



A guide to minimising nitrous oxide emissions from nitrogen fertiliser applications in wheat



Australian Government
Department of Agriculture
and Water Resources



ADDING VALUE TO THE BUSINESS OF CROPPING



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Contents

Introduction	5
1 Why are nitrous oxide emissions an issue?	6
2 Under what conditions in cropping are emissions most problematic?	8
3 Nitrogen management in wheat	12
- Knowing how much nitrogen is available from the soil	
- Influence of legume crops on plant available soil nitrogen (N)	
- Matching nitrogen supply with nitrogen demand in the crop	
- Use of nitrification inhibitors	
4 Using new technologies to visualise crop nitrogen demand	16
5 References and Acknowledgements	22

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Introduction

So why should growers minimise nitrous oxide (N₂O) emissions when using nitrogen fertilisers?

Minimisation of N₂O emissions are a “win win” for both the grower and the environment, saving the grower dollars in unnecessary fertiliser expenditure whilst preventing emissions of an important greenhouse gas to the environment. Nitrous oxide emissions typically equate to much larger gaseous losses from the soil as dinitrogen gas (N₂). Whilst dinitrogen is not a greenhouse gas, losses as small as 2 kg N/ha of nitrous oxide indicate nitrogen losses from the soil as dinitrogen 20 - 30 times greater (i.e. 40-60 kg N/ha or at \$1.10 per kg N about \$44-66/ha if you were to make good the loss with nitrogen fertiliser).

Nitrous oxide as a greenhouse gas has 300 times the warming potential of carbon dioxide. By adopting simple measures such as measuring soil mineral nitrogen and soil carbon the grower can better match the need for nitrogen fertiliser application to crop demand, and reduce the risk of gaseous losses that are damaging to both the environment and farm profits.

Background to this guide

A guide to minimising nitrous oxide (N₂O) emissions from nitrogen fertiliser applications in wheat has been based on three years research examining the influence of nitrogen management in wheat at two research sites in southern Australia, Yarrowonga in Victoria and Hart in South Australia.

The guide covers how nitrogen management in wheat following legume and non-legume break crops related to both crop yield and nitrous oxide (N₂O) emissions.

Although this research programme was set up primarily as a demonstration of management strategies that growers could adopt, the field research was carried out in large replicated field trials which allowed statistics to be gathered on the measurements taken. As a demonstration project the layout of the field studies only allowed the study of the nitrous oxide (N₂O) emissions in particular treatments and did not cover the emissions of the legume and non-legume crops grown before the wheat.

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1 Why are nitrous oxide emissions an issue in agriculture?



Key points

- Nitrous oxide emissions are one of the major losses of nitrogen from the soil that could otherwise be used by crops.
- They are also one of the most damaging greenhouse gases with 300 times the warming potential of carbon dioxide.
- Efficient management of nitrogen fertilisers and soil nitrogen reserves is important for both profit and the environment, it's a "win win" for both crop yields and preventing global warming.
- Nitrous oxide (N_2O) emissions result from the presence of high levels of soil nitrates that are denitrified under waterlogged conditions.
- The same soil conditions that cause elevated nitrous oxide (N_2O) emissions also result in the loss of dinitrogen gas (N_2) from the soil, which whilst not a greenhouse gas represents a potential loss of plant available nitrogen greater than nitrous oxide.
- During denitrification losses of dinitrogen gas N_2 represent a far greater loss of nitrogen from the soil than nitrous oxide, up to 80 times greater when the soil is waterlogged but typically 20-30 times greater.

Nitrogenous fertiliser is the most important input in Australian grain growing since it is an input that allows growers to increase the yield potential of their crops. However, previous research conducted under the National Agricultural Nitrous Oxide Research Program (NANORP) has found that high proportions of nitrogen (N) fertiliser can be lost as nitrous oxide (N_2O) under particular soil conditions.

Of the nitrogen based gases emitted from the soil, nitrous oxide (N_2O) is the most damaging greenhouse gas. Greenhouse gases trap a proportion of the solar radiation that is radiated back into space from the earth, thus contributing to global warming. These gases, whilst being essential for life on earth, have been increasing due to human activities and there has been a focus on ways to mitigate their production and effects. Greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide, ozone and some artificial chemicals such as chlorofluorocarbons (CFCs). In broad acre cropping it is greenhouse gas emissions connected with nitrous oxide emissions and the use of nitrogenous fertilisers that has been the primary focus of mitigation.

Not all greenhouse gases have the same warming effect and nitrous oxide is particularly damaging since one unit of nitrous oxide results in the same amount of warming as approximately 300 units of carbon dioxide (CO_2).

The soil conditions that lead to higher losses of nitrous oxide also lead to emissions of dinitrogen gas N_2 (see section 2). Dinitrogen is not a greenhouse gas but represents the largest nitrogen losses from the soil and makes up almost 80% of the gases in the earth's atmosphere. Its release from the soil represents a loss of potentially plant-available nitrogen rather than a greenhouse gas. The amount of nitrogen lost from the soil as dinitrogen gas is up to 80 times greater than the amount of nitrogen lost as nitrous oxide, with the ratio of losses being strongly affected by the water content or more precisely, the oxygen content of the soil. Despite this varying ratio between nitrous oxide and dinitrogen, the same general soil conditions of denitrification result in the release of both nitrogen gases, meaning that nitrous oxide emissions are a measurable indicator of nitrogen loss from the soil.

The following are very broad statements on soil conditions that are not easy to verify and quantify but help with basic understanding.

Result of higher emissions of nitrous oxide from the soil:

- Loss of fertility.
- Potentially lower nitrogen use efficiency.
- Poorer nitrogen management for crop production.

Result of lower emissions of nitrous oxide from the soil:

- Higher soil fertility.
- Potentially higher nitrogen use efficiency.
- Better nitrogen management for crop production.

2 Under what conditions in cropping are emissions most problematic?



Key points

- The labile fraction (microbially-active fraction) of the organic soil carbon determines both the fertility and potential risk of gaseous nitrogen losses from the soil.
- The organic soil carbon content is a key driver of the amount of mineral nitrogen available for plant growth.
- More organic carbon (labile) = more potential for nitrogen mineralisation = higher soil nitrate content in autumn (assuming adequate summer/autumn rainfall).
- Higher soil nitrate content + excessive soil water (waterlogging) = increased risk of losing nitrogen as gases such as nitrous oxide and dinitrogen
- Loss of nitrous oxide and dinitrogen gases to atmosphere = loss of fertility.

- Growers and advisers should be familiar with:

The organic matter content of their soil, or more particularly the carbon content of their soil.

The level of mineral nitrogen available in the soil when making decisions on nitrogen fertiliser applications.

- They should also keep in mind that:

Persistent waterlogging as a result of poor drainage may decrease plant-available N.

Parts of the rotation that restore or build up fertility such as pasture/legume phase are themselves at higher risk of nitrogen losses if soil conditions are suboptimal for drainage under wet conditions.

Higher soil mineral nitrogen in the soil accumulated through a pasture/legume rotation needs to be accounted for when planning nitrogen fertiliser strategies.

High organic matter and high water content in the soil

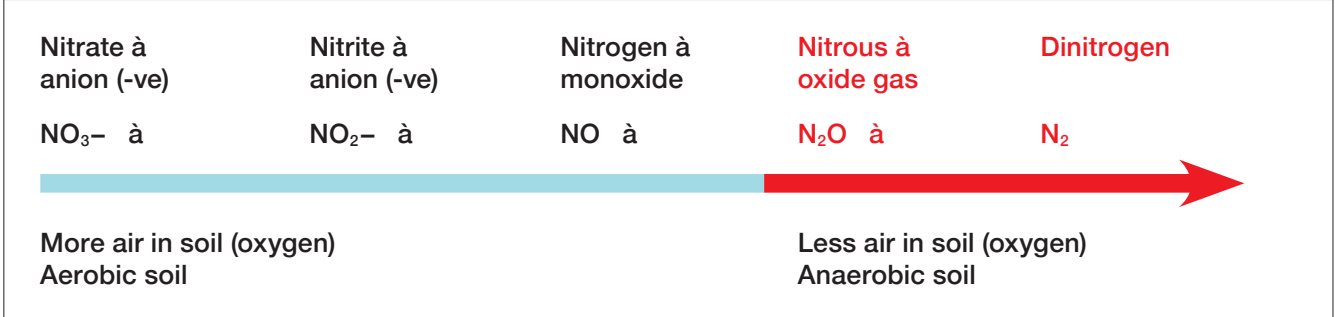
Gaseous losses of nitrous oxide and dinitrogen represent a loss of soil fertility. Nitrogen mineralised from soil organic matter and applied nitrogenous fertilisers can both be lost as nitrous oxide and dinitrogen gases. These gases are a by-product of soil microbial respiration under low oxygen/waterlogged conditions. This soil process is termed denitrification.

Normally soil microbes use oxygen for respiration, breathing out CO₂, but if the soil is extremely wet and oxygen levels become depleted, a group of microbes called the 'denitrifying bacteria' switch to using nitrate as their oxygen source instead. The denitrification process occurs when soil conditions move from being aerobic to anaerobic and there is a higher percentage of water-filled pore space.



Chambers used to capture nitrous oxide emissions in the project.

Denitrification process – results in loss of soil fertility



What is Soil Organic Matter (SOM), organic nitrogen (ON) and organic carbon (OC), labile carbon and plant available soil mineral nitrogen (nitrate and ammonium)?



Soil organic matter is comprised of a number of nutrients, present within the decomposing plant residue, with the top two most common elements being carbon (C) and nitrogen (N). Plant residues are considered to be part of soil organic matter when the origin of the material is no longer discernible. At this stage, the entity known as soil organic matter has a relatively stable ratio of carbon to nitrogen (C:N ratio), of 10:1. This means that for every unit of nitrogen, there is 10 units of carbon. Other nutrients such as phosphorus and sulphur are also present in their own stable ratio. This stability means that estimates of soil organic matter, and nutrients (including nitrogen) within the soil organic matter, can be determined from measurements of soil carbon; a simple, cheap test that is routinely done in soil analysis.

Soil carbon is called 'organic carbon' if it is primarily derived from plant residues. Inorganic carbon is primarily present in the form calcium carbonate, or free lime. Although the soil is composed of large amounts of **organic carbon and nitrogen** these compounds cannot be used by plants as a source of nutrition. The reason for this is that nutrients are bound up in complex carbon-based structures, or forms. A nutrient is in an 'organic form' when it is bound to carbon (e.g. **organic nitrogen**). As these structures are decomposed/ broken down by soil microbes, the nutrients within them are slowly released, or 'mineralised' from the carbon-structure, into forms that plants can access (e.g. Mineral N). Only a small proportion of the total soil N is in the form of 'mineral N', which is comprised of nitrate and ammonium (a precursor to nitrate). This process is termed nitrogen mineralisation.

Labile carbon is the fraction of organic carbon in soil organic matter that can be broken down relatively quickly by microbes (or mineralised) to provide plant available mineral nitrogen. Labile carbon is the major food source for soil microbes and is associated with soils that can mineralise large amounts of plant-available nitrogen in the form of nitrate and ammonium.

Rotation

The vast majority of dryland cropping soils in Australia, particularly in the lower rainfall environments, are not particularly rich in labile sources of carbon as the residues from cereal crops are high in structural lignin and hemicellulose-type compounds which are only broken down slowly by soil microbes under water-limited conditions. In addition, the frequency of water logging in these environments is far less frequent than in higher rainfall zones or irrigated crops. As a consequence, dryland cropping emissions are generally regarded as being lower than those from other farming systems. In this project, soil carbon (total C %) was measured under both legume and canola trial sites prior to seeding to a depth of 30 cm, with total C ranging from 0.9 – 2.3% at the Hart site in South Australia from 1.0 – 1.7% and at Yarrowonga in NE Victoria. With these soil carbon levels, N₂O emissions from fertiliser applications across three seasons of the project were slightly elevated compared to the unfertilised control. In some seasons, where high soil water content and waterlogging was an issue, N₂O emissions were increased above background level and cumulative values were at the higher end of those reported from dryland farming (>2 kg N₂O-N/ha/season).

Where carbon content of the soil has been increased by virtue of a mixed rotation and the use of a pasture phase, waterlogging can seriously elevate the nitrous oxide levels (up to 8 kg N₂O-N/ha/season). So moving from the grass/legume phase to the cropping phase of the rotation can result in the release of large quantities of plant available nitrogen, particularly on farms with higher rainfall. Whilst the pasture phase is of benefit to the whole cropping rotation, it represents the potential high risk of nitrogen being lost (in gas form) if nitrogen fertiliser management does not take account of this large soil mineral nitrogen reserve, or if the soil becomes waterlogged in the period of moving from the legume-dominant pasture phase to crop.

The important aspects of this understanding is recognising where there is greater potential for higher nitrogen losses and then to take account of nitrogen in the soil when managing fertiliser application to these crops. i.e. matching nitrogen supply to nitrogen demand. An important starting point for managing crops with nitrogen is recognising the link with soil organic carbon content.

Drainage

Whilst soil properties and condition such as clay content, texture and degree of compaction clearly have a part to play in the severity of waterlogging, this work has indicated the importance of drainage in terms of protecting soil fertility. Crops suffering transient waterlogging (recorded in project trials) benefited from nitrogen availability prior to those waterlogging events, but clearly, where waterlogging is an ongoing issue, fertility will not be maintained and the economics of applying fertiliser will be poor.

Fertiliser type

Nitrate fertilisers (such as ammonium nitrate) are associated with quick plant uptake but they are also more vulnerable to higher nitrous oxide losses if crop is under waterlogged conditions at application, than urea based fertilisers. Therefore, it is important to avoid using large amounts of nitrate fertiliser under anaerobic soil conditions.



Fertiliser types used in the project AOTGR2-0015.



Conditions at the 2016 Yarrowonga site resulting reduced crop establishment and the highest nitrogen losses in the project over the three year period at this site. Photos taken from May - August, 2016.

3 Nitrogen management in wheat

Key points

- Taking account of available soil nitrogen reserves prior to the main applications of nitrogen (N) fertiliser in wheat is a key measure to improve nitrogen fertiliser management, N efficiency and avoiding losses to the atmosphere.
- Recognise that legume crops in the rotation typically leave 25-35 kg N/ha additional nitrogen in soil after harvest compared to cereal crops, and will mineralise more N in-crop.
- Whilst nitrogen needs to be supplied to growing wheat crops throughout the growing season, it is important to recognise that only 20-30% of a wheat crop's needs are required prior to stem elongation.
- Targeting the majority of nitrogen to the wheat crop just prior to early stem elongation is the best way of matching N supply to crop demand.
- Predictive models such as Yield Prophet® can more accurately determine yield potential and therefore the N fertiliser requirement.
- Seasonal climate forecasts are also more accurate later in the season i.e. July-August for determining yield potential and therefore calculating the correct amount of nitrogen fertiliser to apply.
- Nitrous oxide emissions under dryland cropping systems are generally low and may not benefit from the use of nitrification inhibitors.
- Cropping systems in higher rainfall zones, tropical climates and with higher nitrogen requirements are more suited to the use of nitrification inhibitors.

Matching N supply to crop demand and incorporating seasonal forecasts is an effective management strategy to minimise nitrogen (N) losses. In the majority of situations, these general principles provide a framework that generates higher nitrogen use efficiency and optimises the yield and economic return from fertiliser application. An effective strategy for minimising nitrogen losses and optimising yield will be based on:

- Right Product.
- Right Rate.
- Right Timing.
- Right Placement.

However, the project also identified that this strategy doesn't always work from a yield perspective, especially in seasons when a proportion of early nitrogen is required at sowing to get the crop through transient water-logged conditions, high stubble loads or low soil residual nitrogen. Where applied, pre-sowing nitrogen dose should not be excessive and should reflect the development stage of the wheat crop. In addition, for some growers, in-season nitrogen spreading poses a logistical problem in terms of time required to cover larger farm sizes and lack of optimal soil moisture for spreading.

Knowing how much nitrogen is available from the soil

While mineral nitrogen is produced from organic nitrogen throughout the year, there are peaks in its production from autumn to spring, depending on when soil conditions are most favourable for nitrogen mineralisation (warm soil, adequate soil moisture). There is a mid-year low in soil mineral N production, as soil microbial activity slows down when soil temperatures decrease in winter. This period will be longer in cooler and wetter environments. In our current cropping systems, sowing in early May exploits the greater availability of soil nitrogen at the autumn peak of nitrogen mineralisation.

Knowing how much plant available mineral nitrogen is in the soil makes it easier to target appropriate nitrogen fertiliser rates and timing for a given grain yield and protein target. Paddocks with high pre-seeding soil mineral nitrogen levels or an oversupply of fertiliser can produce higher N losses (e.g. N₂O emissions). For example Table 1 highlights the range of soil N values reported from twelve years of sampling, ranging from 10 – 200 kg N/ha. This is a large range and using the incorrect value in your nitrogen budget can have a significant impact on the fertiliser nitrogen requirement for your crop (that is, under or over supply of nitrogen).

It is common to measure for plant available soil mineral nitrogen prior to seeding by soil sampling to a depth of 60 cm and measuring nitrate and ammonium concentrations. In-season soil nitrogen testing at GS30-31 (first node formation) is also becoming more popular. Delaying soil sampling offers greater accuracy in nitrogen budgeting as the quantity of available soil nitrogen is known at the time of peak crop demand.

Influence of legume crops on plant available soil nitrogen

Legume crops such as field peas, faba beans and lentils generally leave higher residual levels of both plant available mineral nitrogen (due to atmospheric nitrogen fixation) and more organic nitrogen in the roots and residues. The microbial breakdown of legume residues results in the release of higher levels of soil mineral nitrogen than cereals since the ratio carbon to nitrogen in the residue is much lower than cereal straw. The expectation is that this residual legume nitrogen will be slowly released in-season and therefore the following crop will require less nitrogen fertiliser compared to cereal or canola stubbles.

Accurate measurement of these reserves allows nitrogen fertiliser applications to be reduced relative to other rotation positions, leading to better nitrogen use efficiency. For example, a large dataset of pre-season measures of soil mineral nitrogen collected from farmer paddocks in South Australia suggested that, on average, concentrations of soil mineral nitrogen after legumes can be expected to be 25-35 kg N/ha (equivalent to 55-75 kg urea/ha) higher than following cereals (Table 1). Thus, growing legumes has the potential to save considerable amounts of nitrogen fertiliser and to reduce N₂O emissions in subsequent cereal crops which has been demonstrated in previous studies (Mielenz et al. 2016). In the absence of a soil test, available soil nitrogen from legume stubble can be estimated as approximately 18 kg/ha N per tonne of legume grain harvested according to a recent research study (Peoples et al 2017).

It is important to note there are potential disadvantages to legume crops leaving higher residual soil nitrogen levels from an N₂O loss perspective. Higher available soil nitrogen over summer fallow may increase the potential for N₂O compared to cereal stubbles in seasons with high summer rainfall. Also, if the soil nitrogen level and mineralisation potential is underestimated in the nitrogen fertiliser budget, there is the potential to over-fertilise and increase the chance of nitrogen losses via N₂O.

Table 1. Examples of autumn measures of concentrations of plant available soil mineral nitrogen (0-60 cm) following cereals or break crops from commercial cropping paddocks located on the Yorke Peninsula, the Mid-North and Upper North of South Australia between 2002-2014 (adapted from Peoples et al. 2015).

Paddock use in the previous year	Number of paddocks sampled	Soil mineral N	
		Measured range (kg N/ha)	Average (kg N/ha)
Wheat	847	8 - 200	67
Barley	267	9 - 203	56
Faba bean	99	36 - 187	97
Field pea	110	43 - 158	90
Lentil	248	26 - 245	87

Matching N supply with N demand in the crop

As long as roots are active and the crop is growing, plants are able to take up nitrogen at any time during the growing season. However, the effect of nitrogen application on grain yield and grain protein varies according to the time of application. Typically for a May-sown wheat crop in southern Australia 20-30% of the total N may be taken up by the start of stem elongation. The nitrogen taken up at this time is not only helping to build the yield potential of the crop but is also providing the N reserves for grain protein. Most of the nitrogen present in the grain as protein is derived from nitrogen remobilised from the leaves and other green tissues during grain filling. By flowering, about 80% of the total crop nitrogen has accumulated, but this can exceed 90% under dry spring conditions.

Adopting canopy management principles and avoiding excessively bulky vegetative crops may enable us to better match nitrogen rate and timing with yield potential as defined by the water available to the crop. While grain yield advantages aren't often measured from delayed nitrogen applications, the advantages of nitrogen applied at early stem elongation compared to all upfront include:

Reduced risk of losses through applying nitrogen fertiliser when crop needs it

In seasons where soil moisture levels give greater confidence of a nitrogen response, higher nitrogen rates can be employed in the spring without creating overly thick crop canopies that are prone to lodging. In general, delayed nitrogen application can improve nitrogen use efficiency and minimise N₂O emissions. The risk of losing nitrogen via N₂O (or leaching) is greater with pre-winter fertilisation since the root systems are less developed and the crop demand for nitrogen is lower compared with early spring.

Better nitrogen use efficiency and quality of grain

Nitrogen applications can be delayed until the end of tillering to the start of stem elongation (GS30-31) without a significant effect on yield. However, the ability to exploit delayed nitrogen applications depends on the availability of soil moisture and the frequency of rainfall when the nitrogen is applied. In some cases, there may be a lower response from a delayed application of nitrogen compared to nitrogen applied at sowing.

Better matching nitrogen with crop demand and soil water availability

Crops top-dressed at early stem elongation are better matched to soil moisture levels. For example, as seen in section 2 at Yarrowonga, severe water logging early in the season often resulted in higher N₂O emissions from upfront nitrogen applications. Where nitrogen was delayed and guided by the seasonal forecast, nitrogen use efficiency was greater as observed through higher protein levels.

Use of predictive models and other seasonal forecasts

Decisions on the need for nitrogen fertiliser can be made with better knowledge of the crop's yield potential in July-early August (GS30) than in May and June. Predictive models such as Yield Prophet® can more accurately determine yield potential and therefore the nitrogen fertiliser requirement. Similarly, seasonal climate forecasts are also more accurate later in the season i.e. July-August.

Use of nitrification inhibitors

Nitrification inhibitors (or enhanced efficiency fertilisers) can be used to control the rate of fertiliser nitrogen release or nitrogen availability compared to traditional fertilisers such as urea. The effect of nitrification inhibitors on crop production and N₂O emissions has been shown to strongly depend on site-specific conditions, such as soil texture, rainfall and temperature.

One of the more common nitrification inhibitors evaluated in Australia is Entec® Urea. Entec contains the compound 3,4 dimethylpyrazole phosphate (DMPP) which can be added to granular fertilisers. In dryland cropping systems such as Hart and Yarrowonga, the use of DMPP nitrification inhibitor did not incur a yield penalty, but did not improve grain yield or quality compared to the equivalent rate of nitrogen applied as urea. This was not surprising at Hart, as this region does not experience prolonged periods of waterlogging where DMPP should work. At Yarrowonga however, there were long periods of water logging in 2014 and 2016, but grain yield or quality (including total N uptake) was not improved.

In one season of this study, N₂O losses from DMPP were measured at Yarrowonga (Table 2). Overall only one out of six fertiliser nitrogen application rates/timings significantly increased N₂O emissions compared to the control. At Yarrowonga DMPP was applied at GS31 with no effect on cumulative N₂O emissions. However, if the DMPP treatment was incorporated by sowing (IBS), the potential for this inhibitor to reduce emissions during the peak period water logging period (June-August) may have resulted in a significant reduction. There was a trend for reduced emissions when nitrogen was applied in this fertiliser form compared to urea controls.

Inconsistent results in dryland farming systems indicates that based on productivity, the increased cost of purchasing fertiliser with a nitrification inhibitor is not cost effective for a farmer. As discussed in section 2, dryland cropping systems are low N₂O emitters and therefore the use of nitrification inhibitors are less practical. Cropping systems in higher rainfall zones, tropical climates and with higher nitrogen requirements (e.g. sugar cane) are environments where nitrification inhibitors currently have a clearer fit.

Table 2. Cumulative N₂O emissions (g N₂O-N/ha/season) for nil, 80 kg N/ha applied IBS or GS31 for wheat following a legume or canola at Yarrowonga, VIC 2016.

Treatment	g N ₂ O-N/ha/season	
	Canola	Field bean
Nil	1779	809b
80 kg/ha IBS	2443	2738a
80 kg/ha GS31	2556	2052ab
80 kg @ GS31 + DMPP	1872	1135b
LSD (P≤0.05)	ns	1262

4 Using new technologies to visualise crop nitrogen demand



Key points

- Crop sensor technology, such as Greenseeker®, quantifies differences in crop canopy greenness (chlorophyll content) and crop canopy ground cover. Normalised difference vegetation index (NDVI) is the most commonly reported measurement from these sensors.
- N Rich reference strips allow growers and advisers to better visualise the potential nitrogen supply from the soil and crop sensors such as Greenseeker® allow differences to be quantified objectively.
- In the project Real Time Tactical (RTT) treatments were set up based on comparing N Rich strips with the unfertilised crop.
- The RTT treatment used the wheat crop itself to display nitrogen responsiveness and for nitrogen fertiliser application to be tailored accordingly.
- RTT treatments typically achieved yields similar to the high nitrogen rate (80 kg N/ha), but at a lower nitrogen rate, resulting in high Nitrogen Use Efficiency (NUE) and economic performance. This was equivalent to a 25% and 60% reduction in fertiliser nitrogen required for wheat following canola and legume, respectively.
- Achieving high NUE is expected to achieve better emissions outcomes, with more nitrogen used by the crop and less nitrogen available for loss. This represents a win-win, where the N strategy optimises both economic and emissions outcomes.
- Inaccuracy in nitrogen rate calculation occurs when the relationship between grain yield Response Index (RI) and in season NDVI RI does not fit the 1:1 relationship. This occurred at Hart in 2014.
- Improvement in the RTT approach could be achieved by understanding what conditions cause this relationship to deviate from a 1:1 relationship.
- RTT treatment allows continued monitoring of crop and season and adjustment of nitrogen input post GS31.
- RTT treatments are based on post emergent N application. Therefore it has limited fit where nitrogen is applied up front at seeding.

Using crop sensors to “visualise” inherent fertility and nitrogen supply to the crop

Crop sensor technology such as Greenseeker® measures the combined effects of chlorophyll concentration (green colour) and canopy biomass through indices such as the normalised difference vegetation index (NDVI). This technology enables differences in the crop canopy to be measured quickly and objectively. Differences in soil nitrogen availability can result in crop canopies that differ in chlorophyll concentration and total canopy biomass. Given suitable growing conditions (i.e. no other major constraints) lower nitrogen availability results in wheat crops that have lower biomass and lower chlorophyll content, and as a consequence lower NDVI values. Conversely, higher values are generally indicative of higher nitrogen supply to the crop canopy. The example depicted in Figure 1 illustrates the appearance of two wheat crops compared at the same growth stage with differing nitrogen supplies and as a consequence differing NDVI values from Greenseeker®.

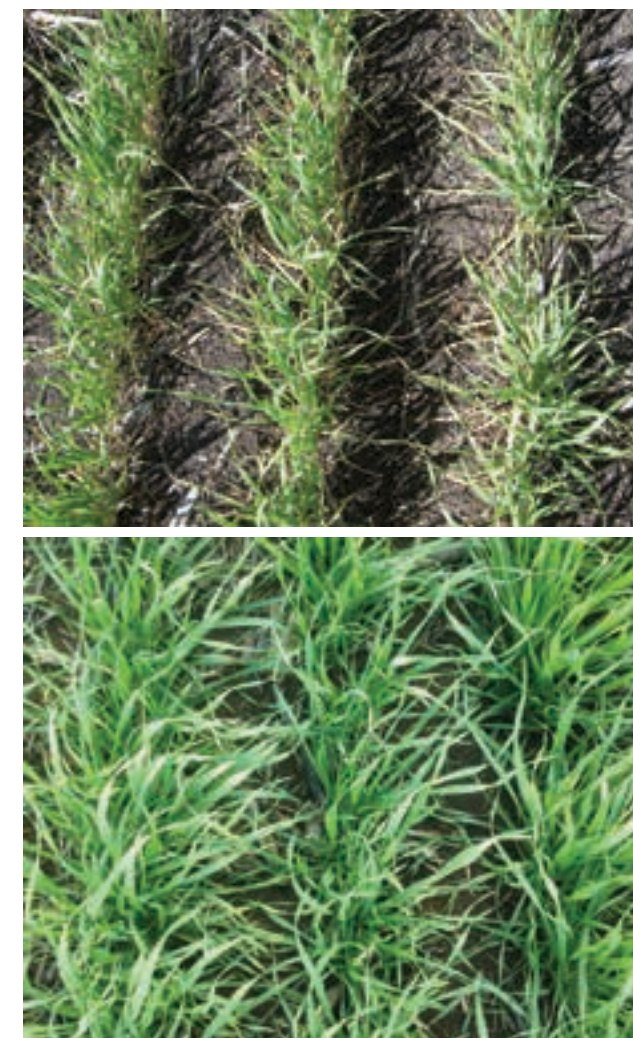


Figure 1. The wheat crop grown with a low soil nitrogen available at planting (top photo) gave a NDVI measurement of 0.50 whilst the wheat with greater nitrogen supply gave a reading of NDVI 0.69 (bottom photo).

Measuring crop reflectance with a Greenseeker®

The hand held Greenseeker® measures reflectance from the crop canopy at particular wavelengths of light, principally the red (656 nm) and near infra-red (774 nm) wave bands. These wavebands are important in relation to crop health, red light is absorbed by chlorophyll for photosynthesis, whereas near infra-red light is reflected from plant biomass with good cell structure. Therefore red light reflectance declines with increasing chlorophyll and near-infrared reflectance increases in response to increasing biomass. Whilst the human eye can be trained to distinguish between thick and thin crop canopies and varying levels of green, the Greenseeker is able to quantify objectively differences in crop canopy size and greenness. Since light reflected from the crop diminishes with distance from the crop, reflectance values from the specific wavelengths are used in ratios so that any difference in distance from the target is nullified, though the sensors must still operate within the height range of the sensors light source. These reflectance values from different wavelengths can be used in a plethora of vegetative indices ratios, the most common of which is NDVI (Normalised Difference Vegetative Index).

In the project the Greenseeker was used to demonstrate whether we could better measure and manage crop nitrogen status in the demonstration trials. In order to do this nitrogen (N) rich reference strips were set up with high rates of nitrogen fertiliser applied to the crop at sowing. Comparison of the N-rich strip with the surrounding crop the following spring allows the diagnosis of whether the surrounding crop will be responsive to nitrogen fertiliser application, and if so the difference in canopy growth can be used to gauge the size of the nitrogen fertiliser response. Where no N response is observed between the crop and N-rich strip it indicates that nitrogen supply has been sufficient to maximise growth and other resources are more limiting than nitrogen. The use of crop sensor technology can be used in this situation to quantify the difference between the crop and the N-rich reference strip. The comparison of the two can then be used to calculate a response index (RI). The higher the Response Index RI in the spring at the start of the stem elongation (period of maximum nitrogen uptake) the greater the likely response to nitrogen fertiliser applied.



Handheld Greenseeker® for measuring assessing crop canopy reflectance in the Red and Near Infra-Red parts of the spectrum.

How do different levels of fertility influence the visual appearance of the wheat crop canopy and how can this assist us estimating nitrogen supply?

The pictures below illustrate how N-rich reference strips can be set up in a wheat crop usually at establishment (typically with 100-200 kg N/ha applied in small trial plot size areas) and then during early spring (start of stem elongation - Zadoks GS30-32) can be used to assess the inherent nitrogen supply of the paddock by comparing appearance to the surrounding crop (which received no nitrogen at planting). If there is little difference between the surrounding crop and the N Rich strips then it reveals that the paddock may have good inherent fertility or that nitrogen at that stage is not the limiting factor to growth.

Differences in inherent paddock fertility and nitrogen supply to the wheat crop and its influence on visual crop appearance and NDVI Response Index from N Rich strips versus unfertilised crop.

	High fertility (High N availability) No visual difference	Intermediate fertility Some visual difference	Low fertility (Low N availability) Strong visual difference
N Rich			
	NDVI 0.84 High nitrogen Status	NDVI 0.84 High nitrogen Status	NDVI 0.73 High nitrogen status
Crop with no N			
	NDVI 0.83 – No nitrogen applied NDVI Response index = 1.01	NDVI 0.74 No nitrogen applied NDVI Response index = 1.14	NDVI 0.50 No nitrogen applied NDVI Response index = 1.46

Differences in inherent paddock fertility and nitrogen supply to the wheat crop and its influence visual crop appearance and NDVI Response Index from N Rich strips versus unfertilised crop.

Project case study

N-rich strips are very effective ways of visualising nitrogen supply from the soil using the wheat plant itself as the soil test for nitrogen available to the crop. Whilst there is good general value in using N- rich strips for characterising large soil nitrogen reserves it is more complicated to use the N-rich strips to calculate the exact amount of nitrogen that needs to be applied. The following section of this guide has been put forward as a project case study and covers the results of field trials carried out only in this project (AOTGR2-0015). It is not a recommendation but a simple report on what was achieved using the crop sensor as a tool to better assess soil nitrogen supply. A single treatment was set up in all project trials to look at the nitrogen demand in wheat following canola and legumes using crop sensor technology to calculate how much nitrogen fertiliser should be applied. This treatment was referred to as the Real Time Tactical management treatment or RTT treatment, since it used the greenness and density of the crop canopy in early spring represented by the Greenseeker® NDVI to determine the nitrogen application rates to be applied to the crop.

In season response to nitrogen at the start of stem elongation using Response Index (RI) provides some insights to the likely grain yield response to nitrogen at harvest time. However, the relationship between in season canopy response and final grain yield response is still dependent on interactions with climatic and soil water conditions. In this study, the relationship between in season response (Response Index) and grain yield response was often close to 1:1 (Figure 2). However, there were examples in the project

where this relationship did not hold. For example, the grain yield response to nitrogen at Hart in 2014 was far more responsive than indicated by the in season growth response (Figure 2) taken at the start of stem elongation (GS30-32). In the project trials when calculating a nitrogen rate from the in season NDVI RI a 1:1 relationship with grain yield RI was assumed.

Nitrogen rate was calculated by using the in season NDVI RI with an estimate of the water limited yield potential. Water limited yield potential was estimated either using Yield Prophet or French & Schultz models in this project. Dividing the water limited yield potential by in season NDVI RI provides an estimate of nitrogen limited yield potential. Based on the yield deficit due to nitrogen deficiency a nitrogen rate can be calculated with protein targets and nitrogen use efficiency (NUE) recovery that are assumed and held constant.

As nitrogen rate increases the efficiency at which nitrogen drives increased production declines. The marginal rate of return for each additional kg N applied also declines. In these trials the yield response to nitrogen was 13.3 kg grain/kg N for nitrogen application up to 40 kg/ha at GS31 (Figure 3). When nitrogen rate is increased to 80 kg/ha N the additional nitrogen above 40 kg/ha increased yield at 7.3 kg grain/kg N (Figure 3). For a nitrogen fertiliser cost of \$1.08/kg N (\$500/t urea) and wheat price of \$270/t a yield response of 4 kg grain/kg N is required to break even. This is ignoring any protein responses to nitrogen application. On average the nitrogen rate and application timing calculated in the real time

tactical (RTT) treatment generated the highest nitrogen use efficiency (NUE), the equal highest partial gross margin and highest return on investment (ROI) (Table 1). However, if a \$15/t premium was paid for H2 grade (protein > 11.5%) wheat over APW grade (protein 10.5-11.5%), then the partial gross margin of the 80 kg N/ha treatment applied at GS31 increases to \$211/ha and ROI increases to 244%, making its economic performance more competitive with RTT treatment.

The RTT treatment was able to achieve these high NUE and ROI results at lower nitrogen rates than the high N treatments. This equated to a 25% and 60% reduction in fertiliser nitrogen required for wheat following canola and legume, respectively. Using lower nitrogen rates would suggest that lower emissions are also likely from this treatment. This represents a potential win-win where the RTT treatment optimises both economic and emissions outcomes.

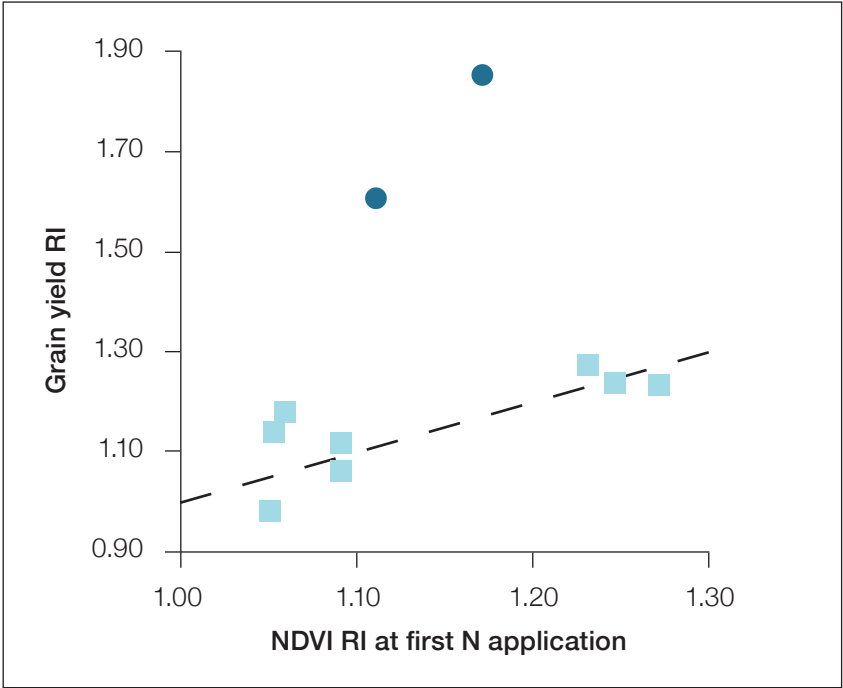


Figure 2. Relationship between in season NDVI RI and final grain yield response index for Hart 2014, 2015 and 2016 and Yarrowonga 2014 and 2015, ex canola and ex legume. Blue dots are Hart 2014, ex canola and ex lentils. Black dashed line is 1:1 relationship.

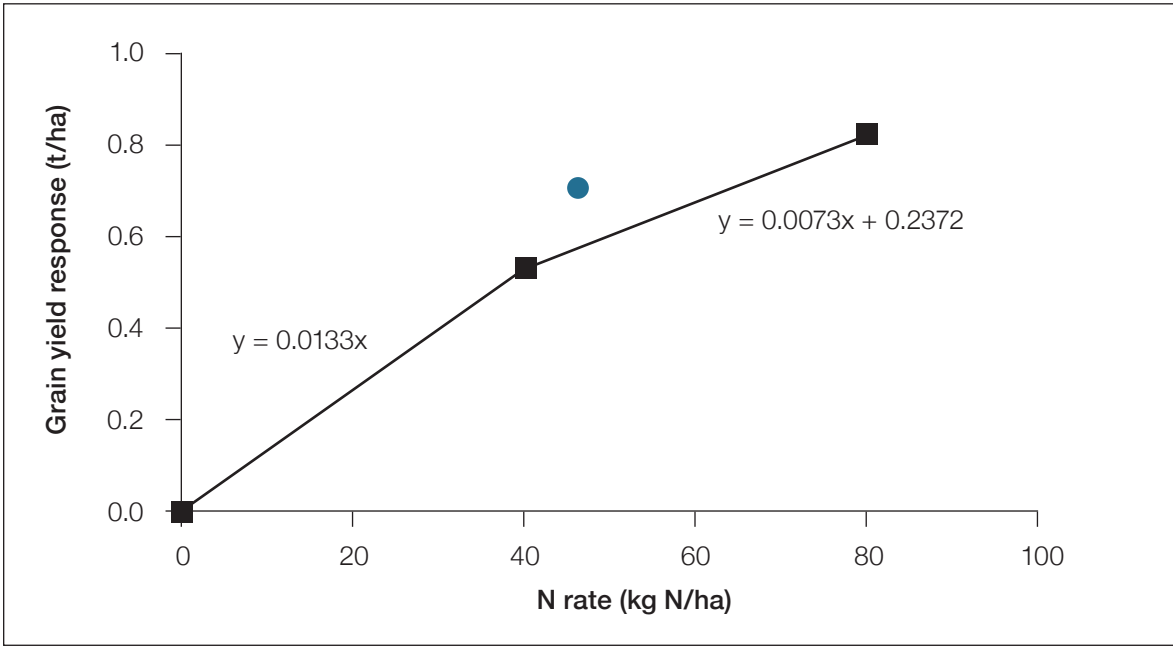


Figure 3. Average grain yield response across all sites to post emergent nitrogen application applied as urea (excluding Yarrowonga, 2016). RTT treatment blue dot above the line.

Table 3. Average treatment response from all site years (excluding Yarrowonga, 2016). Calculations based on urea price of \$500/t and wheat price of \$270/t.

Treatment	N applicaton (kg N/ha)	Grain yield (t/ha)	Protein (%)	Grain yield response (t/ha)	NUE (kg grain/kg N)	Partial gross margin (\$/ha)	Return on investment (%)	NUE (% recovery)
Nil N	0	4.18	9.2	0.00				
40kg N/ha @ GS31	40	4.71	10.4	0.53	13.3	100	231%	45.89
80kg N/ha @ GS31	80	5.01	11.9	0.82	10.3	136	157%	45.92
80kg N/ha @ sowing	80	5.02	11.1	0.84	10.5	140	162%	37.60
80kg N/ha @ 31 with nitrification inhib.	80	4.86	11.4	0.67	8.4	95	110%	37.08
Real time tactical treatment	46	4.89	10.7	0.71	15.2	140	281%	51.50

5

References and Acknowledgements

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