3.2 Nitrogen

For general management guidelines pertinent to all nutrients, see chapter 3.1 'Nutrient budgeting'. Most issues pertinent to N are dealt with in that chapter, but some additional issues specific to N are dealt with here.

N is a nutrient found in high quantities in dairy effluent. N is an essential nutrient for dairy pasture and crop production, and dairy effluent can be used to replace some of the N required within these systems. N in dairy effluent is subject to many conversions and losses throughout handling, storage and land application, and these are difficult to quantify. Because N is a highly mobile nutrient, it must be managed carefully to avoid adverse environmental impacts.

More intense scrutiny of N management within dairy farms is occurring owing to off-site impacts. Volatilisation and denitrification cause some N to be lost as either nitrous oxide (N_2O) or ammonia gas (NH_3). Nitrous oxide, a greenhouse gas, is implicated in climate change (AGO 2007, Dalal *et al.* 2003, Thomas *et al.* 1999). N from surface runoff has been found to contribute to eutrophication—the nutrient enrichment of ecosystems—which can lead to outbreaks of blue-green algae (Harrison 1994, Robson and Hamilton 2003). Leaching of nitrate (NO_3^-) has also polluted groundwater owing to high concentrations of applied N, typically on free-draining soils (Cameron and Di 2004, Silva *et al.* 1999).

Forms of nitrogen and nitrogen cycling

The cycling of N is complex and highly variable in effluent management systems (Gourley *et al.* 2007b). N within dairy effluent is found in both organic and inorganic forms, the latter as ammonium (NH_4^+) and nitrate. Dairy effluent typically contains 60% to 85% organic N, and initially only a small proportion of N occurs in inorganic form (Barkle *et al.* 2000). When effluent is applied to land, N can undergo a number of changes, including:

- immobilisation of inorganic forms by plants and microorganisms to form organic N compounds
- mineralisation—the decomposition of organic N to ammonium
- nitrification—the oxidation of ammonium to nitrite (NO_2^-) and then to nitrate
- denitrification of nitrate to nitrous oxide and N gas (N_2).

The processes involved when dairy effluent is applied to land (Kruger *et al.* 1995) are explained here. On the application of dairy effluent to land, the amount of N mineralised or immobilised depends on the form of organic matter present, temperature and soil moisture. Under suitable conditions, microbial populations increase rapidly. This provides a large sink of N for use in cell synthesis. Ammonium can also be used by the microbial biomass provided there is a carbon source in the effluent to support growth. This incorporation is termed immobilisation, the opposite of mineralisation; the balance between the two processes is determined largely by the C:N ratio of the added material. As a rule of thumb, if C:N > 25, there is net immobilisation, because sufficient carbon is present to stimulate microbial growth such that all the N added in the effluent is incorporated into the microbial cell structure. It is important to realise that the decomposition of organic material is driven by the demand of the soil microflora for C as an energy source and building block for new cell growth. The release of N (as NH_4^+) and P and other inorganic material from the organic matter is only incidental to this microbial growth process. Nitrification is an aerobic process in which the relatively immobile ammonium form is transformed into nitrate, which can be readily leached from soil. Temperature and oxygen supply govern the rate of nitrification. Under aerobic, warm conditions there is almost complete conversion of ammonium to nitrate in the surface soil within a few days of effluent application. Denitrification occurs under anaerobic conditions: oxygen is in short supply, so bacteria use nitrate or nitrite as a source of oxygen and produce N_2O and N_2 gases, which are lost from the soil.

Nitrogen losses

Around half of the N in fresh faeces and urine may be present as ammonia or be converted to ammonia shortly after excretion. This ammonia is very volatile, and unless it is absorbed by, or reacts chemically with, some substance, most of it escapes into the air. This process continues during treatment and storage. High temperatures and high pH increase ammonia loss. Loss of N from effluent increases with storage time. Long-term storage systems such as ponds have the greatest N losses. In solids-separation systems, about 10% of total N is retained in the solids. Significant amounts of N are commonly lost from most effluent treatment systems. This may be regarded as an advantage or a disadvantage, if the objective is effluent reuse with minimum N pollution hazard or efficient use of the fertiliser N content. More than half of total N excreted and most of the potential volatile N is present in urine. Any urine N that dries on concrete surfaces will escape to the air. If manure is stored as a liquid or absorbed in bedding, N losses are reduced (Kruger *et al.* 1995).

Nitrogen fixation

N fixation by legumes may be an important N input in both pasture and mixed-cropping dairy operations (Gourley et al. (2007b). In pasture systems that include legumes, N input from fixation can vary between 10 and 270 kg N $ha^{-1}{\cdot}y^{-1}$ but is typically between 80 and 100 kg N $ha^{-1}{\cdot}y^{-1}$. The amount of N fixed from the atmosphere by legumes is difficult to measure directly owing to spatial and temporal variability and the complexity of measurement techniques. Consequently, fixed values or ranges are often used, or N fixation is predicted using established algorithms, which are often incorporated into decision support tools and models.

Nitrogen in dairy effluent

N conversions and losses from dairy effluent vary depending on the amount excreted from animals, exposure to the atmosphere before suspension in water, the time the effluent is held in storage ponds and the method of land application. Accordingly, these conversions and losses vary significantly between dairy farms and are difficult to quantify, so data must therefore be seen as indicative only.

Excreted nitrogen

The amount and characteristics of animal manures excreted are dealt with in detail in chapter 1.2 'Characteristics of effluent and manure'. A dairy cow excretes approximately 3.2 kg of N per lactation within the area of the shed and yards (DPI 2005). However, this should be used as a guide only, as it varies considerably with location and feed type. The inorganic portion of this N is subject immediately to volatilisation and denitrification.

Effluent storage for nitrogen retention

Provided that storage ponds are lined correctly and seepage losses are negligible, N within storage ponds is generally converted into gaseous forms. Mason (1996) found that in a dairy effluent pond, N was lost mainly by volatilisation, at an average removal rate of 0.75 g ammonia $m^{-2}{\cdot}day^{-1}$. In addition to volatilisation, organic N in dairy effluent slowly mineralises into inorganic forms within storage ponds at a rate dependent on temperature, regardless of oxygen status (Zhao and Chen 2003). The amount of N in dairy effluent ponds varies with depth (McDonald *et al.* 2005) and between farms (see chapter 2.3 'Anaerobic, aerobic and facultative ponds' for typical ranges in concentration). As a result, Waters (1999) recommends analysis of the final effluent stream to be applied to land in each individual case.

Land application

The amount of N applied to land in dairy effluent depends on solids separation, the degree of aeration or agitation of storage ponds, the storage period and effluent pH. Applying dairy effluent to land can stimulate mineralisation and nitrification, resulting in a significant increase in soil nitrate concentrations (Zaman *et al.* 1998), but also significant N volatilisation (Chastain and Montes 2004). In the latter case, ammonia is released to the atmosphere; N losses of 25% have been recorded (Carey *et al.* 1997). Application methods and evaporation rates have not been found to significantly influence these processes (Chastain and Montes 2004).

Nitrogen uptake by pasture

Typically, the mineralisation of organic N in conventional dairy systems is less than the requirements of a standard dairy pasture, even where atmospheric N fixation by legumes contributes, so N applications are normally required (NSW Dairy Effluent Subcommittee 1999, Price 2006). Between 20% and 40% of effluent-applied N was utilised by pasture in the short term (Carey *et al.* 1997, Di *et al.* 2002), but the remaining N can take up to 3 years to become available to plants (NSW Dairy Effluent Subcommittee 1999).

Surface runoff of nitrogen

The N in dairy effluent applied to land is vulnerable to runoff losses facilitated by rainfall or irrigation, typically in the form of ammonium (Smith *et al.* 2001). Although N losses can be minimised by effluent incorporation through ploughing, runoff losses are typically controlled sufficiently through sound soil conservation practices such as vegetation retention, surface water runoff interception and sediment trapping (NSW Dairy Effluent Subcommittee 1999). The risk of N loss from dairy effluent application areas can be assessed through use of the Farm Nutrient Loss Index (FNLI) (Gourley *et al.* 2007a).

Nitrate leaching

Nitrate is susceptible to leaching and is potentially hazardous to groundwater supplies used for human consumption. The rate of leaching is highest in free-draining soils. Cameron and Di (2004) found that in addition to leaching of the susceptible nitrate N, ammonium and organic forms can also be lost through this mechanism. The land application of N therefore requires careful management in free-draining soils. Research has shown that the urine component of dairy effluent supplies most of the leached nitrate (Silva *et al.* 1999), and that splitting effluent applications (into multiple, smaller applications) can reduce N leaching losses (Cameron and Di 2004). The leaching of urine during grazing is of greatest concern, as a significant proportion of N ingested is excreted, typically back onto pasture, where N application rates far exceed the ability of the pasture to utilise the N (Cameron and Di 2004, Haynes and Williams 1993, Whitehead and Raistrick 1993).

Nitrogen loadings

Any N deficit in a dairy pasture or cropping system is typically rectified through fertiliser applications timed to coincide with peak N demand. Careful effluent and N fertiliser application is required, as the inorganic N forms are relatively mobile within soils and are readily taken up by a crop or pasture, volatilised or leached, and the organic portion of N is released slowly over time. In addition, N surplus can occur on dairy pastures where effluent has been applied over many years, as total organic N levels can accumulate.

Nitrogen management

Most Australian soils are naturally low in N, and most agricultural pastures and crops, with the exception of legumes, require N applications to attain optimum production. N is readily taken up by plants and is required in significant amounts at certain critical growth stages. Owing to the transient nature of N, applications are typically distributed throughout the growing season and are often timed to meet peak demands. A quick response and regular applications are typically required to rectify N deficits. Soil analysis for N is not a reliable predictive tool for N management as there is no reliable soil test for N (Gourley *et al.* 2007a). Other indicators such as leaf analysis, plant symptoms and projected crop requirements (e.g. based on N removed in produce) are more reliable (Strong and Mason 1999). It is difficult to indicate typical annual maintenance rates for a dairy pasture, as the requirements vary considerably depending on management and location. However, annual application rates up to 200 $kg{\cdot}ha^{-1}{\cdot}y^{-1}$ are typical, and rates up to 300 $kg{\cdot}ha^{-1}{\cdot}y^{-1}$ are acceptable on high-yielding kikuyu (*Pennisetum clandestinum*) pastures. These applications would typically be applied in split dressings of 20 to 60 $kg{\cdot}ha^{-1}$ at optimum times for yield maximisation.

Monitoring nitrogen

Details on monitoring N throughout a dairy effluent management system are provided in chapter 7 'Monitoring and sampling'.

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