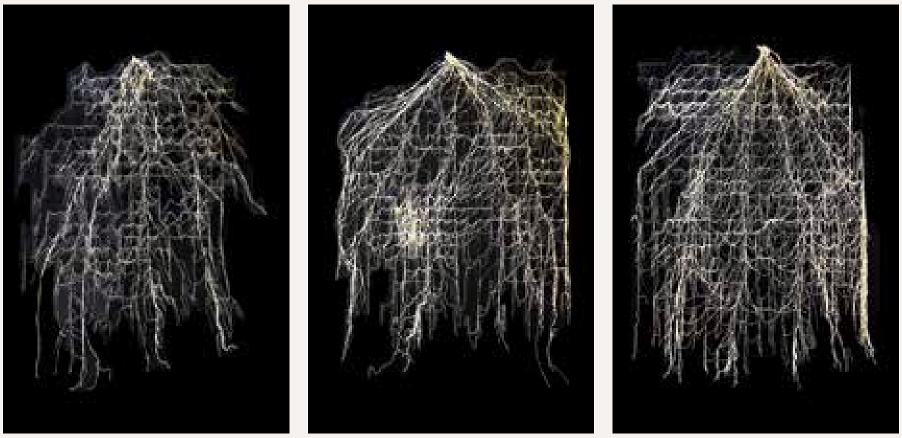
This stratification has caused nutrient and water reserves to become spatially separated. Productivity in any given set of seasonal conditions depends on how crop root systems respond to this.

Growers have responded by deep-banding fertiliser (at a depth of 15 to 25 centimetres) in layers where the soil stays moist longer. But the big question is whether deep-rooting traits may prevent roots from finding or proliferating around these bands or, conversely, the phosphorus band may limit expression of the deep-rooting phenotype.

With GRDC investment, the University of Queensland is exploring the interactions between nutrient placement, root development and water use in wheat and sorghum.

In this article, we compare the ability of durum wheat genotypes with contrasting wide or narrow root angles to utilise phosphorus placed in different parts of the soil profile in an otherwise low-phosphorus vertosol soil (Colwell P less than five milligrams phosphorus per kilogram). Fertiliser phosphorus applications (MAP) simulated (i) a subsoil band at 25cm, (ii) an enriched 10cm topsoil layer, and (iii) homogenous dispersal throughout the soil profile.

Figure 1: Roots that encounter a nutrient-rich zone or patch often respond by proliferating within it. Shown here are root responses of durum wheat with deep-rooting traits (narrow root angle) grown in a low-phosphorus rhizobox system (40 by 60 centimetres) with phosphorus applied in either a subsoil band (25cm) or dispersed through the top 10cm of the soil profile. The control treatment had no phosphorus applied.



Source: Frederik van der Bom

ROOTING PATTERNS

We used rhizoboxes to visualise the short-term responses to phosphorus placement after 38 days and observed clear root proliferation in zones of higher phosphorus availability (see Figure 1).

The genotype with a narrow root angle tended to show a stronger biomass response to banded phosphorus than the wide root angle. The opposite was true when phosphorus was stratified in the topsoil.

Using a lysimeter system with large 30cm-diameter cores, we studied the interaction between placement, moisture and genotype through to flowering. We compared a well-watered treatment with one in which topsoil was allowed to dry out as the season progressed – typical of field conditions.

Again, we found clear responses to phosphorus placement, with increases in shoot biomass particularly for the topsoil and dispersed treatments. There was a smaller response to banded phosphorus, which is consistent with the small volume of soil enriched in a profile that has otherwise low phosphorus availability.

Ultimately, both genotypes took up similar amounts of phosphorus and produced a similar amount of biomass when phosphorus was banded, but the wide-angled genotype showed a slower phenological development than the narrow-angled one, consistent with the observations in the rhizoboxes. This suggests the wide-angled genotype took longer to develop sufficient roots around the band and acquire phosphorus. Further work is underway to confirm these findings and to assess the implications for grain yields.

The drying topsoil reduced biomass and phosphorus uptake compared to the well-watered treatments, with the largest reduction observed where phosphorus was confined to the topsoil layer typical of many northern region cropped fields. Under these conditions, any advantage of wide root-angle genotypes in being able to scavenge the phosphorus-rich topsoil was diminished.

Current research will explore the response to periodical rewetting events, the impact of starter phosphorus fertiliser, and compare wheat and chickpea under field conditions on the Darling Downs. □

GRDC Codes UQ00086, UQ00078, UQ00063, UOQ1805-005

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Boosting deep-phosphorus availability in vertosols

Expanding the volume of soil enriched with phosphorus has the potential to boost nutrient use efficiency

By Dr Nelly Raymond, Dr David Lester and Professor Mike Bell

■ Subsoil banding has emerged from GRDC-invested University of Queensland research as a strategy to improve crop access to phosphorus fertiliser.

It provides plant-available phosphorus in soil layers that are not as susceptible to drying out between intermittent in-crop rainfall events. It is particularly effective on the vertosol soils in north-eastern Australia, where crops rely on stored soil moisture for extended periods.

Despite the consistent crop responses, there are concerns that crops struggle to obtain enough phosphorus from deep bands to meet crop demand and achieve the water-limited yield potential.

FINANCIAL BENEFIT

The rate of phosphorus application is the single most important determinant of the magnitude and longevity of crop responses to deep bands.

Financial returns from a large upfront investment in deep phosphorus application depend on responses in both the year of application and in subsequent years across a crop sequence.

Analyses across sites in Central and Southern Queensland have shown uniformly positive responses in cumulative gross margins of the deep phosphorus treatments across crop sequences of four to six crops, even at higher rates of initial phosphorus application (40 to 60 kilograms of phosphorus per hectare).

However, the amount of extra grain produced is linked to the seasonal conditions and water-limited yield potential.

When available water is limited and crop yields are low, a relatively large crop response (such as a 30 per cent yield increase) might not have a major economic impact.

However, evidence suggests that even though deep banding typically increases phosphorus uptake by 3 to 4kg/ha in a single year over soils with the traditional in-furrow phosphorus application at seeding, crop production is often still limited by phosphorus.

BROADER BANDS

Our theory is that the small soil volumes enriched with phosphorus around bands are rapidly drying in response to root proliferation, and in-crop rainfall events are often not large enough to re-wet the bands during the season.

Phosphorus fertiliser mixed through a larger soil volume may enhance crop phosphorus acquisition, provided there is not a reduction in phosphorus availability due to the greater soil–fertiliser interaction.

This is being tested as part of a GRDC-invested University of Queensland study. A selection of vertosol soils from Queensland and northern NSW experimental sites were incubated at constant temperature and moisture for periods of up to 12 months. Each soil received a simulated fertiliser input of 50 milligrams of phosphorus per kilogram applied as MAP – the normal commercial phosphorus fertiliser in these cropping regions.

The results (Figure 1) show there is substantial variation between vertosols in both the extent to which the applied phosphorus will increase estimated plant-available phosphorus (measured in a Colwell P test) and the residual phosphorus available over time.

Understanding the soil parameters that cause these differences between cropped vertosols will ultimately help to identify the best application method in each soil type.

We are also monitoring growth and phosphorus uptake by wheat and chickpea crops in field trials in Central and Southern Queensland in the 2020 crop season. A mix of banded and dispersed phosphorus treatments applied at different rates in different profile layers will provide an ideal opportunity to benchmark the phosphorus acquisition by responsive crops in vertosol soils. □

GRDC Codes UOQ1905-009, UQ00082, UQ00078, UQ00063

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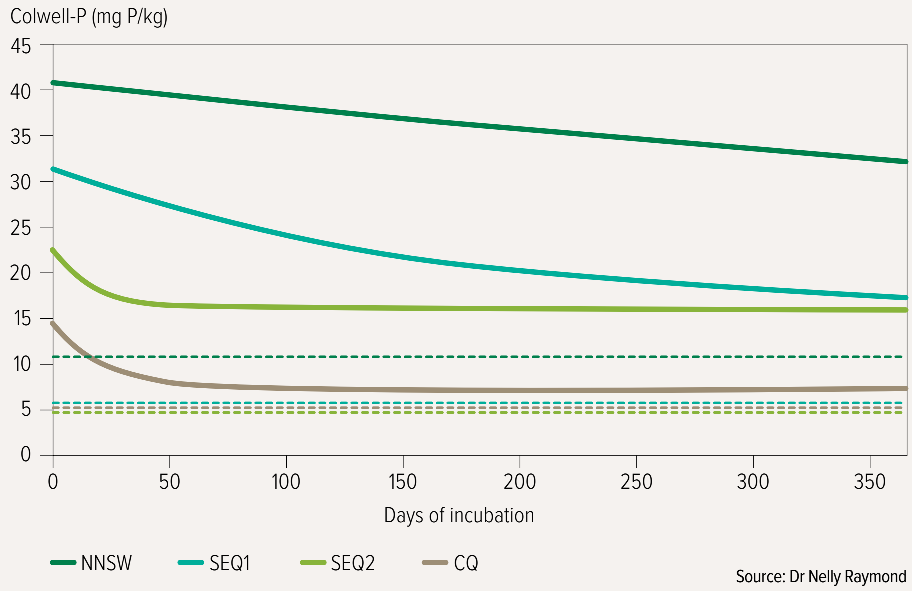
Figure 1: Phosphorus availability (as Colwell P) in response to MAP applied at 50 milligrams of phosphorus per kilogram in selected vertosol soils from the northern region in a laboratory incubation. Soils were incubated at constant temperature and moisture. Dotted line is initial Colwell P, solid line is Colwell P after MAP application.



Source: Dr Nelly Raymond

Biofertiliser potential in native fungus

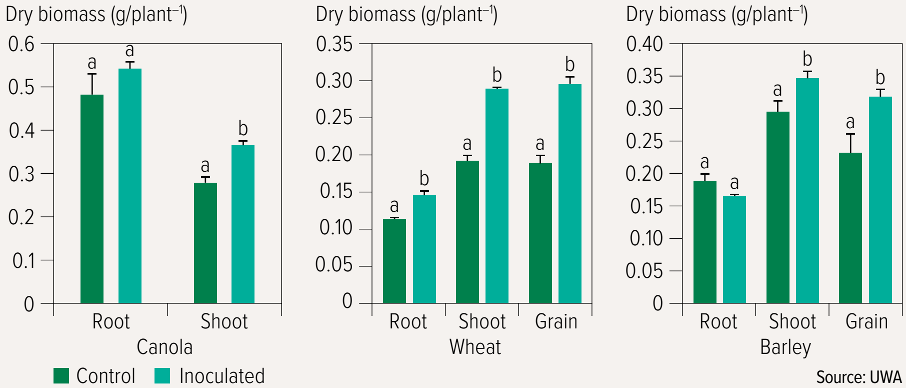
Discovery of a native symbiotic fungus may offer potential as a biofertiliser for grain crops

By Dr Khalil Kariman, Dr Craig Scanlan and Professor Zed Rengel

KEY MESSAGE

The native fungus *Austroboletus occidentalis* may have potential as a biofertiliser, significantly increasing shoot biomass in wheat, barley and canola when soil is inoculated with the fungus

Figure 1: Biomass responses to the novel fungal symbiont (*Austroboletus occidentalis*) in three major grain crops grown in a low-nutrient soil. Bars with different letters are significantly different (p≤0.05). Error bars indicate variability assessed by standard errors (4 replicates).



Source: UWA

■ Fungi play a vital role in soil nutrient cycling, making nutrients such as phosphorus and nitrogen more available for plants. A special group of these fungi, known as mycorrhizal fungi, live in mutually beneficial relationships with plants and present an opportunity to be harnessed as living sources of biofertiliser for grain crops.

With GRDC investment, research at the University of Western Australia is investigating the biofertiliser potential of a native symbiotic fungus (*Austroboletus occidentalis*). This fungus has co-evolved with native plants in Jarrah forests in WA, providing growth and nutritional benefits to host plants by releasing nutrients in the soil and without forming mycorrhizal structures in roots.

Glasshouse experiments have shown the fungus markedly improves plant growth and nutrition and induces tolerance in host plants to environmental stresses such as drought. The challenge is to quantify the beneficial responses in crops and to harness this hidden fungal resource for growers' advantage.

CONTROLLED EXPERIMENTS

Controlled-environment experiments allow the investigation of plant – microorganism interactions in a managed way to provide scientifically valid results. Such experiments undertaken with *A. occidentalis* have demonstrated the growth and nutritional benefits, in particular phosphorus and nitrogen, of this native fungus in wheat, barley and canola grown in a low-nutrient sandy soil (Figure 1).

On completion of the trials, the soil inoculated with the fungus had lower pH compared with the control due to fungal activities (for example, exudation of organic acid anions), leading to greater nutrient availability, especially phosphorus, to crops.

Soil inoculated with this native fungus did not affect root colonisation by indigenous arbuscular mycorrhizal fungi in wheat and barley, indicating a compatibility between the native fungus and arbuscular mycorrhizal fungi. This means mycorrhizal crops can obtain benefits simultaneously from both fungal types.

While canola is non-mycorrhizal – that is, unable to draw benefits from arbuscular mycorrhizal fungi – it can still benefit from the fungus, as indicated by the shoot yield improvement in Figure 1.

Indeed, a previous glasshouse experiment demonstrated the fungus significantly increased canola shoot biomass and grain yield (by 20 per cent) in a field soil containing a high level of phosphorus (46 milligrams of phosphorus per kilogram, Colwell).

In vitro examination of *A. occidentalis* nutrient cycling abilities, using Petri dishes, showed it solubilised three water-insoluble – and therefore plant-unavailable – phosphorus forms. It was able to solubilise calcium phosphate, iron phosphate and aluminium phosphate via exudation of organic acid anions, which is considered a possible mechanism leading to enhanced soil phosphorus availability to crops.

Further controlled-environment trials are underway, characterising the benefits of the fungus to the three major grain crops in two different soil types under different soil phosphorus levels.

FUTURE FIELD TRIALS

Trials planned for 2021 will characterise the extent of the crop benefits of the novel biofertiliser under field conditions. In particular, researchers will focus on its ability to enhance crop nutrition, particularly phosphorus and nitrogen, and stress tolerance, principally drought.

While it is early days yet, this work indicates the potential to effectively harness soil biota to reduce fertiliser inputs in cropping systems. □

GRDC Code UWA1904-005

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GLASSHOUSE EXPERIMENTS HAVE SHOWN THE FUNGUS MARKEDLY IMPROVES PLANT GROWTH AND NUTRITION AND INDUCES TOLERANCE IN HOST PLANTS TO ENVIRONMENTAL STRESSES SUCH AS DROUGHT. THE CHALLENGE IS TO QUANTIFY THE BENEFICIAL RESPONSES IN CROPS AND TO HARNESS THIS HIDDEN FUNGAL RESOURCE FOR GROWERS' ADVANTAGE.

Annual legumes to build soil nitrogen for crops

The national Dryland Legume Pasture Systems project is making progress enhancing nitrogen-fixing legumes in rotations

By Ross Ballard, Dr Ron Yates, Dr Belinda Hackney, Dr Bonnie Flohr and Michael Moodie

KEY POINTS

- **Choosing annual pasture legume species adapted to regional conditions and optimising their establishment can make integrating pasture phases into cropping sequences more economic and effective in low-rainfall environments**
- **Two new pasture legumes adapted to low-rainfall mixed-farming regions are scheduled for release in 2021, with more to follow**

■ Optimising nitrogen-fixing annual legume growth in rotations can reduce the subsequent crops' reliance on synthetic fertilisers and buffer against seasonal conditions and commodity price uncertainties.

With investment from GRDC, the Department of Agriculture and Water Resources, Australian Wool Innovation and Meat & Livestock Australia, the national Dryland Legume Pasture Systems (DLPS) project brings together researchers from the South Australian Research and Development Institute, the research division of the Department of Primary Industries and Regions, CSIRO, Murdoch University, NSW Department of Primary Industries, the Graham Centre for Agricultural Innovation and Frontier Farming Systems. The project's focus is to develop improved pasture legume cultivars and low-cost establishment methods to improve both production and adoption of annual legumes in mixed farms in the low-rainfall regions (less than 450 millimetres per annum) and potentially boost crop production.

PASTURE MANAGEMENT

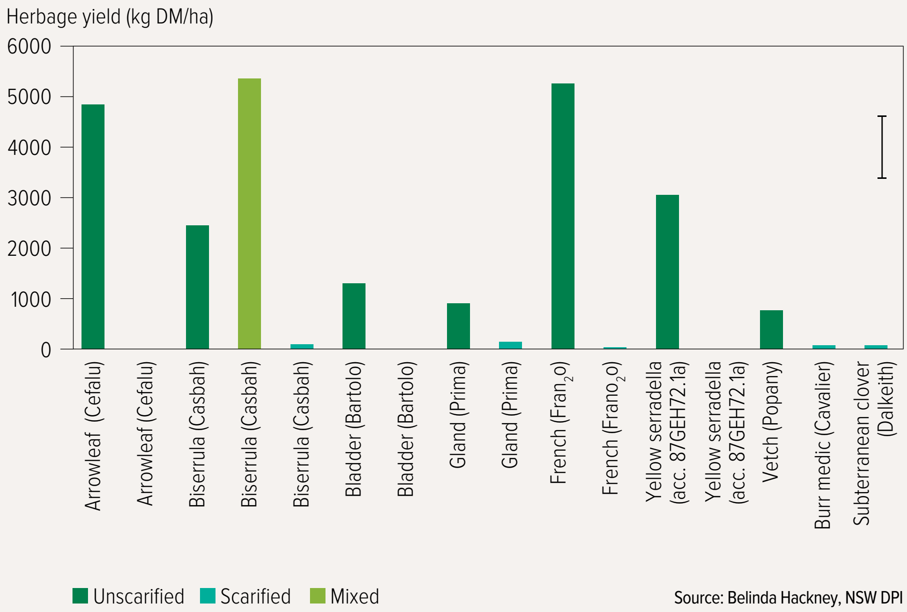
Alternative establishment practices to reduce costs and increase production in the establishment year are under investigation. Where seed of aerial-seeding legume species can be harvested on-farm, a supply of cheap seed can provide flexibility to quickly improve or increase the pasture area in response to market or climatic conditions.

Summer sowing, where unscarified or in-pod seed is sown in February, relies on high summer temperatures aiding hard-seed breakdown. The softened seed is able to germinate and emerge on opening rains and start growing with warmer temperatures.

For effective summer sowing, species and cultivar selection with the right hard-seed breakdown pattern to suit regional conditions is critical. Generally, breakdown is slower in Western Australia and SA, where temperature fluctuation is the main driver of hard-seed breakdown, with hard-seeded French serradella cultivars and bladder clover the most reliable summer-sowing options.

However, in NSW, where summer soil moisture levels are often higher, hard-seed breakdown is more rapid and summer sowing suits a wider range of the species suitable for on-farm harvesting, including biserrula, serradella, gland clover, bladder clover and arrowleaf clover. Summer sowing has resulted in vigorous early growth of these legumes (Figure 1), as they survive an earlier germination due to deep root systems and, for some, improved transpiration regulation.

Figure 1: Herbage yield (kg DM/ha), measured on 31 August 2020, of annual legumes sown either as unscarified or in-pod seed in late February or as scarified seed in late May at Condobolin NSW, 2020. Note an additional treatment (mixed) was included in the summer sowing of biserrula which consisted of 70 per cent unscarified seed and 30 per cent scarified seed.

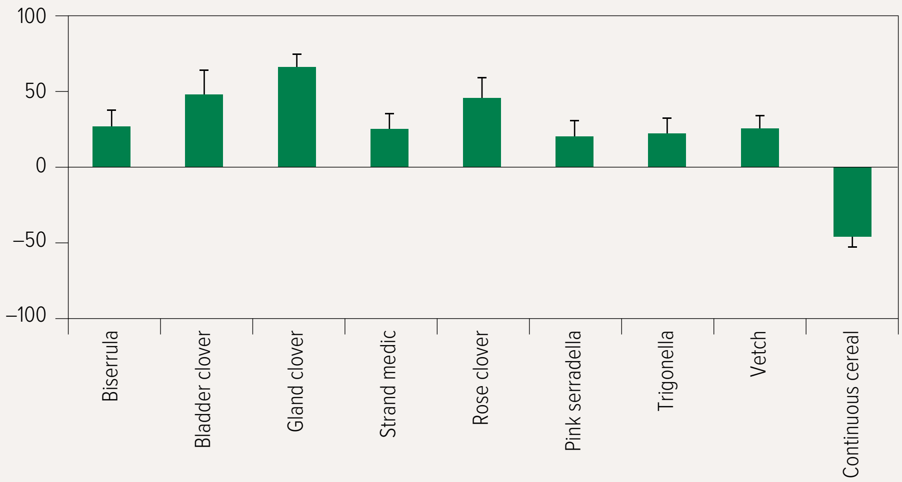


Source: Belinda Hackney, NSW DPI

In SA and Victoria, reasonable establishment has also been achieved by summer sowing medic pods, but overall autumn establishment using scarified seed has been most consistent.

When cropping after legumes, a proportion of the seed produced in previous years will germinate. However, conventional pre-cropping knockdowns will control these early germinations. Competition from the crop generally prevents establishment of any later germinating legumes and the new-generation species such as biserrula, serradella, bladder and gland clover that may establish are readily controlled by a wide range of commonly used in-crop selective broadleaf herbicides.

Figure 2: Change in soil mineral nitrogen between pre-sowing in 2019 and pre-sowing 2020 for autumn seeded legume treatments and continuous cereal.



Source: Michael Moodie, Frontier Farming Systems

FIXED NITROGEN BENEFITS

Assuming 20 kilograms of fixed nitrogen is produced per tonne of shoot dry matter, then a 3t pasture contributes about 60kg per hectare, whereas a 5t pasture contributes 100kg/ha.

Where a range of annual legumes were grown in the Victorian Mallee, mineral nitrogen levels were 70 to 120kg/ha greater than after cereals, with the highest levels measured after the clovers (Figure 2).

Cereal yields are being determined, but modelling undertaken by CSIRO has estimated that an extra 35kg of soil mineral nitrogen at the start of the season could result in 180kg/ha extra wheat yield.

Photos: Ross Ballard, SARDI

On suitable soil types, well-nodulated pink serradella can provide abundant nitrogen to subsequent grain crops. This one was established under the previous cereal crop at Lameroo in South Australia.

NEW LEGUMES

Different pasture legumes prefer specific soils, so the regional performance of existing and new pasture legumes has been a focus. Medics continue to be the best option for neutral/alkaline sandy soils in the SA/Victorian Mallee, but are outperformed by new-generation legumes in WA and NSW. Serradella has been the stand-out on the deep sands in WA, while bladder clover and *Trigonella balansae* perform well on more loamy soils. In NSW, biserrula, arrowleaf clover, bladder clover, gland clovers and serradella all performed well on acidic loams under the 2018-19 extreme drought.

Two new cultivars with improved low-rainfall adaptation are setting the standard to beat for future releases and will be available in 2021.

Seraph – formerly PM-250 – is the first strand medic with resistance to the foliar fungal pathogen Powdery mildew (*Erysiphe trifolii*). It also has tolerance to particular herbicide residues (sulfonylurea, imazamox and imazapyr) and is a prolific seed producer, although not readily header harvestable. It is suited to neutral and alkaline sandy loams receiving 275 to 400mm rainfall, where it has been 16 per cent more productive than Angel medic, which it will replace.

Fran$_2$o, an earlier-season (90 days to flowering), hard-seeded French serradella developed by Dr Brad Nutt at Murdoch University, was released in 2020. Developed for summer sowing, the seed can be harvested on-farm by a cereal harvester. Fran$_2$o is suited to areas with low-to-medium rainfall (250 to 350mm) and is well-adapted to free-draining acidic soils, but can also grow well on neutral loams. The plant is tolerant to Group B herbicides that include imazamox, imazapyr and flumetsulam.

Also under evaluation and showing promise are helmet clover (*Trifolium clypeatum*), earlier-maturing bladder clover, trigonella (*Trigonella balansae*), disc medic and other legume accessions including astragalus (*Astragalus hamosus*), arrowleaf clover, rose clover and yellow serradella. □

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Pulse nitrogen boost for acid soils

Elite rhizobia are screened by the Nitrogen Fixation Program using hydroponics, before intensive evaluation in trials to determine the best performers for regionally differing acidic soil types. Photo: Ross Ballard, SARDI

By Ross Ballard, Dr Belinda Hackney, Dr Ron Yates, Chris Poole, Dr Elizabeth Farquharson, Dr Matthew Denton, Dr Judith Rathjen and Dr Maarten Ryder

KEY POINTS

- A suite of improved rhizobia strains that is better adapted to acidic soils is being evaluated for release
- Performance of new rhizobia strains is regionally specific
- Awareness is increasing of the effect of management practices such as fungicide and herbicide use on rhizobia activity and nodulation

■ Increasing pulse crops' nitrogen fixation efficacy is one way to reduce nitrogen fertiliser input costs for following crops, but regional specificity and inoculation and crop management practices need to be addressed for maximum effect.

With GRDC investment, three regional Nitrogen Fixation Program (NFP) projects are focusing on extending the adaptation and reliability of pulse crops through releasing more robust inoculant strains and improving inoculation practices.

The NFP brings together a research team from the South Australian Research and Development Institute (SARDI), Murdoch University and the New South Wales Department of Primary Industries, in collaboration with the University of Adelaide and the Western Australian Department of Primary Industries and Regional Development.

HARNESSING NITROGEN FIXATION

Where nitrogen fixation is working well, the rule of thumb is that pulse crops should contribute about 20 kilograms of fixed nitrogen per tonne of shoot dry matter, although this can vary from nil to 30kg N/t shoot DM.

Regional soil characteristics, in particular acidity, can affect nodulation and nitrogen fixation. Additionally, soil moisture at sowing, inoculation practices, the use of pesticides and trace element fertilisers, particularly seed dressings, can also affect nodulation and nitrogen fixation.

Traditionally, a single rhizobia strain was selected and produced for each crop or pasture legume, which was broadly adapted across the country. However, current results indicate a more sophisticated approach may be needed, with elite strains identified for use in specific regions or states.

HUNT FOR ELITE RHIZOBIA

Group E/F inoculants used for field peas, faba beans, lentils and vetch were initially isolated from soils with pH_{Ca} more than 7.0. So it was not surprising they struggled to perform in soils with pH_{Ca} less than 5.5, where legumes are now being increasingly grown. Elite strains of rhizobia with better acidity tolerance were isolated from Australian soils by SARDI and from Sardinia by Murdoch University. Four elite strains have now been evaluated in field trials across SA, WA and NSW.

In 13 field trials in SA and Victoria (2016–18), where the average soil pH_{Ca} was 4.7, an acid-tolerant strain isolated in SA increased average nodulation by 57 per cent, nitrogen fixation by 24 per cent and grain yield by 14 per cent. In four sites and nine trials in NSW, where soil pH_{Ca} ranged from 4.5 to 5.2 across sites, an acid-tolerant strain isolated in Sardinia increased nodulation by more than 30 per cent in field peas and vetch, and doubled nodulation in lentils.

In WA, recent field trials are revealing similar increased production from the inoculation of new strains in comparison to the commercial strains in acid soils. Additionally, experiments have identified a strain with higher desiccation tolerance and outstanding survival once inoculated on seed, increasing its ability to persist in soil. This makes it a good candidate for dry sowing.

Chickpea nitrogen fixation efficiency is reported to be lower than other legumes, and nodulation measured in research trials is commonly low. This is not surprising, as the Australian inoculant strain has remained unchanged for 40 years, so there are good prospects for improvement. A cohort of promising rhizobia strains for chickpeas has recently been identified and is undergoing evaluation.

MANAGEMENT EFFECTS

Even with elite rhizobial strains, management decisions can significantly reduce pulse crops' nodulation and nitrogen fixation. For example, fungicides are commonly used on seed prior to sowing and can adversely affect rhizobia survival, resulting in poor nodulation and reduced nitrogen fixation. Similarly, trace element seed dressings can also be highly toxic to rhizobial inoculants.

The team has identified rhizobia strains differing in tolerance to common seed dressing fungicides and subsequent field nodulation. Minimising time of rhizobia exposure to treated seed is essential to achieving effective nodulation and, where possible, separation of inoculants from seed-applied fungicides or trace elements should be considered.

Preliminary work has shown effects of both applied herbicides and herbicide residues on pulse nodulation, nitrogen fixation and yield. The team has found herbicides belonging to groups B and I have detrimental effects on legume nodulation and decreased nodulation was also measured when applying Group C herbicides in WA. In NSW, nodulation penalties from previous-season Group B or I usage may have been more pronounced on a clay soil with pH_{Ca} 5.5 than a sandy site with pH_{Ca} 4.6. ☐

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CHICKPEA NITROGEN FIXATION EFFICIENCY IS REPORTED TO BE LOWER THAN OTHER LEGUMES, AND NODULATION MEASURED IN RESEARCH TRIALS IS COMMONLY LOW. THIS IS NOT SURPRISING, AS THE AUSTRALIAN INOCULANT STRAIN HAS REMAINED UNCHANGED FOR 40 YEARS, SO THERE ARE GOOD PROSPECTS FOR IMPROVEMENT.

Figure 1: New acid-tolerant rhizobia strains (left) increased the early growth of faba bean, compared with the commercial inoculant strain (right) on acidic soils pH_{Ca} 4.4. Wanilla SA, 2017.

Source: Elizabeth Farquharson, SARDI

DO I NEED TO INOCULATE?

Apart from the cost, inoculation is often a messy and time-consuming practice during the busy seeding period, so growers only want to inoculate where they are confident of getting a response. DNA soil tests developed by SARDI to quantify rhizobia numbers are ongoing but will soon help remove uncertainty around inoculation decisions, potentially saving significant time and money. GRDC has invested in further developing these tests as part of the southern Nitrogen Fixation Program at SARDI.

Using these DNA tests from soil samples, it will be possible to determine the likelihood of inoculation response in paddocks, allowing for the more strategic application of inoculants. The first test measures the number of rhizobia in soil that nodulate E/F legumes (field peas, faba beans, lentils and vetch) and will first be available in SA and Victoria in 2021.

NUTRIENT PERFORMANCE INDICATORS

HOW EFFECTIVE IS YOUR FERTILISER PROGRAM

Nutrient Performance Indicators (NPIs) assess how effective and efficient nutrient applications were.

ARE YOU PLAYING THE LONG GAME?

NPIs build confidence your crop nutrition strategy meets long-term fertility goals and the current season.

PARTIAL FACTOR PRODUCTIVITY (PFP)

Did the crop respond to the nutrient input?

$$PFP = \frac{\text{grain yield (kg)}}{\text{nutrient applied (kg)}}$$

Typical ranges:
PFP-Nitrogen 40-80
PFP-Phosphorus 100-250
PFP-Potassium 75-200

PFP below typical ranges indicates low response, or too much nutrient applied.

PARTIAL NUTRIENT BALANCE (PNB)

Was more nutrient added or removed from the paddock?

$$PNB = \frac{\text{nutrient removed (kg)}}{\text{nutrient applied (kg)}}$$

PNB >1.0 indicates nutrient depletion from the soil.

USE PFP AND PNB TOGETHER

HIGH PFP + HIGH PNB

High productivity at the cost of soil reserves.

LOW PFP + LOW PNB

Nutrient losses to the environment. Something other than nutrients limiting.

AND RELATE TO SOIL TESTS

GRDC