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GRDC

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OPTIMISING NITROGEN CRITICAL FOR SUCCESS

Profitable and sustainable nitrogen strategies are vital to ensure the future of grain production in Australia

By Dr Cristina Martinez, Dr Stephen Loss

The burden of choice can rest heavily when making nitrogen fertiliser decisions. How much to apply and when, will it rain, what if it does not and – most importantly – what is the optimal economic rate?

Nitrogen is the single-biggest variable cost and is often the biggest driver of the water-limited yield gap in cereals, especially in favourable seasons. Increasingly, the environmental impact of nitrogen losses is under scrutiny around the world.

In recent decades, many intensive grain production systems have mined soil organic matter, reducing the soil's ability to supply nitrogen and compromising soil fertility.

INCREASING IMPORTANCE

Over the past 30 years, demand for nitrogen fertiliser has increased fourfold. Fertiliser purchases are typically about 20 to 25 per cent of the variable costs for Australian grain growers. Even before the recent price spikes, grain growers spent about $1.1 billion on nitrogen fertiliser each year. Yet the yield potential of many cereal and canola crops remains limited by nitrogen. It is estimated that alleviating this deficiency could increase national wheat yields by 40 per cent and substantially improve farm profit.

Nitrogen deficiency also results in low grain protein content, reducing the value and marketability of grain.

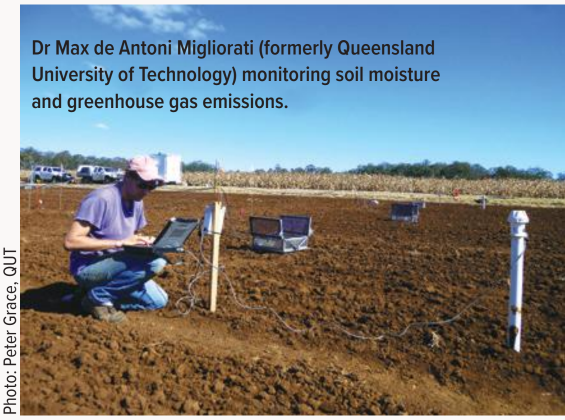
Nitrogen losses – through denitrification, volatilisation and leaching – are more than just a direct cost to growers. Losses can damage waterways and their contribution to greenhouse gas production is a significant cost to the grains industry and the wider community. The need to include emissions generated during the manufacture and distribution of fertiliser in the farm's footprint makes it even more important to limit these losses.

PRIORITIES

GRDC is committed to improving nitrogen use efficiency to help growers increase production and profitability and reduce greenhouse emission intensity. One of the biggest challenges faced by the industry is that much of the understanding of soil nitrogen dynamics was developed prior to the shift to continuous cropping and reduced tillage.

In the past, many growers relied on an extended legume pasture phase to restore soil nitrogen supplies and organic carbon. Today, legume crops play a role in boosting nitrogen supplies, but they are by no means ubiquitous in cropping systems around the country and the amounts of nitrogen they add to the system can be variable.

Several GRDC investments aim to update our knowledge of the factors that influence the cycling and availability of both soil and fertiliser nitrogen. Last year, GRDC made a substantial investment in nationally coordinated research to better understand nitrogen losses as a crucial first step to reducing these losses and limiting their impact on the environment.



Dr Max de Antoni Migliorati (formerly Queensland University of Technology) monitoring soil moisture and greenhouse gas emissions.

Photo: Peter Grace, QUT

The knowledge gained through GRDC research is used to update the modelling that underpins nitrogen decision support tools and to better inform efficient use of nitrogen fertilisers. Crop simulation models and their nitrogen cycling routines are also used to estimate greenhouse gas emissions for the grains industry. These are critical in demonstrating the grains industry's sustainability credentials to Australian and international communities. Evolving grain production systems mean that ongoing research is vital to secure the future of our industry. □

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GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

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COVER IMAGE: Crops that follow legume crops benefit from an average of at least 50 kilograms of additional mineral nitrogen compared with those following cereal crops.

PHOTO: Mathew Dunn, NSW DPI

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Calculating the nitrogen benefit from legume crops

Maximising the nitrogen legacy from legume crops depends on maximising biomass and ensuring high nitrogen fixation rates

By Tony Swan, Mathew Dunn

KEY POINTS

- **The value of legume nitrogen benefits can be significant at more than $200 per hectare when urea prices are $1200 per tonne**
- **To maximise the nitrogen legacy, maximise crop biomass and nitrogen fixation by selecting the best legume crop, variety and sowing time for your soil and getting the agronomy right**

Declining pre-sowing soil mineral nitrogen and grain protein levels, together with recent increases in nitrogen fertiliser prices, have refocused attention on the value of legume crops as a nitrogen source.

Soil organic nitrogen mineralises by an average of 2.5 per cent per year in continuous cropping systems. Failure to restore it with pasture phases or grain legumes means that the relative spend on nitrogen fertiliser could double from nine to 10 per cent of gross margins in 2017 to 18 per cent in 2067.

To maintain crop yields, growers either need to increase the rate of nitrogen fertiliser or incorporate more legume crops and pastures into the system.

LEGUME LEGACY

To evaluate the benefit of legumes, CSIRO Agriculture and Food and the NSW Department of Primary Industries established field experiments at Wagga Wagga, Condobolin, Urana and Greenethorpe in NSW with GRDC support.

The aim was to measure the impact of legumes on soil mineral nitrogen available to subsequent crops and the yield and dollar value of this benefit to the system.

All sites were sown to wheat in 2017 before commencing three-year phased rotations of barley/canola/wheat or legume/canola/wheat in 2018, 2019 or 2020 under a range of nitrogen fertiliser strategies. The legume crops included lentils, chickpeas, lupins, faba beans and vetch hay.

Soil nitrogen testing, undertaken when sowing canola in the subsequent season, showed that legume crops provided an average increase of at least 50 kilograms per hectare of additional mineral nitrogen compared with those following cereal crops across all legume crop types, seasons and sites.

Much of this nitrogen was not available directly after the legume harvest but became available over the summer fallow period and as the nitrogen mineralised throughout the season.

At the relatively high urea prices of $1200 per tonne in early 2022, the value of legume nitrogen benefits can be significant at more than $200/ha.

These figures do not include the potential value of further in-crop mineralisation during the following growing season or beyond, even when the loss of nitrogen from the various end-uses, such as grain or hay removal, are accounted for.

MAXIMISING THE BENEFITS

The choice of legume crop was less important than ensuring that the best legume species and variety was selected to suit local soil and climatic conditions. Getting the agronomy right to ensure effective nodulation and high biomass is key.

While there was a significant amount of variability in the extra soil mineral nitrogen available to subsequent crops, this was related to the site, season, choice of crop and end-use option.

Maximising biomass production maximises the potential to fix nitrogen. A legume that is well-suited to its environment will likely derive more than half of its nitrogen requirements for growth from atmospheric nitrogen via fixation, provided there are no constraints to nitrogen fixation.

Poor nodulation can result from low rhizobia numbers, poor inoculation procedures, residual herbicides and subsoil constraints such as acid subsoils, but these can all be overcome with good management.

Legume crops with a high grain yield or those cut for hay production do not always provide a net input of mineral nitrogen; however, there are other benefits to a double break. These include weed and disease benefits as well as assisting in the breakdown of cereal stubble. □

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Table 1: The additional soil mineral nitrogen available at sowing following each legume crop at four field sites (averaged across 2019, 2020 and 2021 sowing dates) and final average of 50kg of nitrogen/ha across all sites x crops x years. The resulting urea saving (kg/ha) and additional canola yield (kg/ha) as an average for all legumes (crops x years) and an overall average (sites x crops x years).

		Wagga Wagga	Greenethorpe	Urana	Condobolin	Average
Extra mineral nitrogen (kg N/ha)	following lentil	34	–	70	42	
	following lupin	15	–	–	60	
	following faba bean	–	67	50	–	
	following vetch hay	37	63	77	37	
	average across all crops					50
Average urea saving (kg/ha)		29	120	69	94	78
Average extra canola yield (kg/ha)		210	180	380	110	220

Source: CSIRO

Nitrogen banking: a long-term approach to risk

Nitrogen banking could hold the key to long-term profitability

By Professor James Hunt, James Murray, Hayden Thompson

KEY POINTS

- Current seasonal risk approaches to nitrogen fertiliser are often based on the assumption that nitrogen fertiliser is a lost cost if it is not used in the year of application
- One Victorian trial has shown a simpler approach based on nitrogen banking that can improve soil fertility, long-term yield and gross margins

Photo: James Hunt, University of Melbourne

The University of Melbourne's Dr Arjun Pandey compares treatments at the GRDC nitrogen management trial at Dookie in north-eastern Victoria.

Nitrogen fertiliser is a costly input and its use increases the cost of production and Value at Risk (VaR) for growers. The idea of applying sufficient nitrogen to maximise yields regardless of the season is a source of trepidation for many growers and advisers.

Instead, many try to match nitrogen fertiliser to seasonal yield potential – but Australia's highly variable seasonal rainfall and the limited predictability of seasonal forecasts make this difficult.

The cost of nitrogen fertiliser is a factor in these decisions, but concerns about the potential for crops to hay-off under high nitrogen and terminal drought stress, and environmental losses of nitrogen through volatilisation, denitrification and leaching, also play a role.

It is often assumed that if nitrogen from fertiliser is not taken up by the crop in the year of application, it is a lost cost. However, unused fertiliser plays a vital role in maintaining the fertility of continuous cropping systems and is taken up by crops at least two years after the initial application.

Wheat crops typically only extract about 30 to 40 per cent of their nitrogen requirement from fertiliser. The most important source of nitrogen for crops – about 60 to 70 per cent – is the 'bank' of mineral nitrogen that is already in the soil, or which mineralises from organic nitrogen during crop growth.

On average, less than half of nitrogen fertiliser is taken up by crops in the year of application, making unused fertiliser the biggest source of 'deposits' into the nitrogen bank in continuous cropping systems.

In medium and low-rainfall regions with heavy textured soils, the majority of applied nitrogen that is not used in year of application will remain in the soil for use in subsequent seasons and is not a lost cost. This means there is little downside risk to occasional over-application of nitrogen, provided cashflow can be managed.

While it might seem pragmatic to reduce risk by lowering nitrogen applications, the result is a chronic long-term decline in soil organic nitrogen and a corresponding reduction in soil organic matter. A whole-of-system approach is needed to rebuild crop potential.

Nitrogen management systems such as Yield Prophet® and nitrogen banking, which use a soil test for mineral nitrogen, have been shown to increase both profitability and sustainability of cropping systems.

MEASURING PROFITABILITY

In 2018, the Birchip Cropping Group established a field trial to evaluate strategies for top-dressed nitrogen at Curyo with pilot funding from La Trobe University. The site was supported by the Mallee Catchment Management Authority through Landcare funding from 2019 to 2021.

The strategies were:

- replacement – replacing the nitrogen removed in grain;

- national average – 45 kilograms nitrogen per hectare;
- nitrogen banks – soil mineral nitrogen plus fertiliser total of 100, 125 or 150kg of nitrogen/ha (NB100, NB125 and NB150);
- Yield Prophet® probabilities – YP100 (100 per cent chance of achieving target yield, decile 1 rainfall required), YP75 (75 per cent, decile 2 to 3), YP50 (50 per cent, decile 4 to 7) and YP25 (25 per cent, decile 8 to 9); and
- nil – only starter nitrogen was applied.

The first year (2018) was dry with little rainfall after the nitrogen was top-dressed, yet soil testing at the start of 2019 found 58 per cent of applied fertiliser nitrogen remained as mineral nitrogen and had moved into the soil profile. It is unknown how much of the remainder had been immobilised into organic nitrogen and how much was lost from the system.

Both the nitrogen banking and Yield Prophet® strategies were able to close the yield gap and improve gross margins (Figure 1) by profitably alleviating nitrogen deficiency. But the banking approach is simpler and less time-consuming than the seasonal risk-based approach as it does not rely on calculations of seasonal yield potential.

These strategies remained profitable even when the fertiliser price increases observed in 2022 were used to calculate gross margins. These profits held, regardless of whether the grain prices were based on the five-year average or the higher 2022 prices (Figure 2). Using a urea price of $1400 per tonne and 2022 grain prices, the most profitable strategies were YP50 and NB125.

POSITIVE N BALANCES

The most-profitable strategies had a small positive nitrogen balance (Figure 3), whereas the district average mined an average of 50kg of nitrogen/ha in soil organic nitrogen and, in theory, about 600kg/ha of soil carbon.

Legumes and organic wastes could provide effective alternatives to nitrogen fertilisers while prices are high but, regardless of the source, high grain prices mean investment in nitrogen is well worth the expense.

While the field research has only been conducted at a single location over a limited number of years, crop simulation modelling suggests the findings are applicable across a wide range of rainfalls and soil types. The most-profitable nitrogen bank target depends on environmental yield potential and ranges from 80kg of nitrogen/ha in low-rainfall environments to 275kg/ha in high-rainfall environments.

More work is needed to confirm the value of nitrogen banking in multiple environments, including quantifying the potential for losses in different soil types and rainfall zones.

To achieve this aim, GRDC invested in the Curyo trial in 2022 and added 11 new field sites in Victoria and South Australia, and four in southern New South Wales. These were managed by Birchip Cropping Group and FarmLink and preliminary results are expected to be delivered in March 2023. ☐

GRDC Codes BWD2204-003RTX, BWD2204-002RTX, FLR2206-001RTX

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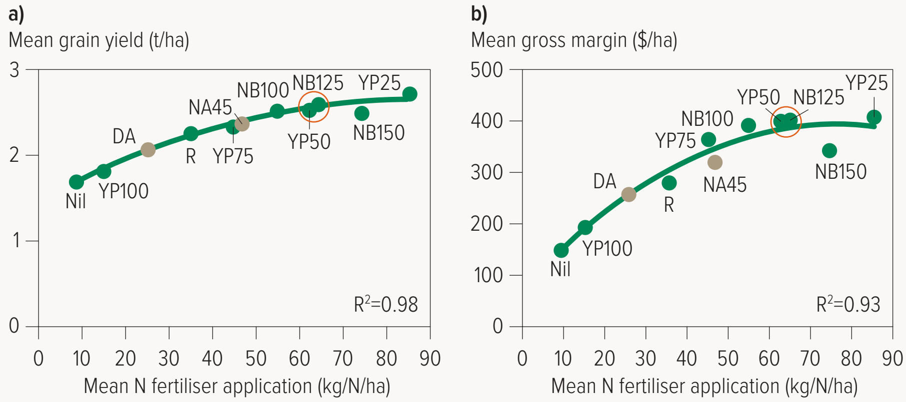
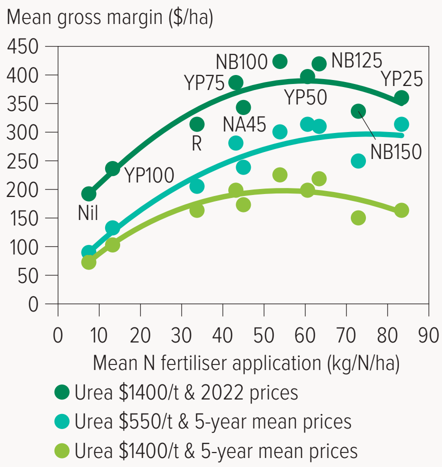
Figure 1: Both nitrogen banking (NB) and the Yield Prophet® (YP) strategies closed the yield gap (a) and improved gross margins (b) at Curyo, Victoria. Sum of results for 2018 to 2021 with five-year average costs and prices. NA = national average, DA = district average, R = replacement.



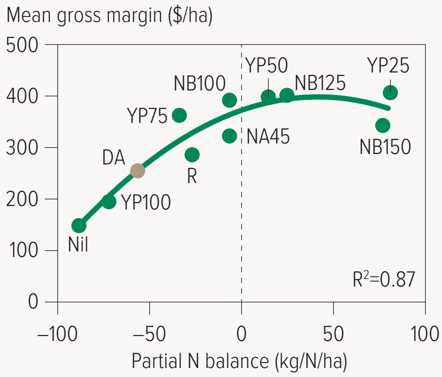
Source: James Hunt, University of Melbourne

Figure 2: The nitrogen banking (NB) and the Yield Prophet® (YP) strategies remained profitable even with the higher fertiliser prices observed in 2022, regardless of whether the grain prices were based on the five-year average or the higher 2022 prices. NA = national average, R = replacement.



Source: James Hunt, University of Melbourne

Figure 3: The most profitable systems (total for the four years 2018 to 2021) had a small positive nitrogen balance. NB = nitrogen banking, YP = Yield Prophet®, NA = national average, DA = district average, R = replacement.



Source: James Hunt, University of Melbourne

Nitrogen's value extends beyond yield

Photo: Dr Mark Farrell, CSIRO

Growers can potentially improve soil organic matter and fertility by planting cover crops, which provide a slow release of carbon and nitrogen as they break down, boosting microbial populations.

The soil nitrogen supply often provides the bulk of a plant's needs, but the supply needs to be replenished regularly to maintain healthy soils

By Dr Mark Farrell, Dr Gupta Vadakattu, Dr Lynne Macdonald

KEY POINTS

- Nitrogen is being gradually mined from Australian soils by conservative application of nitrogen fertiliser
- Supporting the soil microbial community with a balance of carbon and nitrogen is essential for nutrient cycling, and promoting water infiltration and retention
- Soil stocks of nitrogen need to be nurtured and replenished on an ongoing basis

To maximise profit, nitrogen fertiliser is typically applied at rates that are lower than those required to maximise yield. This sufficiency approach means that nitrogen mined from soil organic matter is not replenished, causing a long-term decline in the soil nitrogen bank.

A critical component of soil health, soil organic matter contains an intrinsically balanced ratio of carbon and nitrogen. It supports the soil microbial community, which is essential for nutrient cycling – particularly nitrogen – and promotes water infiltration and retention.

Once soil organic matter is lost, it takes a long time to rebuild. To use a financial analogy – it is easy to run up a lot of debt, but trying to reverse that situation is a very difficult task.

A more-sustainable approach is to maintain and nurture soil organic matter levels. To achieve that, inputs must exceed exports and losses.

Building soil organic matter has the added benefit of ensuring that sufficient credit is available to meet a sudden need – such as the high nitrogen requirements of a bumper canola crop.

Conversely, if the system has been run down, a lack of soil organic matter makes it more prone to nitrogen losses.

Conservation farming and stubble retention are gradually rebuilding organic matter in Australian soils, but this requires a supply of both carbon and nitrogen. Growing productive crops generates biomass to return carbon to the soil as it decomposes, provided there is also sufficient nitrogen and a healthy microbial population.

REBUILDING SOIL NITROGEN

There are three ways that growers can potentially improve soil organic matter and fertility:

- nitrogen banking;
- legume crops and pastures; and
- cover or break crops.

Nitrogen banking is achieved by increasing fertiliser rates to ensure nitrogen is not limiting. The strategy has already proven successful in the Victorian Mallee, where losses are minimal and any fertiliser not utilised by the crop in the year of application is mostly carried over to the following season.

Losses are generally low in most dryland environments, but the approach will need to be tested in wetter environments where losses are more likely.

While legume crops export the bulk of fixed nitrogen as grain, crop residues that remain have a much-higher proportion of nitrogen than cereal residues. Nitrogen fixation by pastures is another source of soil nitrogen, but research suggests that more could be done to optimise nitrogen fixation by pasture rhizobium.

It is important to remember that rhizobia are at their most efficient when soil supplies of nitrogen are deficient. Increasing the soil nitrogen supply has the potential to reduce the value of nitrogen fixation by legumes.

Unlike harvested crops, break crops or cover crops are returned to the soil and provide a slow release of carbon and nitrogen as they break down, boosting microbial populations.

Recent Landcare and GRDC-supported research has shown that cover crops reduce 'lossy' nitrate concentrations, which might reduce the risk of greenhouse gas emissions and leaching, while soil organic nitrogen and microbial nitrogen pools increased. In turn, these pools then become plant-available during the subsequent growing season.

Substantial research into microbial nitrogen processes is being undertaken by CSIRO Agriculture and Food as part of the national GRDC investment led by the University of Queensland. This work seeks to greatly improve our ability to predict nitrogen availability and vulnerability to loss, and thus improve fertiliser management decisions and increase profitability while limiting environmental impacts. □

GRDC Code UOQ2204-010RTX

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grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/02/addressing-the-rundown-of-nitrogen-and-soil-organic-carbon

Protecting soil fertility is paramount for continuous cropping

The best practices for productivity and profitability are essential to protect and rebuild soil organic matter, including organic carbon and nitrogen supplies

By David Lawrence, Jayne Gentry

KEY POINTS

- Land clearing leads to sharp declines in soil organic matter and organic carbon
- Fallowing is the biggest cause of organic matter declines in cropping soils
- Growing highly productive crops and pastures is essential in arresting the decline

Photo: Jayne Gentry, Queensland Department of Agriculture & Fisheries

Queensland Department of Agriculture and Fisheries staff Rod O'Connor and Patricia Balzer sample soil in remnant vegetation at Brigalow in Queensland to evaluate the impact of land-use and farming practices on soil organic carbon levels.

■ Soil organic matter is critical for healthy soils and sustainable agricultural production. It provides food for microbes and the microbial activity that supplies nutrients to crops, maintains soil structure and water infiltration and helps keeps pathogen populations in check. However, soil organic matter levels are declining under continuous cropping.

On well-structured soil, the biggest impact of this decline is the loss of soil nutrients, especially nitrogen. For example, annual mineralisation of nitrogen from organic matter on recently cleared brigalow soils in Queensland can be as high as 300 kilograms of nitrogen per hectare, but this could decline to about 50kg/ha after 30 years of cropping.

This drop in fertility can be managed by increased rates of fertiliser. However, management must be spot-on to match nitrogen rates to crop needs, as lower organic matter levels mean the soil is less resilient and less able to respond to seasonal changes.

CARBON DECLINE

Soil organic matter is approximately 60 per cent organic carbon, which is an easily measured indicator of organic matter, soil health and the sustainability of long-term crop production.

GRDC investment from 2008–17 enabled the Queensland Department of Agriculture and Fisheries to work with growers to identify the effects of land-use and farming practices on soil organic carbon levels across the northern grain region.

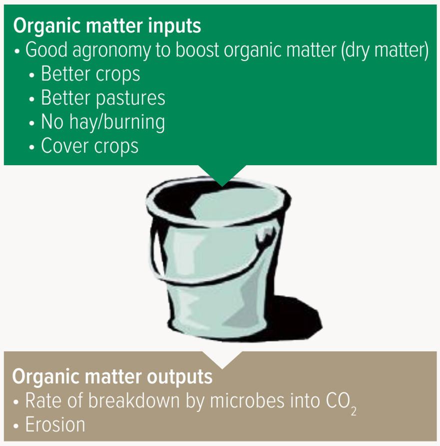
Paired-site comparisons on 500 paddocks showed that clearing land for cultivation for 20 or more years led to a consistent decline in soil organic carbon. The main cause of this decline in cropping systems was fallowing to store moisture.

Fallow efficiencies of between 20 to 30 per cent mean that 70 to 80 per cent of fallow rainfall is lost to evaporation. It is not used by plants to produce dry matter and replenish the organic matter that continues to be decomposed by microbes in the moist soil.

Mixed farmers who grow prolonged pasture phases have much-greater potential to rebuild and manage their soil organic matter and carbon levels than grain-only farmers. However, these pasture phases must produce high levels of dry matter based on a good supply of nitrogen from fertiliser or legumes. There was little improvement in organic carbon from poor pastures that were deficient in phosphorus and lacked strong legume medic growth.

Pastures phases of at least five years were needed to generate a significant increase in organic carbon levels. Well-grown pastures could generate

Figure 1: Soil organic carbon levels are a balance between organic dry matter inputs, losses and decomposition.



Source: David Lawrence, QDAF

soil organic carbon improvements of up to one tonne per hectare per year.

CONTINUOUS CROPPING

Building soil organic matter within continuous cropping systems, or at least limiting the decline, requires good agronomy to grow high-yielding crops with as much dry matter as possible, as often as possible (Figure 1).

The best practices are already well-known to growers:

- use zero or reduced tillage to maximise water capture;
- grow more crops and higher-yielding crops with adequate nutrition;
- consider cover crops and companion crops if they can increase dry matter production without compromising grain yields;
- avoiding burning and baling that removes dry matter and nutrients from the paddock; and
- use pasture phases where practical.

Introducing the best profitable practices as soon as possible – rather than waiting until soils suffer major declines – is important, both in younger country and to prolong the gains after pasture phases. □

GRDC Code DAQ2007-004RMX

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Rewriting nitrogen fertiliser 'rules of thumb'

By Professor Roger Armstrong, Dr Ashley Wallace, Dr Katherine Dunsford

KEY POINTS

- **Traditional rules of thumb estimate crop uptake of nitrogen fertiliser at 50 per cent**
- **Agriculture Victoria research suggests 34 per cent may be more appropriate for the southern region**
- **Accurate soil nitrogen measurements to depth will also improve nitrogen budgeting**

Commonly used rules of thumb, which advisers and growers use to make fertiliser decisions, are based on a nitrogen fertiliser uptake of about 50 per cent of what is applied. Now Victorian research undertaken in growers' paddocks puts that figure at just 34 per cent.

These rules are based on a measure of starter nitrogen from soil testing, an estimate of in-crop mineralisation and the crop utilisation figure of 50 per cent. They do not account for nitrogen losses.

Despite many advisers and growers relying on these rules of thumb and nitrogen budgets, a GRDC 2015 survey revealed most were concerned that major changes in soil fertility and cropping systems had compromised the rules' ability to estimate fertiliser needs. Minor adjustments based on local experience and pre-sowing soil nitrogen testing were unlikely to address these misgivings.

Likewise, existing decision-support tools are based on data developed in an era when pasture legume-leys dominated cropping systems or on acid soils in southern New South Wales. These are vastly different to the continuous cropping, conservation cropping practices and alkaline soils that dominate cropping in the southern region.

MEASURING UPTAKE

With this in mind, Agriculture Victoria research supported by the Australian Government examined uptake and losses of applied nitrogen across low, medium and high-rainfall cropping zones and irrigated cropping systems in Victoria.

To measure nitrogen fertiliser uptake, nitrogen-15-labelled urea was top-dressed ahead of rain events to cereal crops – predominantly wheat – in line with grower practices. Experiments supported by the Australian Government's 'Action on the Ground' initiative targeted nine paddocks each year from 2014–16. After harvest, nitrogen-15 was measured in the straw, grain and soil. Missing nitrogen was attributed to unaccounted losses, believed to be mainly denitrification, but possibly also volatilisation and leaching.

The average crop recovery of nitrogen was surprisingly consistent at 34 to 35 per cent across the different regions and cropping systems (Table 1). However, there was a great deal of variability between individual situations depending on seasonal conditions, with water supply the single-most-important determinant of nitrogen use efficiency.

In seasons with low growing-season rainfall, crop uptake was reduced but losses also tended to be reduced. Conversely, in wetter seasons, the amount of nitrogen fertiliser taken up by the crop increased but so did losses.

While seasonal variability will always be a challenge when estimating nitrogen fertiliser requirements, utilising a figure of 34 per cent crop recovery, rather than 50 per cent, will improve the usefulness of the rules of thumb in southern cropping systems. Accurately measuring nitrogen in the soil profile at sowing is another essential component to nitrogen budgeting.

An assessment of losses, which also included data collected as part of the Australian Government's 'Filling the Research Gap' investment, showed that the extent of losses varied by environment and soil type (Table 1).


Photo: Agriculture Victoria

Agriculture Victoria's Dr Ashley Wallace says that utilising a figure of 34 per cent crop recovery, rather than 50 per cent, will improve the usefulness of nitrogen fertiliser rules of thumb in southern cropping systems.

Significant losses can occur in low and medium-rainfall and irrigated cropping systems, not just in the high-rainfall zone as previously thought. However, the ability to mitigate these losses is hampered by uncertainty as to the fate of fertiliser nitrogen and the dominant loss pathways.

The new national GRDC investment, led by the University of Queensland, is targeting a better understanding of nitrogen cycling and losses across Australian cropping systems. It is a first step towards preventing these losses and supporting growers to better manage nitrogen fertiliser. □

GRDC Code UOQ2204-010RTX

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grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/02/nitrogen-fertiliser-use-efficiency-rules-of-thumb-how-reliable-are-they

Table 1: Mean crop recovery and losses (range in brackets) of nitrogen-15 labelled fertiliser nitrogen from the crop/soil system within the season of application using pooled data from nine sites (2014–16). Nitrogen was applied as top-dressed urea during the vegetative/early tillering stage.

Zone and cropping system	Crop recovery of top-dressed nitrogen	Loss of top-dressed nitrogen
Low to medium-rainfall dryland	34% (2 to 75%)	25% (2 to 47%)
High-rainfall dryland	34% (22 to 50%)	32% (4 to 53%)
Irrigated	35% (12 to 60%)	41% (26 to 57%)

Source: Dr Ashley Wallace

GRDC GROUNDCOVER

Highly productive crops can be more greenhouse gas efficient

By optimising nitrogen efficiency, it is possible to improve financial returns and reduce greenhouse gas emissions per tonne of grain produced

By Dr Maartje Sevenster, Dr Lindsay Bell

KEY POINTS

- Nitrogen fertiliser use accounts for the largest greenhouse gas emissions in the grains industry
- This represents both a financial and environmental cost
- Fertiliser application practices that improve nitrogen use efficiency have the potential to increase yield and reduce emissions per tonne produced

■ Nitrogen fertiliser is under the spotlight as the largest source of greenhouse gas emissions in the grains industry. But the imperative to reduce nitrogen fertiliser losses is not just about reducing greenhouse gases, it is also about protecting the bottom line. Fertiliser is simply too expensive to waste.

Greenhouse gas emissions are generated via both the on-farm application of fertiliser and off-farm in the manufacturing and energy sectors. Emissions associated with nitrogen fertilisers account for about 38 per cent of emissions in the grains industry. On-farm losses – particularly losses of nitrous oxide (N_2O), a potent greenhouse gas – contribute 15 per cent of emissions, which could potentially be reduced by improving nitrogen management practices.

Using less fertiliser is not the solution. Reducing fertiliser rates reduces yield, mines soil nitrogen and carbon and reduces the ability of the soil to buffer emissions.

TACKLING EMISSIONS

To evaluate the potential to reduce greenhouse gas emissions from the grains sector, GRDC invested in modelling analysis across every subregion of Australia. The work was led by CSIRO Agriculture and Food in partnership with the NSW Department of Primary Industries.

The analysis found that by improving the efficiency of nitrogen use, growers stand to increase yields and generate a 10 per cent reduction in the intensity of total emissions.

Crop yields, nitrogen losses and soil carbon processes were analysed using the Agricultural Production Systems sIMulator (APSIM) model in locally relevant cropping sequences over a 30-year period from 1990–2019. Modelling allowed the exploration of the impact of different nitrogen management strategies across a broad range of environments and seasonal conditions.

The study compared current industry nitrogen fertiliser practice with application rates based on either a 2005 national average of 38 kilograms of nitrogen per hectare or 2015 average of 58kg/ha against improved nitrogen management scenarios. These included a current best management practice of split application adjusted to seasonal outlook and soil moisture status, or a perfect (but not currently possible) scenario where nitrogen was continually topped up through to flowering to match crop demand.

As expected, increased rates of nitrogen fertiliser led to increased greenhouse gas emissions per hectare (Figure 1a), but grain production increased at a greater rate. This means that the intensity – or emissions per tonne of grain production – decreased (Figure 1b).

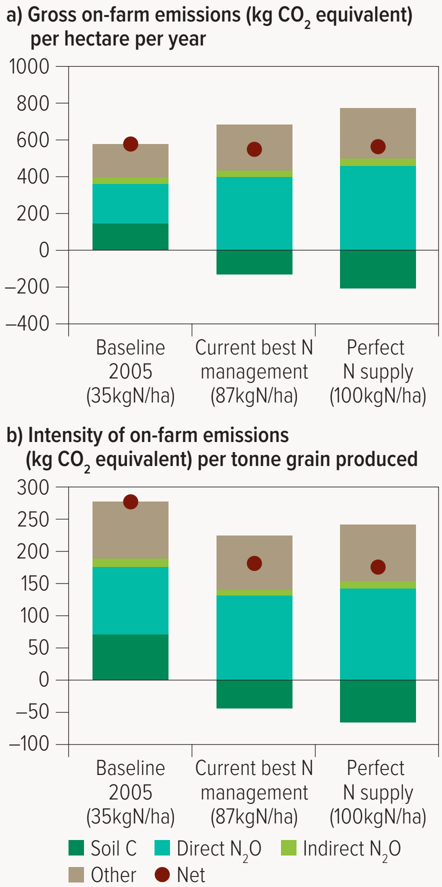
NITROGEN AND CARBON TRADE-OFFS

Increasing the rate of nitrogen application also generated more crop biomass, which meant that increased nitrous oxide emissions were offset by lower soil carbon emissions and in some cases by carbon fixation (Figure 1a).

Although the results were highly variable depending on seasonal conditions, the trend was consistent over a 30-year period, albeit with some regional differences.

While different rotations were explored in the analysis, further work is required to understand the impact of increasing nitrogen-fixing legume crops and pastures or green manures on total emissions and emissions intensity.

Figure 1: National APSIM modelling simulations showed that increasing nitrogen rates increased the gross on-farm emissions per hectare – particularly nitrous oxide (N_2O) – but as yield and biomass also increased, this was offset by reduced emissions through soil carbon loss (a). More importantly, increased grain yield led to a net reduction in emissions intensity per tonne of grain produced (b).



Source: Dr Lindsay Bell, CSIRO

However, one thing is clear: to maintain a productive grains industry and feed the world, it is vital to optimise yield gains in the seasons where it is possible, as efficiently as possible. □

GRDC Code CSP2006-011RTX

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National study into nitrogen losses

A comprehensive field research program aims to plug gaps in our understanding of nitrogen cycling and losses across Australian grain growing regions

By Professor Mike Bell

KEY POINTS

- The current knowledge of nitrogen cycling pathways is limited to specific locations and cropping systems
- GRDC has invested in a national program to develop a comprehensive understanding of nitrogen cycling and loss in Australian grain growing regions
- The data will be used to improve nitrogen forecast models that underpin adviser recommendations and predict greenhouse gas emissions

■ Growers spend about $1.1 billion on nitrogen fertiliser each year. In most cases nitrogen losses are not substantial; however, as much as 25 to 70 per cent of applied nitrogen can be lost from the system under particular climatic scenarios and in certain soil types.

Nitrogen cycling through the soil, air and water is complex and there are many ways that nitrogen – in different chemical forms – can enter and leave the system.

The main pathways for loss are the gaseous pathways of volatilisation and denitrification, while leaching occurs where water flushes the nitrogen below the crop root zone. Nitrogen can also be temporarily immobilised in the soil, but this can become available to the crop in the future via mineralisation.

Soil properties, climate and plants all combine to influence the chemical and biological processes that drive nitrogen cycling.

Previous studies have investigated nitrogen pathways in specific cropping systems and locations and this data has been used in nitrogen modelling that underpins adviser recommendations. However, the amount of nitrogen that remains unaccounted for is highly variable and depends on many factors including the soil type, cropping system, location and seasonal conditions.

This means that models are still not able to accurately estimate losses in a specific situation or to determine if, and when, immobilised nitrogen might again become available to plants.

PLUGGING THE GAPS

A national $11.9 million GRDC investment aims to plug these gaps in our understanding of nitrogen cycling and loss pathways. The four-year project, led by the University of Queensland, will be the first to take a systematic approach to quantifying nitrogen cycling and losses across the diverse range of soil and environmental conditions where grains are grown.

Partner agencies include Queensland University of Technology (QUT), CSIRO, University of Western Australia, Murdoch University, New South Wales Department of Primary Industries, Queensland Department of Agriculture and Fisheries, Western Australian Department of Primary Industries and Regional Development, the South Australian Research and Development Institute and Agriculture Victoria.

The research will focus on the fate of 'missing' nitrogen, which is not accounted for in the soil, the grain or the crop residue at the end of the season. The aim is to help growers and advisers understand and minimise nitrogen losses, while maximising fertiliser use efficiency in crops.

The work will build on previous research to deliver a comprehensive national dataset that will be used to improve the Agricultural Production Systems sIMulator Next Generation model. The modelling, led by Dr Kirsten Verburg and Dr Peter Thorburn from CSIRO Agriculture and Food, will use the data collected from the field trials to test whether the improved models can more accurately predict nitrogen cycling and losses in the field.

NATIONWIDE TRIALS

Twelve field trials – four in each GRDC region – will target different soil types, crop sequences and rainfall zones. Duplicate irrigation treatments, at one site in each region, will improve the understanding of fertiliser nitrogen dynamics under wet versus dry seasonal conditions. The field sites will be managed by the relevant state agencies.

The project is unique in that the same research techniques will be used throughout the country and will track the fate of fertiliser nitrogen for up to three consecutive seasons, rather than just looking at the first season after application.

This consistency will enable the comparison of different rainfall environments and production systems, including mixed-farming systems and summer cropping. The sites will cover a broad range of background fertility and soil types.

PATHWAY FOCUS

Each three-year trial will track the fate of nitrogen fertiliser using fertiliser enriched with the naturally occurring nitrogen-15 isotope. Denitrification and volatilisation will be evaluated in detail at selected sites augmented with laboratory studies.

The denitrification work, led by Professor Peter Grace from QUT, seeks to better quantify the impact of different soil types and seasonal conditions. For instance, we know that the amount of nitrous oxide (N_2O) produced is similar in clay and sandy soils; however, the losses of dinitrogen gas (N_2) are substantially higher in clay soils due to the greater frequency of waterlogging and low oxygen availability.

Volatilisation research will be led by Dr Graeme Schwenke from NSW DPI. Volatilisation is highly dependent on climatic conditions after fertiliser nitrogen application and has so far been little studied in the field under Australian conditions. This loss pathway could become increasingly important as more growers broadcast their nitrogen onto the soil surface, rather than tilling it into the soil.

Not all processes lead to nitrogen being permanently lost from the system. CSIRO Agriculture and Food's Dr Mark Farrell and Dr Gupta Vadakattu will evaluate the impact of soil microbes on nitrogen mineralisation and immobilisation and residue decomposition to better understand how nitrogen moves in and out of the soil organic matter pool. The impact of stubble retention and decomposition rates is an important factor in this research.

The project also provides an opportunity to develop future capabilities with PhD students based at the University of Queensland, QUT and Agriculture Victoria. □

GRDC Code UOQ2204-010RTX
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Photo: Professor Peter Grace, Queensland University of Technology

Field collection chambers are used to capture gaseous losses from denitrification. The lids are closed during the monitoring period.

Photo: Professor Mike Bell, University of Queensland

Nitrogen losses will be measured at 12 field sites across the country by applying nitrogen-15 labelled urea to the trial plots as either granular urea or as urea in solution. In this image, University of Queensland's Professor Mike Bell demonstrates in-soil banding of urea in solution.

Photo: Professor Peter Grace

Portable mass spectrometer and gas emission monitoring equipment will measure dinitrogen gas (N_2) and nitrous oxide (N_2O) emissions from denitrification in the lab to supplement field experiments.

NSW Department of Primary Industries technical staff Pete Formann and Clarence Mercer with new monitoring equipment to measure ammonia volatilisation from broadcast urea near Tamworth, NSW.

Photo: Dr Graeme Schwenke, NSW Department of Primary Industries

Getting a firm grip on nitrogen losses

Better information is needed to quantify and mitigate the impact of denitrification and volatilisation in Australian cropping systems

By Dr Graeme Schwenke, Professor Peter Grace, Professor Mike Bell

KEY POINTS

- Not enough is known about denitrification and volatilisation, the two main pathways for nitrogen losses in cropping systems
- National field trials aim to improve the understanding of these processes to help growers and advisers reduce these losses on-farm

■ High prices for nitrogen fertiliser and recent wetter-than-average conditions have focused attention on the spectre of denitrification, which can cause substantial losses of soil and fertiliser nitrogen.

Denitrification and volatilisation are the two main gaseous loss pathways for nitrogen from cropping systems, but there are still many gaps in our understanding of the mechanisms and importance of these losses across diverse Australian grain growing regions.

Quantifying these losses is a significant component of the national GRDC nitrogen investment led by the University of Queensland. The results will be used to improve the ability of the existing Agricultural Production Systems sIMulator (APSIM) model's soil nitrogen module to estimate total denitrification and will introduce a volatilisation component to the model for the first time.

Nitrogen losses are highly variable and depend on many factors including the soil type, cropping system, location and seasonal conditions. This research will study these losses over three seasons at field trials in a range of cropping systems and soil types across Australia.

Losses of ammonia (NH_3), dinitrogen gas (N_2) and nitrous oxide (N_2O) will be measured using stable isotope-labelled nitrogen fertiliser recovery experiments with the aim of identifying opportunities to reduce these losses on-farm.

VOLATILISATION

Total volatilisation losses from surface-applied urea and manures are typically less than 20 per cent of applied nitrogen for urea and less than 30 per cent for manures, but can range from zero to 65 per cent. When these nitrogen sources are incorporated into the soil, losses are generally negligible.

Ammonia (NH_3) gas can be volatilised from soil, plants or plant residues, fertiliser and animal manures. In the air it causes environmental pollution that can travel long distances, causing soil acidification and nitrogen inputs that reduce water quality and biodiversity.

Alkaline soil conditions increase the likelihood of volatilisation and the addition of nitrogen fertiliser as urea to soils tends to increase alkalinity in the short term, depending on soil pH and the ability of the soil to buffer these changes. Soils rich in clay minerals and organic matter are better able to buffer changes in pH and reduce volatilisation than are sandy soils.

DENITRIFICATION

Denitrification is a significant nitrogen loss pathway in some agricultural soils, with the microbially mediated process producing harmless dinitrogen (N_2) gas as well as the potent greenhouse gas nitrous oxide (N_2O).

While the loss of dinitrogen simply represents a waste of a valuable crop input, nitrous oxide emissions have received considerable attention as a potent greenhouse gas that has 273 times greater global warming potential than carbon dioxide (CO_2). The typically smaller losses of nitrous oxide can therefore have a big impact on industry emissions profiles. The processes and soil characteristics that determine the ratio of dinitrogen to nitrous oxide in gaseous nitrogen emissions are not well understood.

Denitrification is typically more common in poorly drained and high-clay soils. Seasonal gaseous nitrogen losses in eastern Australian grains systems may exceed 50 per cent of the applied nitrogen fertiliser, averaging 27 per cent on the high clay vertosols in north-eastern Australia.

The potential for large losses of nitrogen due to denitrification can be reduced by practices that reduce the concentrations of nitrate in the soil, such as split fertiliser applications and adjusting fertiliser application rates to account for existing soil mineral nitrogen stores in the soil profile. □

GRDC Code UOQ2204-010RTX

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Liming a risky partner for sulfate of ammonia

Sulfate of ammonia might be a cheaper source of nitrogen fertiliser, but the risk of volatilisation losses increases when it is applied in close succession to lime

By Associate Professor Louise Barton, Paul Damon, Dr Fiona Dempster, Professor Zed Rengel

Photo: Evan Collis

University of Western Australia researchers Associate Professor Louise Barton and Paul Damon are investigating the risk of volatilisation associated with the practice of applying sulfate of ammonia in close succession to surface lime.

KEY POINTS

- Applying sulfate of ammonia in close succession to surface liming could increase the risk of nitrogen losses via ammonia volatilisation
- The practice is common enough in Western Australia to raise concerns
- Research is underway to quantify the risks

■ Anecdotal evidence suggests that applying sulfate of ammonia in close succession to surface liming, and prior to seeding, increases the risk of volatilisation. Although the data is limited, it is feasible that nitrogen fertiliser losses from ammonia volatilisation could be as high as 30 per cent for Western Australian soils under certain conditions. Given the increasing reliance on nitrogen fertilisers in WA, and greenhouse gas emissions associated with their production and use, understanding whether this is a significant loss pathway is important.

A RISKY BUSINESS

A short-term study quantifying the frequency of the practice and the level of risk is being led by the University of Western Australia (UWA), with the assistance of Murdoch University as part of the SoilsWest alliance. An exhaustive literature search did not find any research directed at this practice, although there was enough evidence to demonstrate the risks.

Volatilisation losses depend on the timing and placement of nitrogen fertiliser, soil pH and soil pH buffering capacity, plus environmental conditions. In eastern Australia, research has found volatilisation losses of up to 34 per cent when sulfate of ammonia is applied to alkaline soils that contain free lime.

Given that lime increases soil pH, it is reasonable to expect that applying sulfate of ammonia to recently limed soil would increase the risk of ammonia volatilisation.

COMMON ENOUGH

To assess the extent of the practice, UWA surveyed 13 agronomists whose clients crop a total of 1.6 million hectares throughout WA's grain growing regions.

The survey showed that the broadcasting of lime and sulfate of ammonia over paddocks is not extensive, but common enough in the WA grainbelt to warrant further investigation.

The majority of advisers (nine of 13) said that that they had clients applying lime and sulfate of ammonia in close succession, although this ranged from five per cent to 100 per cent of a client base. When this practice takes place, it occurs from one year in three to one year in six, usually prior to sowing canola.

Five of the 13 advisers raised concerns about gaseous nitrogen losses occurring when lime and sulfate of ammonia were applied in close succession, while three consultants believed sulfate of ammonia was an inefficient source of nitrogen fertiliser.

Glasshouse experiments are already underway to evaluate potential volatilisation losses from surface applications of lime and sulfate of ammonia. Initial results, which compared ammonia volatilisation losses in response to different simulated rainfall scenarios, put losses in the range of less than one per cent to 20 per cent.

The greatest losses occurred from the limed soils under a 'low' break-of-season rainfall, with losses more than halved under a 'high' break-of-season rainfall scenario.

The next step in this study is to measure the impact of any losses on the growth and yield of canola and to determine whether the lime continues to promote ammonia volatilisation in a subsequent barley crop grown in the glasshouse.

An assessment of the risk of ammonia volatilisation when lime and sulfate of ammonia are applied in close succession is expected to be delivered to growers and industry early in 2023. □

GRDC Code UWA2202-001RTX

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Solving the mysteries of plant protein composition

To arrest protein decline in wheat, researchers are measuring the impact of nitrogen application timing on leaf and grain protein content and composition

By Samantha Harvie, Professor Harvey Millar, Dr Katharina Belt, Dr Hui Cao

KEY MESSAGE

The impact of different nitrogen application timings on wheat grain protein content and composition is being studied in WA to determine whether there are genetic differences in wheat lines that could be of value.

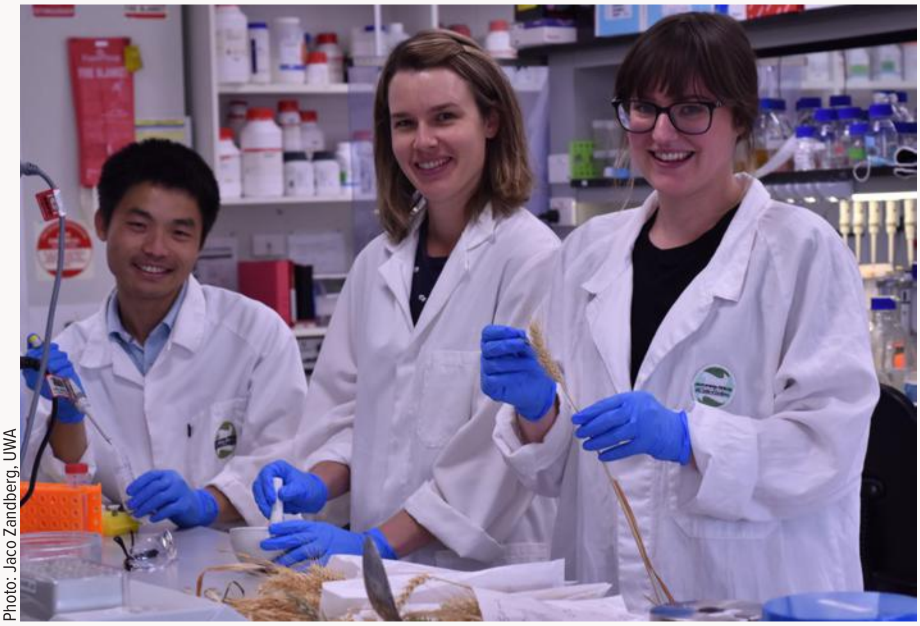

Photo: Jaco Zandberg, UWA

Dr Hui Cao, Dr Katharina Belt and Samantha Harvie measure the impact of different nitrogen application timings on wheat grain protein content at the University of Western Australia.

Maximising protein content in wheat has been the subject of considerable research, but protein level is only part of the story. Protein composition – or the type of proteins produced – is important for wheat quality and end-use markets.

To date, much of the research on grain protein content has focused on soil nitrogen cycling, fertiliser application strategies and uptake into the plant.

PROTEIN COMPOSITION

While split applications of nitrogen fertiliser have often been considered the most effective at boosting grain protein content, researchers are only just beginning to understand how different application strategies affect protein composition and end-use quality.

Following uptake, nitrogen can be converted into various protein compounds that are either stored as plant biomass or converted into grain. These compounds can be broken down multiple times and recycled in different ways.

This process – known as futile cycling – can be highly energy inefficient. Preliminary University of Western Australia (UWA) glasshouse research found that as much as 25 per cent of stored plant proteins can be recycled over and over, but the cost to yield and final grain protein content is not yet known.

European research has shown that the timing of nitrogen can affect the final composition of plant proteins.

To evaluate the potential impact of nitrogen timing on protein content and composition in Australian wheat, GRDC has invested in a postgraduate PhD research project at UWA.

Researchers hope that a better understanding of the biology of grain protein production could help increase protein levels in WA wheat.

Embedded within the School of Molecular Sciences, the research will be the first to measure these processes in the field in Australian soils and varieties.

FIELD STUDIES

The initial field trial at UWA's Shenton Park Field Station in 2022 evaluated the impact of nitrogen application timing on plant protein content in the leaf and grain of six genetically diverse wheat varieties.

It is possible that there could be useful genetic differences in how the wheat lines process plant proteins.

Nitrogen fertiliser was applied at three timings, comparing a time-of-sowing application with split applications either six or 12 weeks after sowing. Protein content and, more importantly, composition was analysed from grain and flag leaf samples collected 10, 20 and 30 days after anthesis.

Along with some additional data collected at Merredin in 2022, the results will inform the basis for a second trial at Merredin in 2023.

Alongside this work, detailed glasshouse and field studies will track nitrogen-15 applied directly to wheat heads to better understand the turnover of individual proteins during the process of futile cycling.

While the process is energy-intensive, it is not known whether it is an essential part of maximising grain protein quality.

Nitrogen-15 is a stable isotope of nitrogen used to determine crop fertiliser use efficiency. It is also used to quantify the amount of nitrogen that crops can acquire from the atmosphere through a process known as biological nitrogen fixation.

Ultimately, a better understanding of the biological function of plant protein cycling and the implications for protein quality could be useful either for making on-farm nitrogen application decisions, or in the breeding of wheat lines that produce a highly desirable combination of grain proteins. □

GRDC Code UWA2202-002RSX

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Advanced genetic techniques target protein and yield

Researchers have unlocked the genetic secrets of improved nitrogen use efficiency and grain protein in wheat

By Professor Wujun Ma, Dr Shahidul Islam, Dr Jingjuan Zhang

KEY POINTS

- Australian wheat varieties typically have low nitrogen use efficiency and grain protein due to poor soils and variable rainfall
- Researchers at Murdoch University have identified genetic clusters associated with higher grain protein and yield
- Genetic markers and breeding material will be made available to Australian breeding programs

Photo: Dr Gang Li, the University of Adelaide

The Murdoch University project team harvesting wheat with genetically improved nitrogen use efficiency at Williams in Western Australia in 2018. From front left: Dr Mirza Dowla, Dr Rongchang Yang, Dr Jingjuan Zhang, Dr Hang Liu, Professor Wujun Ma, Dr Shahidul Islam, Resad Mallik, Dr Yanjie Jiang and Dr Yong Zhao; back row: Professor Jiansheng Chen, Atik Saieed, Dr Zaid Alhabbar and Masood Anwar.

Wheat profitability depends on achieving the ultimate combination of high yield and high grain protein content. However, nitrogen use efficiency and protein content in Australian wheat is typically low due to poor soils and irregular rainfall.

Traits that are expected to lead to better protein content without compromising yield are targeted by Australian breeding programs, but protein is a complex beast that is controlled by multiple genes.

To calculate nitrogen use efficiency, the team at Murdoch University measured the total amount of nitrogen partitioned in the wheat grain – the nitrogen remobilised from leaf to grain – as a proportion of the available nitrogen in the soil. This makes nitrogen use efficiency a key indicator of simultaneously increased wheat grain protein content and yield.

Nitrogen use efficiency can be influenced by multiple different genetic factors that are typically measured by breeding programs.

Since 2015, GRDC has invested in research at Murdoch University to identify gene clusters associated with improved nitrogen use efficiency and to provide this genetic material, along with molecular markers, to Australian wheat breeders.

BETTER BREEDING

The project has been completed, with more than 20 different gene clusters identified that contribute to improving grain protein content and yield through multiple processes within the plant.

The university has worked directly with Australian wheat breeders, whose advice has been valuable in guiding research directions. The project has also supported 10 PhD students to build future capacity in this area.

The team started with two wheat varieties with high grain protein content – LRPB Spitfire⦹ from Australia and Bethlehem from Israel.

These were crossed with high-yielding Australian varieties, such as Mace⦹, Westonia and Suntop⦹, to create six double-haploid populations – the genetically pure or 'inbred' lines used in breeding.

With the goal of identifying genetic material that combines high yield with high protein, the six crosses along with LRPB Spitfire⦹ and Bethlehem were grown at four field sites with distinct environments. Up to 22 traits associated with high grain protein content were measured at the sites at Muresk and Williams in Western Australia and Narrabri in New South Wales in 2018, and Beverley, WA, in 2020.

Quantitative trait locus (QTL) analysis, a statistical method that matches gene clusters to trait measurements from the field, was used to identify clusters that can improve both yield and protein content. These genes are not only effective independently but have an additive affect when applied in tandem.

At least three genes that simultaneously drive grain protein and yield will be made available to Australian breeding companies. More are under investigation. □

GRDC Code UMU1506-001RTX

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Nitrogen price remains secondary to yield and protein targets

By James Hagan

KEY POINTS

- Yield and protein targets should remain the primary focus when making decisions about nitrogen fertiliser rates
- Nitrogen application is still profitable even when urea prices reach $1350 per tonne
- Soil nitrogen testing to depth and efficient application is more important than ever

Given recent nitrogen prices, growers are closely monitoring their fertiliser expenses, which typically account for about 20 to 25 per cent of total input costs. Economic calculations show target yield and protein are still the most important factor in determining profitable nitrogen applications.

The economic analysis, conducted by the Queensland Department of Agriculture and Fisheries (DAF) with GRDC investment, found that agronomically recommended fertiliser rates can still be profitable even when urea prices triple. The above-average grain prices and favourable seasonal yields have further increased profitability.

Importantly, from an agronomic standpoint, better-than-average seasons with higher yield potentials mean it is even more important to replenish depleted soil nitrogen to maintain productive capacity.

FOCUS ON THE TARGET

While reducing nitrogen rates to overcome high fertiliser prices might seem like the obvious solution, it is not necessary as the optimal fertiliser rate is consistent despite increasing prices. The economic analysis has shown that targeting yield and protein is still the most profitable option for growers, even when the price of fertilisers increases significantly.

Using precision or variable nutrient application will also improve the effectiveness of nitrogen application.

It is important to understand how much nitrogen is already in the system to determine how much nitrogen is required to achieve target yield and protein. Growers should accurately measure existing soil nitrogen reserves using deep soil testing.

Economic calculations can then be used to compare the actual cost of fertiliser against potential profits for yield and grain price.

The average price of nitrogen is about $1 per kilogram. For every $1 spent on nitrogen, profits typically increase by $5.

For example, 40kg of nitrogen is required to increase yield by one tonne; assuming 80 per cent efficiency, 50kg needs to be applied. In the past, average nitrogen prices were about $1/kg and a tonne of wheat was worth $300.

Therefore, it would cost $50 to apply enough nitrogen to increase profit by $300 (one tonne), resulting in a profit of $250. Even if nitrogen prices triple, the cost of application will be $150 with a profit of $150.

SIMULATION MODELS

Queensland DAF has undertaken price simulations at multiple locations. Results have shown that the agronomic targets remained profitable even when urea prices reach up to $1350. These calculations were sourced from two tools, CropARM and CliMate. These tools help growers and advisers consider season risk when determining nitrogen requirements.

For instance, calculations showed that a Goondiwindi wheat crop achieved a gross margin of $533 per hectare when the recommended 100kg of nitrogen per hectare was applied and both urea and grain prices were average (Table 1). These calculations were based on a conservative rate of 60 per cent nitrogen recovery by the crop.

As urea prices have increased, the calculations showed that the gross margin reduced to $338, which is still a higher profit compared to when nitrogen rates reduced to 50kg/ha or zero. When above-average wheat prices were factored in, the gross margin increased to $716 when 100kg nitrogen/ha was applied.

These figures do not account for the legacy benefit of applied nitrogen. Research has shown that the majority of nitrogen not available in the year of application is typically available to following crops, contributing to gross margins in the following seasons. □

GRDC Code DAQ2007-004RMX

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Table 1: Comparison of the impact of increased urea prices on gross margins with and without increased grain prices at three rates of urea at Goondiwindi, Queensland. The figures demonstrate that even when urea prices increase to $1350, nitrogen application at 100kg/ha is more profitable than lower rates regardless of whether grain prices are average ($295/t) or above average ($400/t).

Scenario	Average prices	High urea price, average wheat price			High urea price, high wheat price		
Grain price ($/t)	$295	$295	$295	$295	$400	$400	$400
Urea price ($/t)	$450	$1350	$1350	$1350	$1350	$1350	$1350
Nitrogen applied (kg/ha)	100	100	50	0	100	50	0
Median yield (t/ha)	3.6	3.6	2.6	1.5	3.6	2.6	1.5
Income ($/ha)	$1062	$1062	$767	$443	$1440	$1040	$600
Non-nutrition costs ($/ha)	$295	$295	$295	$295	$295	$295	$295
MAP ($/ha)	$36	$36	$36	$36	$36	$36	$36
Urea ($/ha)	$98	$293	$147	$0	$293	$147	$0
Gross margin ($/ha)	**$533**	**$338**	**$239**	**$112**	**$716**	**$512**	**$269**

Source: James Hagan, DAF

Weighing nitrogen fertiliser options in an uncertain future

No forecast is perfect, but the real question is whether upside benefits will outweigh downside risks

By Barry Mudge, Dr Peter Hayman

KEY POINTS

- Top-dressing nitrogen is considered a risky decision involving a comparison of potential losses from a poor season against potential gains from a good season
- Taking the time to document upside potential versus downside can help move intuitive decisions into more concrete calculations

Top-dressing nitrogen is considered a risky decision. Too little and potential yield could be lost; too much can represent an unnecessary cost.

Growers and advisers use a range of tools to identify a target yield and then calculate the nitrogen required to achieve that yield. Some input from seasonal forecasts might be included in setting the target yield. Hitting the target yield is rare. In hindsight, a grower will almost always have under-fertilised or over-fertilised.

Decisions on application rates of nitrogen fertiliser are done by weighing up the likely upside benefits against the downside risks. These decisions are often made intuitively based on past experiences – good or bad.

Unfortunately, the human brain tends to remember negative events more strongly than positive, and often places a bigger emphasis on downside risk than is warranted. This can lead to more-conservative choices. Recent events also play a bigger role in decision-making.

To overcome this natural bias, it is useful to take the decision out of the head and objectively compare the upside and downside of proposed nitrogen rates across a range of potential seasonal outcomes.

A spreadsheet using simple nitrogen budgeting enables a potential rate to be evaluated against each possible seasonal outcome to better demonstrate the relative risk and reward.

Calculations generated as part of the Australian Government's Rural R&D for Profit Forewarned is Forearmed investment are shown in Figure 1.

Potential profit is plotted against seasonal outcome – broken into 10 rainfall deciles – for two different nitrogen rates. The nitrogen rates are based on Yield Prophet® calculations of the nitrogen required to meet potential yield for an optimistic choice of season (decile 7) or the more-conservative average season (decile 5).

If the season achieves decile 7, then 40 kilograms of nitrogen per hectare are required to achieve potential yield. In that case, profit would exceed $270/ha, but this is just one potential outcome. The line representing 40kg of N/ha crosses the zero point about halfway, indicating a downside loss occurs half the time, which is more than compensated by the upside profit.

The conservative approach of applying enough nitrogen for a decile 5 season (12kg of N/ha) would be profitable more often than the decile 7 approach, but the profits are substantially lower. The probability-weighted average profit from aiming at decile 5 is $41/ha, compared with $80/ha for the higher nitrogen rate.

While Figure 1 assumes that the probability of achieving each decile is the same, these calculations can be adjusted to factor in the probabilities from seasonal forecasts.

Growers are always concerned when seasonal conditions are such that applied nitrogen is not used by the crop – usually due to drier springs. However, the evidence from research and modelling suggests that some of this nitrogen will carry over to the following season and this potential profit should be included in the calculations.

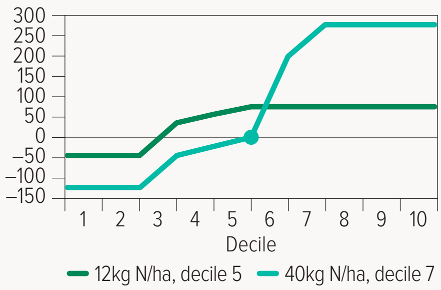
The impact of the carryover nitrogen is greatest in reducing downside regret and has a bigger impact on the more optimistic choice.

There can be no gain without risk – but the risk of missing out on potential upside profit in good seasons when they come along could be the biggest risk of all. ☐

Photo: Country Made Images by Claire

South Australian grower Barry Mudge uses simple nitrogen budgeting to evaluate potential nitrogen fertiliser rates against each possible seasonal outcome to better understand the relative risk and reward.

Figure 1: Plotting potential profit against seasonal outcome demonstrates the relative risk and reward.



Notes: The cautious choice of applying 12 kilograms of nitrogen per hectare, which is enough for decile 5, misses out on the opportunity in deciles 6 to 10 – note the flat line for higher deciles. The more-optimistic choice of applying 40kg of N/ha, which is enough for decile 7, is worse off than the cautious choice in deciles 1 to 6, but much more profitable in the higher deciles. Budgets are based on one tonne of wheat requiring 40kg of nitrogen, wheat price $400/t and nitrogen $2.80/kg plus $10 application.

Source: Dr Peter Hayman, SARDI

GRDC Code MLA1805-001OPX

More information: Barry Mudge, 0417 826 790, theoaks5@bigpond.com; Dr Peter Hayman, 08 8429 0426, peter.hayman@sa.gov.au; forecasts4profit.com.au/cb_pages/rapid_climate_decision_analysis_tool.php

Fertiliser decisions are critical after a big season

For many growers, adequately replenishing the nitrogen supply will play a key role in maintaining productivity after a good season

By Lee Menhenett, Jim Laycock

KEY POINTS

- High-yielding crops in favourable seasons export a lot of nitrogen out of the system
- Moisture levels over the summer will influence nitrogen mineralisation and availability at sowing
- Deep soil nitrogen testing remains the most-effective way to calculate the nitrogen fertiliser required ahead of sowing

For growers lucky enough to have reaped the rewards of good conditions in 2022, nitrogen supply could be a limiting factor going into the next season. It is important to 'take a look under the hood' of each paddock and make sure the nutritional engine has everything it needs to hum to perfection in 2023.

AVAILABILITY

Many factors influence the availability of nitrogen after a good season. High-performing crops export more nitrogen out the gate as grain, potentially leaving soils depleted. Likewise, nitrogen tie-up during stubble breakdown (known as immobilisation) can be a problem in paddocks carrying a high stubble load.

In some cases, the high cost of fertiliser nitrogen in 2022 might have resulted in nitrogen being applied at the lower end of the recommended range, which means there will be a lot of soil carbon looking for nitrogen. In this situation, an early nitrogen application is recommended to set crops up well for the season ahead, regardless of whether the season is below average or better performing.

When planning nitrogen requirements for 2023, start by working out how much nitrogen is available in the soil. Paddock history may not tell the full story. Pay particular attention to any paddocks that did not quite deliver on yield and protein targets, as these indicate nitrogen nutrition was not where it should be.

Rainfall events over summer will increase the amount of available nitrogen through mineralisation ahead of the season. However, too much moisture to the point of extended saturation could put soils at risk of denitrification.

The loss of nitrogen via denitrification occurs in paddocks that experience periods of water inundation leading to anerobic conditions, particularly in warmer conditions and where there is a large source of carbon. In the summer of 2010-11, large areas of Victoria that were flooded for weeks or months suffered substantial losses of nitrogen through denitrification.

The most effective way to get an accurate measure of available nitrogen and determine fertiliser needs is to undertake deep soil nitrogen testing ahead of sowing. High prices for nitrogen fertiliser increase the value of soil testing in guiding fertiliser rate decisions.

RATES AND RISK

Nitrogen decisions are based on the law of diminishing returns. While each dollar of nitrogen generates more than a dollar in yield, it is worthwhile. But it is important to understand how nitrogen influences protein content and, therefore, the quality grade and sale price at delivery. If high fertiliser rates lead to a bump up in the delivery grade, the rate of return can be recalculated for a higher grain value.

Photo: Nicole Baxter

It is important to understand how nitrogen influences protein content and therefore the quality grade and sale price at delivery.

Typically crops use nitrogen to build yield to a point – usually yield plateaus when protein is about 11.5 per cent, or in the range of 11 to 12 per cent. Beyond this point, nitrogen is diverted to improving protein (Figure 1).

Protein levels less than about 11.5 per cent can be a warning sign that nitrogen supply was limiting and crop yields were not where they should be. If milling wheat is downgraded to Australian Standard White (ASW, less than 10.5 per cent), yield has definitely been compromised.

It is 'not in the bag until it is in the bag', as every grower and adviser knows all too well. Fertiliser decisions are based on potential yield. If the season goes pear-shaped, reductions in yield or quality or both will reduce the return on fertiliser in that year. The influence of risk on the fertiliser decision is often influenced by each grower's financial situation. □

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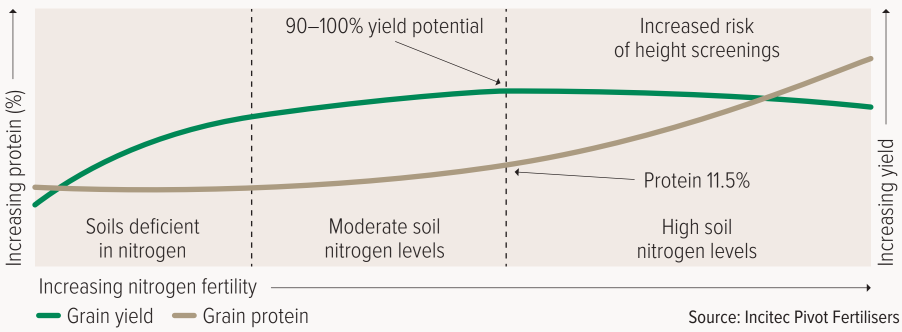
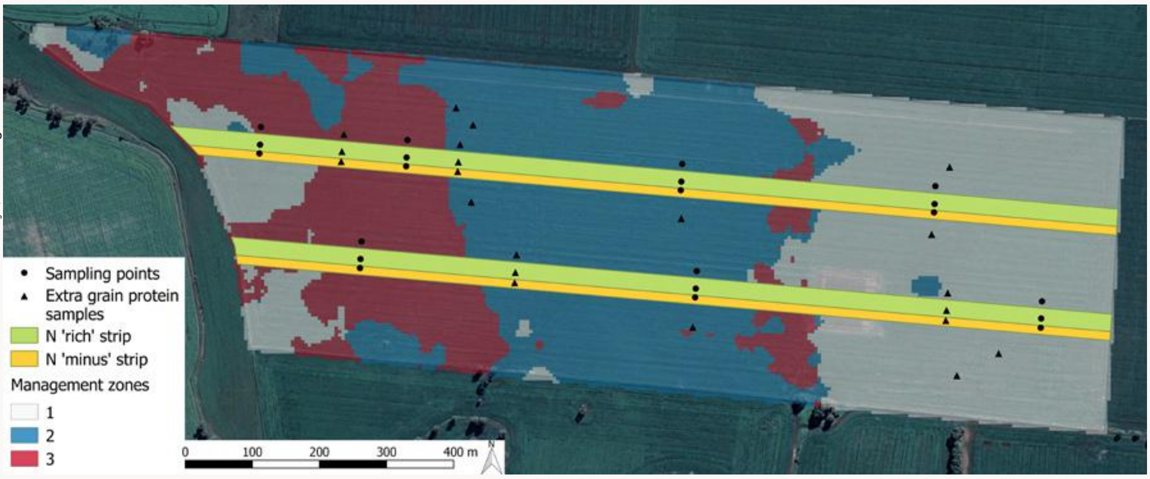
Figure 1: Typically crops use nitrogen to build yield to a point – usually where protein is about 11.5 per cent (range 11 to 12 per cent). Beyond this point, nitrogen is diverted to improving protein. Protein levels less than about 11.5 per cent suggest that yield has been compromised by a lack of nitrogen.



Source: Incitec Pivot Fertilisers



Source: Dr André Colaço, CSIRO Agriculture and Food

Nitrogen-rich (green) and nitrogen-poor (yellow) test strips were established within a standard nitrogen regime at core field sites across Australia. The two extremes enabled the machine-learning model to calibrate the data it received.

Learning to machine better nitrogen decisions

By Dr Rob Bramley on behalf of the Future Farm team

KEY POINTS

- Nitrogen decision-making is based on imperfect models fed by imperfect data
- Research has found that machine learning can use multivariate data coupled with simple on-farm experiments to reduce the level of risk inherent in fertiliser decisions
- GRDC has established a follow-on investment that will work with commercial partner/s to develop the science into user-friendly products for applications on-farm

■ A 2017 grower survey found that most growers used their own calculations or agronomist advice to determine fertiliser rates. Only one-quarter of respondents used nitrogen fertiliser decision-support tools and these growers mostly consulted two or more tools. The recent proliferation of on-farm sensors and remote-sensing data has potential to collect useful data, but it is challenging for growers and advisers to evaluate multiple sources of data.

GRDC's investment in the Future Farm project sought to explore ways of automating complex data processing and analysis steps and increasing grower confidence in nitrogen decision-making.

The project was led by CSIRO Agriculture and Food alongside experts from the universities of Sydney and Southern Queensland, Queensland University of Technology and Agriculture Victoria.

With the survey as a guide to decision-making approaches, the next step was to test alternate approaches and to explore the potential to automate the entire process from data acquisition to fertiliser recommendation and application.

Large-scale field trials across Australia compared a range of approaches to nitrogen fertiliser recommendations including traditional models, sensor-based tools and machine learning.

While the four-year GRDC investment was not a nitrogen project per se, the complexity of mid-season nitrogen fertiliser decision-making and the imperfect nature of the input data made it the ideal test case for this approach.

The results from large-scale core field sites and grower-initiated trials across Australia demonstrated that a machine learning model can make effective nitrogen fertiliser recommendations, with considerably reduced error compared with more-conventional methods.

A critical element of success was the use of simple on-farm trial strips that enabled the model to calibrate the data it received. These consisted of the two extremes of nitrogen-rich and nitrogen-zero test strips within a standard nitrogen regime.

Rather than trying to determine which sensors and data inputs would be the most useful based on agronomic knowledge, the team developed a workflow that leveraged precision ag data, satellite imagery, and lots of other useful (and scalable) data inputs against the explanatory power of large-scale on-farm experiments enabled by variable-rate technology.

This data-driven machine learning model was able to improve profits by about $50 per hectare, even for the top-performing grower collaborators.

THE FUTURE OF DECISIONS

A challenge with traditional decision-support tools is that they rely on a mechanistic agronomic model to estimate nitrogen requirements from known or estimated data. Accurate input data – such as soil nitrogen tests – can be expensive and difficult to gather.

Each source of data brings its own level of error to the calculations. Current mechanistic nitrogen decision-support systems have an error of about 50 kilograms of nitrogen/ha. The machine learning model was able to reduce this to about 15kg/ha, demonstrating its potential to enhance grower confidence in the nitrogen decision.

GRDC and CSIRO have recently established a technology transfer investment that will work with commercial partner/s to develop the validated model into user-friendly products and services.

This approach highlights the power of machine learning in agriculture and the importance of precision agriculture fundamentals – namely yield mapping and variable rate technology – in enabling new value for growers in the digital age. □

GRDC Code CSP1803-020RMX

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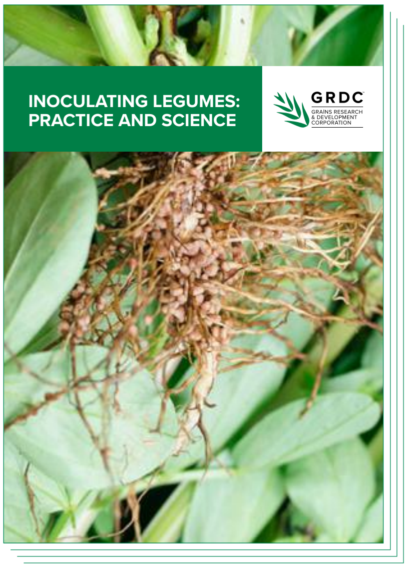
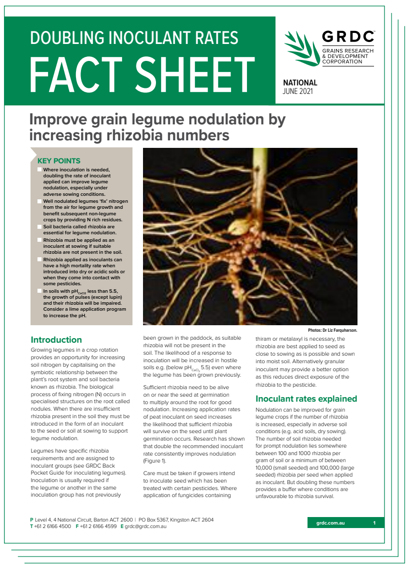
Growing legumes in a rotation increases soil nitrogen and reduces fertiliser requirements for following crops



GRDC has published the following resources (currently in digital format only) with the aim of:

- increasing grower knowledge of legumes, rhizobia, nodulation and nitrogen fixation;
- improving the cost-effectiveness of inoculation as a key farm practice; and
- enabling growers to boost farm profits through improved legume nodulation and nitrogen supplies.



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