MARCH 2014

DENITRIFICATION FACT SHEET

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NORTHERN REGION

REDUCING POTENTIAL N LOSSES

Soil nitrate can be lost through denitrification, a process that can occur when soils are approaching saturation and become depleted in oxygen. Growers can reduce the potential for denitrification in wetter parts of paddocks with five techniques.

KEY POINTS

- Loss of soil nitrate via denitrification is usually minimal, unless soils are waterlogged.
- Denitrification, a naturally occurring process, happens when bacteria convert soil nitrate into nitrogen (N) gases that are lost from the soil. It occurs in soils nearing saturation because oxygen becomes increasingly limited.
- Bacteria need a supply of soil nitrate and readily available organic matter for denitrification to proceed. Denitrification rates are faster at hotter temperatures and in alkaline, rather than acidic, soils.
- Soil nitrate comes from mineralisation of soil organic matter, decomposition of crop residues (especially nitrogen-fixing legumes), and addition of N fertiliser.
- The source of the nitrate determines when denitrification losses may occur. For instance, in N-fertilised summer crops such as sorghum, losses can be large if heavy rains waterlog the soil during hot conditions soon after planting.
- The best way to tell how much nitrate remains in the soil profile after an extended wet period is to have it soil cored and tested for nitrate. Denitrification is extremely variable, so growers need to test wetter areas separately from drier ones.
- Limiting future denitrification losses is difficult. However, growers can reduce the potential for denitrification by using split applications of N fertiliser, enhanced-efficiency fertilisers, growing short-season ‘cover crops’, improving paddock drainage, or planting in raised planting beds.

PHOTO: MIKE BELL

January 2013 floods caused severe waterlogging, nearly submerging these manual chambers in a maturing sorghum crop at Kupunn, near Dalby.

Denitrification: bacteria convert soil nitrate to gases

Denitrification is a process where bacteria convert plant-available soil nitrate (NO_3^-) into nitrogen (N) gases that are lost from the soil.

In normal, aerated soils, bacteria break down organic matter in the presence of oxygen to produce carbon dioxide (CO_2), water and energy. But in very wet or waterlogged soils, oxygen is rapidly depleted, so bacteria use nitrate instead of oxygen for respiration.

Soil doesn’t have to be under water to have low oxygen availability. This can occur in any soil where internal drainage is restricted; for example, soil with a high clay content that drains slowly, or sandy soil over an impervious layer that impedes drainage.

It can be influenced by factors such as the amount of rain, duration of rain, how wet the soil profile was, and capacity for the soil to drain internally.

Denitrification produces several gases: nitric oxide (NO), nitrous oxide (N_2O), then di-nitrogen (N_2).

Di-nitrogen is the main form of N gas that is lost, but the proportion of the different gases produced depends on soil pH and water content.

Once in gas form, the N is no longer available to plants in the soil.

Note: Denitrification is not the same as the process of volatilisation, which is loss of soil N as ammonia gas from fertiliser applied to soil surfaces.

Is denitrification a problem in the north?

Growers have achieved higher crop yields through better moisture conservation, weed control and attention to soil fertility, especially soil N. Denitrification is just one part of the soil N story.

Soil N reserves across the northern region have been in decline for some time due to years of above-average yields, few legume crops in rotations, less N fertiliser application and declining soil organic matter levels.

Loss of N naturally occurs through removal of crop produce; soil erosion; and denitrification, leaching and volatilisation.

Record wet summers in recent years have increased the potential to lose N through the natural process of denitrification because of more widespread incidences of waterlogged soils.

Low soil N has the potential to continue to limit grain protein and yields.

Main influences: oxygen, organic matter, pH, temperature, nitrate

Denitrification is influenced by many factors:

- **Oxygen content** is primarily controlled by **soil moisture content**, which is in turn determined by the **soil texture** (for example, sand, loam or clay) and how quickly the soil **drains**.

  When more than 60–70 per cent of the pores in soil are filled with water, oxygen is rapidly depleted by respiring bacteria. This condition lasts longer in poorly drained soils. Water is not necessarily visible on the surface.

  Even after draining, clay soils can still have micro-sites that remain anaerobic compared to fully aerobic, lighter-textured sandy or loamy soils.
- **Organic matter**: Bacteria need a source of readily available organic matter, either from the soil itself or from the addition of plant or other organic materials.
- **Soil pH** affects both the rate and products of denitrification. It is slow in acidic soil, and rapid at alkaline pH. In acidic soils, more is lost as nitrous oxide; in alkaline soils, most is lost as di-nitrogen.
- **Temperature**: Denitrification occurs at all temperatures, but is slower in colder conditions and faster as it gets hotter. The rate increases exponentially between 15 °C and 30 °C, and peaks between 23 °C and 27 °C.
- **Nitrate concentration** needs to be sufficient for denitrification to proceed.

When and how much N is lost?

Growing a high-yielding crop requires a significant supply of plant-available N. For example, a wheat yield of five tonnes per hectare at 13 per cent protein requires 300 kilograms per hectare of available N in the soil at sowing.

The N required by the crop can come from mineralisation of soil organic matter, decomposition of crop residues (especially N-fixing legumes), and addition of N fertiliser.

Initially, ammonium is produced (or nitrate, in fertilisers such as urea ammonium nitrate). Ammonium is naturally converted to nitrate via the process of nitrification. Plants can take up both ammonium and nitrate.

The source of the nitrate determines when denitrification losses are most likely.

Mineralisation of **soil organic matter and crop residues** is greatest during the warm, moist conditions of a summer fallow. This produces nitrate in the soil early in summer that, under normal conditions, will reside in the soil until a subsequent crop is planted to use it.

Normal rainfall moves some of this nitrate lower down in the soil profile over time, but most is still accessible by the following crop as its roots develop. However, **if very wet or waterlogged conditions develop during the summer fallow period**, some of that nitrate can be lost via denitrification.

Trials at Tamworth measuring one of the denitrification gases, nitrous oxide, showed that significant denitrification occurred in summer after post-harvest mineralisation of N-rich crops such as chickpea and canola.

PHOTO: MIKE BELL

After sown to grass and legume pastures, this sorghum crop shows responses to soil N levels (Kingaroy).

PHOTO: DAVID LESTER

To avoid experiencing severe N deficiency, as in parts of this sorghum crop at Kingsthorpe, collect soil cores before planting to measure soil nitrate and adjust your fertiliser program.

When applying **N fertiliser**, the period of greatest denitrification risk is **between the nitrification of the fertiliser applied and later uptake by the plants**. For crops such as wheat, this can occur in winter.

This was seen in trials at Tamworth in 2010, where heavy rains soon after planting with side-banded urea led to denitrification over the following week.

For summer crops such as sorghum, losses can be large if heavy rains result in very wet soils occurring during hot conditions.

In January and February 2013, trials in NSW (Tamworth and Quirindi) and Queensland (Kingaroy and Kingsthorpe) showed significant losses of nitrous oxide from late 2012–sown crops that had had little early rain after sowing.

Agronomists estimate that, in 2013, northern region growers lost between 10 and 20 kilograms of N per hectare on average through denitrification due to flooding and waterlogging, although losses at individual sites could have been much higher. In normal years without extended rainfall periods and no waterlogging, loss of soil nitrate from aerated soils via denitrification is minimal.

A recent trial near Kingaroy (Queensland) found that none of the urea applied to a wheat crop in a dry season (winter 2011) was lost as gas, but 35 per cent of the fertiliser N applied to the following maize crop was lost via denitrification during a wet summer (2011–12).

Recent evidence indicates that denitrification may be removing N from deep in the soil near decaying roots, as well as from surface soil, but losses in deeper layers are usually limited by the smaller amounts of readily available organic matter there.

In trials near Tamworth (in wheat/sorghum crops) and at Kingaroy (in wheat/maize crops), denitrification was shown to occur within 48–72 hours of significant rainfall events. However, if temperatures are high, and nitrate and plant residue is present, denitrification can occur after 24 hours in very wet, heavy clay soil.

PHOTO: MIKE BELL

Losses can be large if heavy rains waterlog the soil during hot conditions, but getting into the field to measure these losses can be a challenge (Kupunn, January 2013).

Check for N loss with soil tests

A paddock that should have a significant amount of soil nitrate but has been exposed to a prolonged period of heavy rainfall has probably been affected to some degree by denitrification.

Because seasonal conditions may be significantly different from when fertiliser management rules of thumb were developed—for example, the dry decade in the early 2000s—there may be problems relying on rules of thumb or past history to determine fertiliser rates.

The best way to tell how much nitrate remains is to have it soil cored and tested for nitrate. The soil test should include the subsoil too, as flooding and heavy rains can also cause nitrate to leach down the profile.

If the nitrate is still within the top metre of soil, a crop should still be able to access this (if there are no subsoil constraints to root exploration).

Denitrification is extremely variable—even within paddocks—so growers need to test wetter areas separately from drier ones to understand the distribution of nitrate remaining in the soil.

Growers can compare measured soil nitrate levels with those predicted for the paddock using decision-support tools—the difference is a reasonable estimate of what may have been lost through denitrification.

Using this method, researchers found that denitrification was likely at three of six experimental sites in north-west NSW where fallows were very wet or flooded.

Losses were estimated at 60–80 kilograms of N per hectare. Losses of this size were also directly measured at the long-term Incitec Pivot Limited fertiliser trial site at Colonsay during the 2010–11 summer floods.

Although testing is possible two to three weeks after soils have dried out, or water has drained away, it is recommended to test as close to possible to when growers plan to apply N fertiliser, to check if additional N is required before planting.

Growers can also adjust their crop's N requirements to take reduced yield potential from prolonged waterlogging into account.

Growers can manage denitrification

Limiting future potential losses can be difficult, given the highly variable nature of extreme rainfall events and the strategy of accumulating soil moisture and mineral N during a fallow period between crop phases.

What's right for you will depend on the potential economic return of each solution.

Split application of N fertiliser is one method for reducing the pool of soil nitrate at risk of denitrification loss between a single initial dose of fertiliser and plant uptake.

This aims to improve the timing of N application to match crop N demand. A crop's initial demand for N during establishment is low, so the initial dose applied either pre-sowing or at sowing can be reduced, and the remainder applied later as the crop develops. In-crop applications can be made either as side-dress, top-dress, or foliar applications.

However, there are risks and uncertainties in these strategies, with success depending on in-season rainfall events and a good understanding of the pros and cons of high rates of foliar N application.

PHOTO: MIKE BELL

Periodic measurements of nitrous oxide emissions can be measured using manual chambers, as shown in this photo during a fallow after a sorghum crop.

There are a number of **enhanced-efficiency fertilisers** (EEFs) available that can minimise N loss via denitrification. Because soil ammonium is not subject to denitrification, products which contain a nitrification inhibitor with N fertiliser to delay conversion of ammonium to nitrate should reduce the risk of N loss.

These products have been shown to reduce gaseous N losses, but the infrequent and unpredictable nature of most heavy rainfall events makes the extra cost of inhibitor-coated products difficult to balance against possible N losses.

Growing **short-season cover crops** will avoid the accumulation of nitrate in the soil, but uses soil water that would be otherwise be stored for the next cash crop. This effect may be negated by improved fallow rainfall infiltration because of better ground cover generated by the sprayed-out cover crop.

You can reduce the impact a flood event has on soil N levels by reducing the potential for oxygen deprivation to occur. In paddocks with inherent or frequent waterlogging problems, some physical changes may be warranted to **improve paddock drainage**.

Growers might choose to **plant in raised planting beds**, which put the fertilised part of the soil above the original surface level and improve drainage in furrows.

Raised beds are best suited to black, self-mulching soils with a high clay content, and require more careful management in sodic soils.

However, raised beds can bring other benefits such as reducing soil compaction, reducing fertiliser costs when fertiliser is put on top of the beds, and may reduce nutrient losses in run-off.

USEFUL RESOURCES

Nitrogen use efficiency (Update paper)

www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency

Have we got the foundation of N nutrition right? (Update paper)

www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Have-we-got-the-foundation-of-N-nutrition-right

Managing legume and fertiliser N for northern grains cropping (Manual)

www.grdc.com.au/GRDC-Booklet-ManagingFertiliserN

Better fertiliser decisions for crop nutrition (Fact sheet)

www.grdc.com.au/GRDC-FS-BFDCN

Nitrogen decisions—guidelines and rules of thumb (Update paper)

www.tinyurl.com/GRDCnitrogendecs

MORE INFORMATION

Dr Graeme Schwenke

NSW Department of Primary Industries
02 6763 1137
graeme.schwenke@dpi.nsw.gov.au

Dr Mike Bell

Queensland Alliance for Agriculture and Food Innovation
07 4160 0730
m.bell4@uq.edu.au

Maurie Conway

Queensland Department of Agriculture, Fisheries and Forestry
07 4983 7414
maurice.conway@daff.qld.gov.au

Dr Chris Dowling

Back Paddock Company
0407 692 251, 07 3821 3544
cdowling@backpaddock.com.au

GRDC PROJECT CODES

UQ00066, CSP00138, UNE00014

Acknowledgements: Dr Graeme Schwenke, Dr Mike Bell, Maurie Conway, Dr Chris Dowling

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