

Managing Nitrogen - Denitrification

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Introduction

Farmers in Australia apply between 80 and 200 kg N ha⁻¹ to cotton, but only part of this nitrogen is taken up and used by the crop, and the remainder is lost from the plant-soil system. Our work at Narrabri with ¹⁵N labelled fertilizer has shown that the lost nitrogen is emitted to the atmosphere as a result of biological denitrification, and that the losses can be considerable (up to 92% of the amount applied). In this paper we have been asked to address the following: (i) occurrence of denitrification (ii) the risks of denitrification, (iii) practices to reduce denitrification, and (iv) current research on this topic. Before discussing these issues we briefly describe the denitrification process so that the reader fully understands the nature of the problem and the discussion that follows.

Biological Denitrification

It has been established that certain microorganisms in the absence of oxygen have the capacity to utilize nitrate in their respiratory process. The use of nitrate in this way is called biological denitrification, and the reaction results in the production of one or more of the gases nitric oxide, nitrous oxide and nitrogen.

Prior to the discovery in 1946 of nitrous oxide in the atmosphere, most soil scientists took little interest in the process of denitrification, because they were convinced that denitrification was of little economic significance (Broadbent and Clark 1965). However, Adel (1946, 1951) observed that the concentration of nitrous oxide was greater

near the earth's surface than higher in the atmosphere, and he suggested that it was being emitted into the atmosphere as a result of transformation of nitrogen compounds in the soil. The direct observation of nitrous oxide emission from soil by Arnold in 1954, the rapid increase in the use of fertilizer nitrogen in the last few decades, and the increased concern for the effects of farming practices on the environment and climate change has led to a more intensive study of denitrification, and a new awareness of its importance.

The general requirements for denitrification are: denitrifying organisms, nitrate, available organic matter, restricted availability of oxygen, and warm soil temperatures (Firestone 1982).

Denitrifying organisms

About 33 genera of bacteria have the capacity to reduce nitrate, and they exist in all soils. The organisms involved are primarily heterophilic (i.e. they live off organic matter), and thus there is a requirement for a supply of soluble or readily decomposable organic matter (Stevenson 1986).

Nitrate

A prerequisite for denitrification in soil is a supply of inorganic nitrogen in the form of nitrate. The nitrate is supplied by the oxidation of ammonium derived from fertilizer or from the decomposition of organic nitrogen in soil. This process is called nitrification, and it occurs in all soils; the extent of the reaction varies depending on the concentration of ammonium nitrogen and environmental conditions (i.e. temperature, pH, moisture and oxygen). Below 20°C nitrification proceeds at a very slow rate (Frederick 1956), and most studies suggest that the lower pH limit for nitrification is 4. The oxygen and carbon dioxide required by the nitrifying organisms are supplied in the soil water, and thus the moisture content of the soil is of major importance. However, nitrification can proceed in dry soils and the rate of reaction varies with soil texture and those properties which affect osmotic pressure (Schmidt 1982).

Oxygen

Oxygen decreases the rate of denitrification by microorganisms because the denitrifying organisms prefer oxygen to nitrate. Soil water content is important because of its effect on aeration: denitrification is slow in soils when the moisture content is below two-thirds of the water holding capacity, but it is appreciable in flooded soils. It is important to note that denitrification does occur in well drained soils, in anaerobic microsites, such as in pores filled with water, the rhizosphere of plant roots, and in the vicinity of decomposing plant residues (Stevenson 1986).

Temperature

Denitrification occurs at temperatures ranging from 0° to 75°C, but the rate of reaction falls off dramatically below 5°C.

Occurrence of Denitrification

It is apparent from the brief description of denitrification given above that this loss process will occur whenever nitrate is added to or produced in the cotton growing soils of New South Wales and Queensland. This follows because the other four requirements for denitrification, viz. denitrifying organisms, organic matter, lack of oxygen and warm soil temperatures will be present or supplied sometime during the growing season after the application of fertilizer nitrogen. Only the extent of the reaction will vary, depending on the amount of nitrate produced, the soil temperature, the amount of readily decomposable organic matter present, and the oxygen status of the soil.

Nitrogen loss by denitrification can be split into two categories: rapid and extensive losses associated with heavy rains and irrigations, and continuing small losses over a long period in anaerobic microsites (Broadbent and Clark 1965; Bock 1984). An example of rapid denitrification loss is given in the work of Freney et al. (1985), which showed that $\sim 30 \text{ kg N ha}^{-1}$ was lost from a cracking clay in 20 h following an irrigation.

Figure 1 provides an example of continuing small losses of nitrogen over an extended period, which resulted in a loss of 45 kg N ha⁻¹.

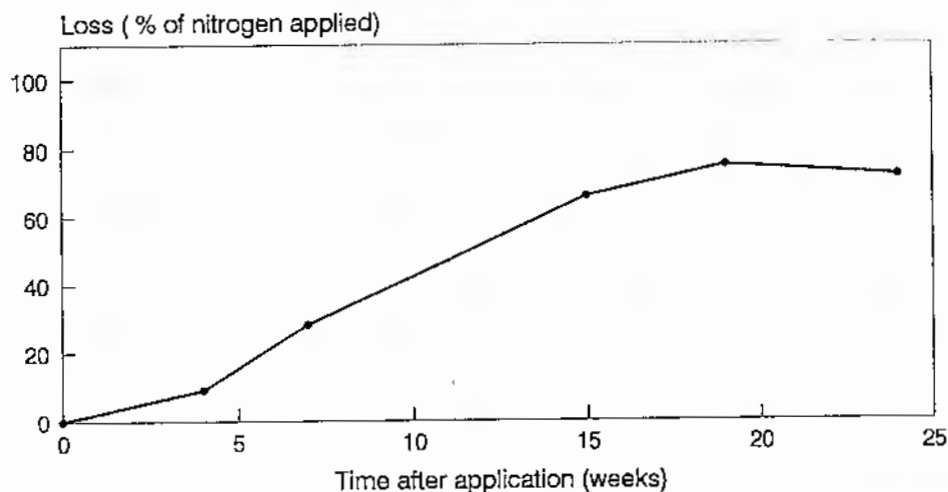


Figure 1. Loss of nitrogen from a grey clay at Narrabri by denitrification following application of urea in May

Risks of Denitrification

The results of our research carried out over four years on the grey clays at Narrabri show that denitrification losses occur each growing season irrespective of the method and time of nitrogen application. Only the extent of the loss varies; losses are lower the closer nitrogen is applied to the time of peak demand by the plant, and are very large when the nitrogen is applied many months before planting. Losses are lower when nitrogen is applied to a healthy, rapidly growing crop rather than to a slow growing, impoverished crop.

The denitrification losses result in wasted fertilizer, wasted energy and application costs, reduced yield of lint, reduced income and increased production of nitrous oxide. Nitrous oxide is a greenhouse gas which is affecting the heat balance of the atmosphere, and in addition is reducing the ozone layer thus allowing more ultra violet light to reach the earth's surface.

Reducing Denitrification

The impact of denitrification can be minimized by adopting either of the following management options:

- (i) adding the fertilizer in the best way and at the best time to make use of the crop's ability to compete with the denitrifying organisms for the inorganic nitrogen in the soil, and
- (ii) reducing the rate and duration of the loss process.

The first approach dictates that fertilizer nitrogen should not be applied before the crop is planted, but rather it should be applied in phase with the crop's demand, and at such a rate that the amount of nitrogen supplied does not exceed the ability of the crop to assimilate it (Keeney 1982; Bock 1984).

Management options available with the second approach include the use of slow-release fertilizers to limit the rate of supply of nitrogen into the soil, and the use of nitrification inhibitors to control the oxidation of ammonium to nitrate. At the present time, slow-release fertilizers are extremely expensive and their use is restricted to special cropping situations. Our trials in cotton with these materials have failed to increase lint yield. Seven chemicals are produced commercially for use as nitrification inhibitors and three of these [N Serve (nitrapyrin), Dwell (Terrazole) and dicyandiamide] are available in Australia. Research trials conducted in U.S.A. have consistently shown that nitrification inhibitors reduce the rate of nitrification; however, the extent of inhibition and length of time for which the inhibitor is active varies with the locality. Inhibitors seem to be less effective in the warmer regions (Hoeft 1984).

Current Work

It has been established in laboratory studies that acetylene is a potent inhibitor of nitrification, but because it is a gas there are problems in introducing it into soil and maintaining the concentration required to limit nitrification during the growing period of

the crop. This problem may be overcome by the use of wax-coated calcium carbide to provide a slow-release source of acetylene, or by the use of non-gaseous acetylenic compounds such as 2-ethynylpyridine or phenylacetylene.

In one of our experiments we evaluated the effectiveness of wax-coated calcium carbide, 2-ethynylpyridine and phenylacetylene in inhibiting nitrification, reducing nitrogen loss and increasing lint yield of cotton in the heavy clay soils of N.S.W., and compared their performance with the commercially available inhibitor, N-Serve.

The study with labelled fertilizer nitrogen applied in the month before sowing showed that in the absence of nitrification inhibitors only 57% of the applied nitrogen was recovered in the plants and soil at crop maturity. The recovery was increased ($P < 0.05$) to 70% by addition of phenylacetylene, to 74% by nitrapyrin, to 78% by coated calcium carbide and to 92% by 2-ethynylpyridine.

In a larger scale field experiment, addition of the wax-coated calcium carbide to provide a slow-release of acetylene significantly slowed the rate of ammonium oxidation in the grey clay for approximately 8 weeks. Lint yield was increased by the addition of the inhibitor at all except the highest level of nitrogen addition. The inhibitor helped to conserve the indigenous nitrogen as well as the applied nitrogen.

Currently we are evaluating the use of Dwell in these grey clays to inhibit nitrification and reduce denitrification losses from fertilizer applied in the month before sowing. Results to date indicate that fertilized treatments receiving Dwell took up considerably more nitrogen later in the growing season which was translated into increased lint yield. At 80 kg N ha^{-1} , Dwell applied at a rate of 1.2 L ha^{-1} increased lint yield above that of the control by $252 \text{ kg lint ha}^{-1}$ ($P < 0.05$). At this stage the chemical analyses are not complete and we cannot provide information on the effect of Dwell on efficiency of use of the fertilizer nitrogen.

Our research shows that the effectiveness of urea fertilizer for cotton grown on the heavy clay soils of N.S.W. can be markedly improved by using nitrification inhibitors. While the results show that 2-ethynylpyridine was more effective than acetylene in reducing total nitrogen loss, 2-ethynylpyridine is presently far too expensive for commercial use in the field, while sufficient wax-coated calcium carbide to treat one hectare (30 kg) can be prepared for about the cost of 10 kg of urea-nitrogen.

The coated calcium carbide not only provides a means of increasing the efficiency of fertilizer nitrogen, but also furnishes a technique for reducing inputs of the greenhouse gas nitrous oxide to the atmosphere.

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