## AUGUST 2013 **PLANT-AVAILABLE NITROGEN** FACT SHEET

## SOUTHERN REGION

# MAXIMISING NITROGEN AVAILABILITY TO CROPS

Nitrogen is vital to crop growth but it is mostly present in soil in an organic form that plants cannot take up. When it exists in an inorganic form, it can be lost from the soil to the atmosphere or leached below the root zone.

Nitrogen is present in the soil in two major forms: inorganic, as mineral nitrogen, or organic, such as soil organic matter, soil microorganisms and plant residues.

Organic nitrogen typically accounts for more than 90 per cent of all nitrogen in soil but usually is not directly available to plants. It must first be converted to either soluble organic compounds, such as amino acids, or inorganic forms, such as ammonium  $(NH_4^+)$  or nitrate  $(NO_3^-)$ , before it can be used by plants.

These conversion processes are carried out by microorganisms as they decompose soil organic matter or residues from previously grown crops and pastures.

During soil organic matter and crop residue decomposition, nitrogen can be removed (immobilised) from plant available forms or released (solubilised or mineralised) into a plant available form. The ratio of carbon to nitrogen in residues is a deciding factor whether nitrogen is removed or released in the soil.

### Removal of N from soil

Nitrogen is removed from soil in production of grain, hay or meat. But losses of plantavailable nitrogen occur by:

- Immobilisation
- Leaching
- Denitrification
- Volatilisation

## **KEY POINTS**

- Organic nitrogen must be solubilised or converted into an inorganic form to be available to plants.
- Plant-available N forms include nitrate, ammonium and some soluble organic compounds, all of which can be lost from the soil if they are not taken up by plants.
- Peak nitrogen demand of crops can be four to five times the rate of nitrogen mineralisation.
- Increases in soil organic matter ensures there is a larger pool of nitrogen to mineralise.
- A 'bulge' of mineral nitrogen can be held at 80 centimetres down the soil profile.
- In 10 years' time, paddocks under continuous cropping will require 40 per cent more nitrogen fertiliser.



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#### Immobilisation

Soluble and mineral nitrogen can be immobilised, or 'tied up', in soil by microorganisms, making it unavailable to plants. It occurs when available nitrogen is immobilised in soil as plant residues with high ratios of carbon to nitrogen are broken down. The microorganisms need more nitrogen to digest the material than is present in the residue.

In acidic soils (pH less than 6.0), microbes immobilise ammonium by preference while in alkaline soils (pH greater than 7.0) nitrate is immobilised before ammonium.

#### How to minimise it

Stubble incorporated into soil can immobilise nitrogen but the extent of immobilisation may be reduced if straw is left on the soil's surface. Immobilisation is increased if there is wet straw near soil nitrogen because as the straw is broken down, nitrogen is required to balance the carbon retained by soil microbes. If grain growers keep straw on the soil's surface rather than incorporating it, the risk of immobilisation will be reduced.

#### Leaching

Nitrogen can be lost from the root zone when it is leached following heavy rain and low evaporation. Leaching losses may be significant in coarse-textured (sandy) soils, in high rainfall areas or in all soils during prolonged periods of high rainfall.

In medium-textured soils, leaching losses are not large. For example, in a wet growing season at Wagga Wagga, where 100 millimetres of rain was received, there was only 4 kilograms per hectare of nitrate-N leached below the root zone.



Urea is at high risk of loss when soil becomes alkaline around a dissolving granule. Any ammonium formed is rapidly converted to ammonia gas, which volatilises and is blown away.

In sandy soils, with moisture, fallow and low evaporation, leaching rates are higher. Conversion of ammonium to nitrate, which is then leached, is also an important factor contributing to soil acidification.

A series of chemical reactions change urea to ammonium in a few days and then ammonium to nitrate, which can be easily leached from soil.

#### How to minimise it

Urease inhibitors slow the chemical reaction of urea to ammonium and nitrification inhibitors slow the conversion of ammonium to nitrate. But these are expensive and in many cases, are yet to be proven reliably profitable in Australia.

Banding urea or anhydrous ammonia in soil at least 30 centimetres apart in high concentrations – such as more than 500 parts per million in each band – will deactivate microbes that cause the reaction of urea to nitrate. This means fertiliser can be applied that provides a delayed release of nitrogen because of the inactive microorganisms.

In seasons where rainfall is significantly above-average, it can be difficult to avoid leaching. But by selecting the right time and putting the fertiliser in the right place, leaching losses can be minimised.

#### Denitrification

Denitrification is the conversion of soil nitrate in the soil to nitrogen gases by soil microbes, including nitrous oxide ( $N_2O$ ), nitric oxide (NO) and di-nitrogen ( $N_2$ ). The microbes which undertake this conversion need oxygen for metabolism, and under waterlogged conditions, (where oxygen is scarce), they obtain oxygen from the nitrate molecules which results in the production of these gaseous oxides and di-nitrogen gas.

Microbes require anaerobic and warm conditions for rapid activity. These conditions are not usually common in southern Australia but denitrification was widespread on flat land in southern NSW in autumn 2012, where waterlogging led to losses of about 80 kilograms per hectare of nitrogen from some soils. It occurs frequently in the Darling Downs, Queensland, where losses of 2kg/ha per day have been measured.

The level of soil total N is extremely sensitive to moisture. In lower rainfall areas, changes in total soil N are often equal to the N removed by crops. In wetter areas, denitrification means more soil N is lost than crops remove.

#### How to minimise it

Denitrification is prolific in waterlogged soils and if nitrogen is in the nitrate form in soils, it will be lost. Ensuring nitrogen stays in its urea or ammonium forms, in a similar way to methods to reduce leaching, can help avoid denitrification.

#### Volatilisation

Volatilisation is the loss of soil nitrogen from the soil or from fertiliser applied to soil surfaces. It is present in the soil in the form of ammonium, and is released into the atmosphere as ammonia gas (NH<sub>3</sub>). The amount of nitrogen lost depends on the soil's nitrogen content and whether environmental conditions are conducive to losses.

Factors influencing volatilisation include:

- Soil pH losses are greater in higher pH soils. For example, in calcareous soils and around dissolving urea granules where zones of high pH are created.
- Temperature the higher the temperature, the greater the potential for ammonia loss.
- Soil moisture wet soil dissolves fertiliser but does not move N into the soil.
- Calcium carbonate lime in the soil reacts directly with ammonium sulphate ((NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>) in some fertilisers, increasing loss.
- Soil clay content clay in soils adsorbs ammonium nitrogen (NH<sub>4</sub>-N), reducing potential for loss.
- Soil buffer capacity clays and organic matter in soil influence changes in soil pH.
- Biological activity ammonium is converted to nitrate which is safe from volatilisation; however, the nitrate created may be subject to loss by denitrification.
- Wind greater losses occur in windy conditions.
- Rain rain moves dissolved fertiliser into contact with soil clays, away from wind.
- Depth of fertiliser ammonia must be at the surface to volatilise while incorporation reduces loss.
- Fertiliser type only the ammonium form is lost. Urea converts to ammonium. Nitrate forms are not volatilised.



Crop peak nitrogen demand can be four to five times the rate of mineralisation. The yellowed-leaf signs of deficiencies in plants are easy to detect.

#### How to minimise it

Urea is at a high risk of being lost when the soil around the dissolving granules becomes alkaline. Any ammonium formed is rapidly converted to ammonia gas, which then volatilises and is blown away. Avoid top dressing urea on very alkaline-surface soils or onto ash, which is alkaline or onto dead leaves which contain urease. Using precision guidance to top-dress urea with direct delivery placing nitrogen (solids or liquids) between the rows can minimise ammonia volatilisation.

#### **Release of N into soil**

Mineralisation is one of the processes where soil organic matter is converted by microorganisms into forms of N that plants can use.

Soil organic matter consists of four main parts – plant residue, particulate organic matter, humus organic matter and resistant organic matter. These different forms of organic matter have different ratios of key nutrients – carbon, nitrogen, phosphorus and sulphur. Variations in these ratios can impact on the speed at which decomposition occurs, which alters the supply of nutrients from mineralisation.

Mineralisation is a continual process where plant available N is produced before and after seeding. The rate of mineralisation varies with soil temperature and water content and, depending on the soil type, it can vary with pH, the amount of organic matter and residues. Mineralisation is slower in acidic soils.

#### **Measuring mineralisation**

The amount of N mineralised between harvest and sowing of the next crop can

be measured by sampling soil before sowing. But after sowing, the amount of N mineralised is more difficult to measure because there is simultaneous mineralisation of nitrogen in the soil and uptake by the growing crop.

In mid spring - when crop growth is greatest - a plant's daily nitrogen demand is typically four to five times the rate of mineralisation. Peak mineralisation is 1kg/ ha/day for an average loam soil with 1 per cent organic carbon. It will be lower for a sandy loam soil. A fast-growing crop will need 4-5kg/ha/day of nitrogen.

In some crops, peak nitrogen demand occurs several weeks earlier than peak supply by mineralisation. This is thought to be because low temperatures early in the season limit mineralisation. Peak nitrogen mineralisation occurs when soils start to warm up in spring. The rate of mineralisation can vary between seasons.

#### More rapid mineralisation

Increasing soil organic matter with legume residues can achieve more rapid mineralisation. The rate of mineralisation in summer and autumn may be high so that legume residues are depleted prior to sowing. This means that in the following crop, the rate of mineralisation is the same or less than soil with no legume residues. Growers need to keep this in mind when budgeting fertiliser application rates.

Large amounts of soil mineral nitrogen at sowing are at risk of leaching from the topsoil to the subsoil, which can lead to surface acidification. It can also leach beyond the root zone of coarse-textured soils. Too much N applied early in the season (resulting in the crop producing too much bulk) can risk the crop haying-off if not enough moisture is received in spring.

#### **Growing N on-farm**

Legume crops and pastures convert atmospheric nitrogen ( $N_2$ ) into organic nitrogen in soil. Legumes that are well-nodulated will fix about 20kg of nitrogen per hectare per tonne of shoot dry matter.

For some legume crops, such as chickpeas and soybeans, a significant portion of this nitrogen may be removed in the harvested grain. For legume pastures, the majority is retained within the paddock.

#### Soil nutrient balance

The ratio of carbon to nitrogen (C:N) is the main factor determining whether nitrogen

will be mineralised (released into soil) or immobilised (removed from soil) during decomposition of crop residues.

All crop residues have a different C:N ratio. Plant material is about 40 per cent carbon. The average C:N ratio of soil organic matter is one unit of nitrogen to 12 units of carbon. Fallowing means that soil microorganisms use the carbon as their energy source and will tie-up nitrogen, which pushes the C:N ratio down to about 10:1. Carbon can be retained through stubble retention, which means the ratio may increase to 14:1.

Examples of C:N ratio includes:

- Cereal stubbles have a high C:N ratio of 50-150 grams of carbon per 1g of nitrogen.
- Lucerne residues have a medium
  C:N ratio of 20-25g of carbon per 1g of nitrogen.
- Sub-clover has a low C:N ratio of 15-20g of carbon per 1g of nitrogen.

#### Increasing organic matter

Management practices can change soil organic matter and alter the types of carbon and nitrogen present in soil. If grain growers increase organic matter in soil, then there will be more organic nitrogen that can be potentially made available to plants.

The breakdown of residues with a high C:N ratio can immobilise nitrogen and reduce the amount of plant-available nitrogen in soil, particularly if those residues are incorporated into soil. Low C:N ratio residues will mineralise nitrogen and increase plant-available nitrogen content.

Adding a pasture sequence to a rotation will help lower C:N ratios. Phosphorus and sulphur help maintain C:N ratios, which will increase nitrogen mineralisation.

The CSIRO, with support from the GRDC, is researching a cost-effective method for measuring soil carbon content and composition which may lead to improved predictions of N mineralisation during a growing season.

#### Deep soil N

Autumn sampling of mineral nitrogen in the top 60 centimetres of soil is a useful guide for N fertiliser at sowing. Deep soil sampling after sowing may be a useful guide for top-dressing but is not as reliable as measurements of shoot density or visual inspection of N fertiliser test strips.

While the sampling depth of 60cm is optimum for most paddocks, the results

need to be interpreted cautiously. Soil with no physical or chemical limitations, for example acidity, salinity or high boron content, will allow crops to grow roots down to about 1.5 metres and take up nitrate from the whole profile.

A poor pasture or late sown, badly diseased or failed crop will leave some nitrate in the soil because of poor uptake. After rain, this can leach into the subsoil and form a 'bulge' of nitrate, some of which is below the normal sampling depth of 60cm.

Unpublished CSIRO data from southern NSW shows about one-quarter of paddocks could have a nitrate bulge which plants can access but which soil tests to 60cm may not completely sample.

#### **Future N levels**

It is important that grain growers understand how to maximise nitrogen uptake by plants. CSIRO research shows that in 10 years' time, continuous cropping will require 40 per cent more fertiliser nitrogen just to keep up with current yields. This assumes the crop's demand is constant at 94kg/ha and takes up half each of the mineralised N and fertiliser N.

In 40 years' time, the rate of nitrogen application must double to maintain yields (refer Table 1). This is because continuous cropping is leading to an exponential decrease in soil total nitrogen and the absence of pasture nitrogen fixation in cropping systems.

#### **Tools for growers**

#### **Nitrogen calculators**

The GRDC has supported development by the CSIRO of yield and nitrogen estimation calculator for dryland cereals and canola:

- Generic Yield and N Calculator a general tool based on user inputs of growing season rainfall. Download it free at www.clw.csiro.au/products/ncalc/index.html
- Your Soil's Water Limited Potential Calculator an automated calculator that estimates water limited potential grain yields and N fertiliser needs for farms with rainfall less than 500 millimetres. Available at www.climatekelpie.com.au
- NBudget Calculator a simple-to-use calculator designed to help farmers and their advisers in Australia's northern grains region, but it does have application in the southern region. Available at www.grdc.com.au/GRDC-Booklet-Managing-Fertiliser-N

#### **Yield Prophet**

Yield Prophet is a crop monitoring and forecasting tool to manage seasonal variability, maximising profit in good years and cut costs in bad years. Developed by the CSIRO and BCG, based on the Agricultural Production Systems Simulator (APSIM), it generates yield probability forecasts including crop details, fertiliser and irrigation applications, paddock rainfall data, climate data, pre-sowing soil test, and soil classification. Available at www.yieldprophet.com.au

#### **CropMate**

CropMate is a web-based application that helps grain growers analyse climate and weather information to make planning and management decisions. It can be used to calculate seeding rates, compare prices of fertilisers, or work out which varieties will be most profitable for to plant, given the available climate and soil information. The free CropMate VarietyChooser app can be accessed through iTunes at http://cropmate.agriculture.nsw.gov.au/

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## GRDC PROJECT CODE

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# Table 1: N mineralisation and fertiliser N requirement (kg/ha) over the next 40 years

Year	N from requirement	Fertiliser N mineralisation
2013	108	80
2023	76	112
2033	54	134
2043	38	150
2053	27	161

This assumes: 1. Constant crop N demand of 94 kg/ha, the calculated average for Temora, NSW. 2. Half the mineralised N and half the fertiliser N is taken up by the crop. 3. Soil total N half-life is 20 years. 4. N mineralisation is proportional to soil total N.

#### **USEFUL RESOURCES**

#### 'More Profit From Nutrition'

Ground Cover supplement, March-April 2012, www.grdc.com.au/GCS97

#### 'Soil Biology Initiative'

Ground Cover supplement, January-February 2012, www.grdc.com.au/GCS96

#### Soil Quality,

www.soilquality.org.au

International Plant Nutrition Institute, http://anz.ipni.net/

Nitrogen volatilisation losses – how much N is lost, GRDC 2012 Update Paper, www.grdc.com.au/Updates

#### MORE INFORMATION

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