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3 Opportunities to reduce nitrate leaching from grazed grassland

A summary of research findings in New Zealand

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1 Executive Summary

In this report, a number of methods to reduce nitrate leaching from grazed grassland were examined. The body of detail given in this report originates from research at Lincoln University in New Zealand, by Dr Keith Cameron and his team. New Zealand is a country with similar climatic and agricultural production systems to that of Northern Ireland. With the incoming Nitrates Directive and Water Framework Directive in Northern Ireland, the potential application of the New Zealand approach in dealing with nitrate leaching, to Northern Ireland may offer potential.

The effectiveness of a number of products in reducing nitrate leaching from grazed grassland was examined. The products examined were Dicyandiamide (Marketed in liquid form as Eco-N), Dicyandiamide (Marketed in granular form as N-care), Taurine (device to distribute the nitrification inhibitor) and Dimethylpyrazole–phosphate (DMPP) (Marketed as Entec).

The conclusions drawn from this report were:

1. Nitrification inhibitors can be effective in reducing levels of nitrate leaching, but this varies with time (decreasing after application to soil), soil conditions, temperature, moisture content and pH.
2. A problem associated with the majority of research to date in New Zealand which examines the usefulness of nitrification inhibitors, is that studies have largely been conducted on a small-scale experimental basis with field lysimeters. Researchers have subsequently extrapolated such data to yield field results. Further research in this area is currently underway through PhD studies at several universities, in collaboration with Summit-Quinphos, Ravensdown and Balance AgriNutrients. Further long-term full-scale farm research is required to examine the effect of DCD on plant toxicity, soil type and climatic variation.
3. Good management practice may be as effective as nitrification inhibitors in reducing nitrate leaching.
4. Nitrification inhibitors alone will probably not provide a complete solution to the problem of nitrate leaching, but they could be incorporated as a useful tool in conjunction with the adoption of good management practices.
5. A concern regarding toxicity to plants is a potential drawback to the use of nitrification inhibitors such as DCD. No research evidence indicating toxicity of DCD or nitrification inhibitors *per se* to other flora, fauna or animals was reported.
6. Factors limiting the use of nitrification inhibitors include cost and the period of time (3 weeks) for which their application remains viable. Dicyandiamide retails at approximately $78/ha (New Zealand) per application, being equivalent to £29/ha (sterling).
7. Natural sources of nitrification inhibitors are being sought to reduce cost.
8. Smaller scale laboratory studies have indicated that the effectiveness of DCD is temperature dependant and its half-life was reduced from 114 days to approximately 20 days, with an increase in temperature from 8°C to 20°C.

9. It is estimated that several applications of Eco-N (Ravensdown Co-operative) would be required during a grazing season, as it may only remain effective for a period of 3-4 weeks. Consequently, cost could be a limiting factor with its application.
10. N-care (Balance Agrinutrients Ltd), when applied as a fertiliser, can also prove costly.
11. Taurine is currently being patented and is hoped to be commercially trialled in 2005 (Summit–Quinphos Ltd).
12. Nitrification inhibitors could offer potential for use in Northern Ireland agriculture, however, they will not provide the complete answer to the problem of nitrate leaching. An adoption of good management practices and the use of nitrification inhibitors to reduce the level of nitrate leaching may offer potential in addressing the local nitrate problem.
13. Dimethylpryazole-phosphate (DMPP) is a much superior nitrification inhibitor to DCD and is effective at lower concentrations.
14. It has not been possible to obtain information on the current scale of usage of DMPP in Europe.
15. Further work in Northern Ireland should be based on DMPP rather than DCD.

2 Introduction

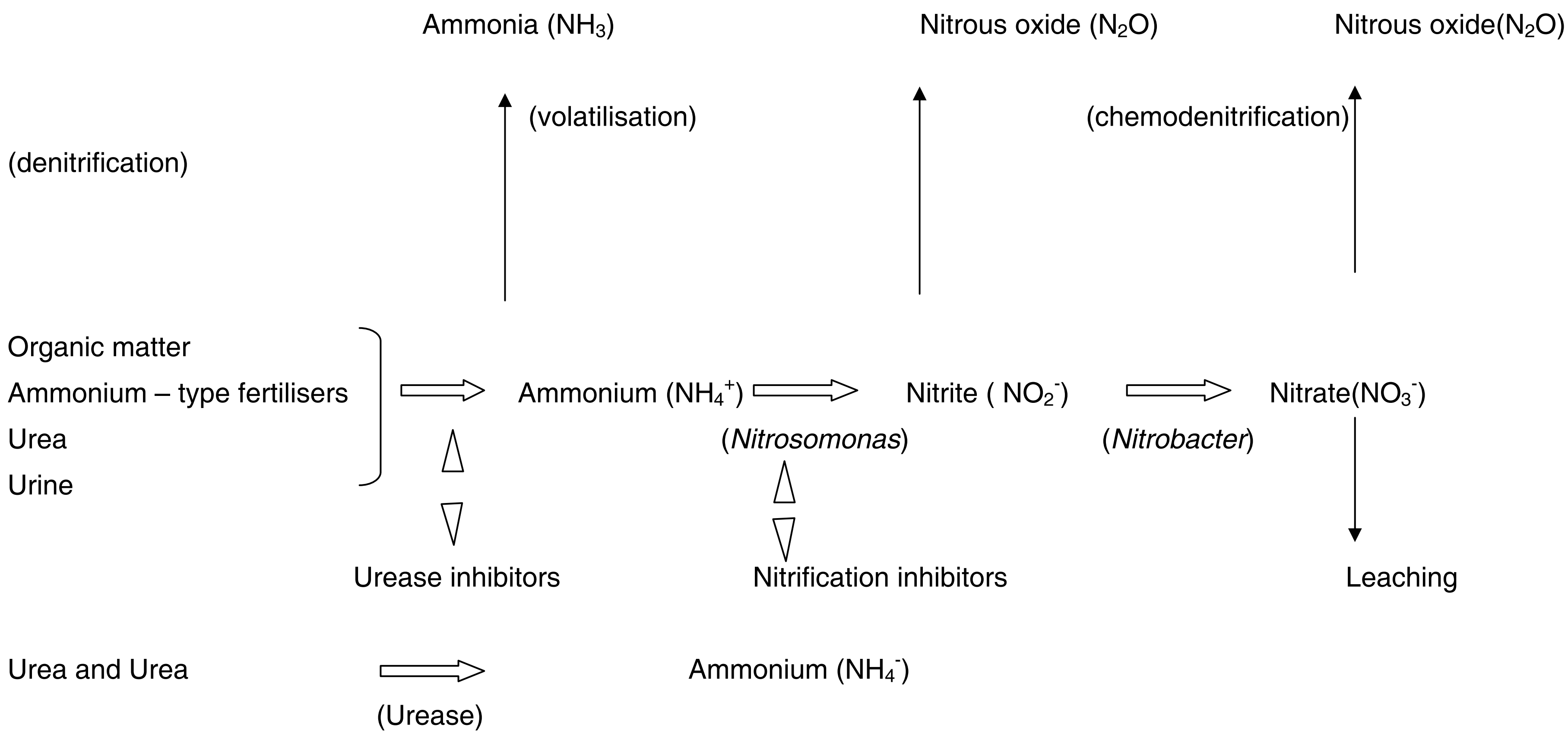
Nitrate leaching from agricultural land in New Zealand has become a greater problem in recent years, particularly with the intensification in agricultural production, with a growing rise in the use of nitrogen (N) fertilisers and the application of agricultural waste to soils. This report reviews research into the use of nitrification inhibitors that was undertaken at the Lincoln University, Canterbury, New Zealand and examines the potential application of this research to Northern Ireland farming situations.

Changes in farming practices in New Zealand have seen a transition, mainly from sheep farming to intensive dairy farming, particularly in the South Island. Consequently, there has been a concomitant increase in the use of N-based fertilisers, pesticides and the application of agricultural manures to soils (Cameron *et al*., 2002). A report prepared by the Ministry of the Environment (1997) highlighted the extent of contamination of ground and surface waters in New Zealand, with up to 40% of lakes containing N levels exceeding 0.3 mg/ml, resulting in lakes being considered eutrophic or hypereutrophic. (http://www.mfe.govt.nz/publications/ser/ser1997/html/chapter7.8.html#The-State-of-our-Lakes). Eutrophication is the process of nutrient enrichment, where a body of water changes from a nutrient poor (oligotrophic) to a nutrient rich (eutrophic) state. Consequently, the New Zealand government issued a recommendation that the level of nitrate in drinking water should not exceed 11.3 mg/ml, a level that is similar to that currently adopted by the European Union.

3 Background

Organic N is converted from ammonia-N (NH_3) to ammonium salts (NH_4^+) by a variety of bacteria, actinomycetes and fungi in a process known as mineralisation. Autotrophic bacteria (*Nitrosomonas*) convert the ammonium to nitrite (NO_2^-) and further modification by other bacteria (*Nitrobacter*) converts nitrite to nitrate (NO_3^-). This process of chemical oxidation is known as nitrification. Nitrogen in these forms is very soluble and is easily removed from the soil by leaching (Figure 1).

Figure 1 Some key biochemical reactions relevant to the use of nitrification and urease inhibitors



(Edmeades,2004)

As a consequence of nitrate leaching from agricultural land, increased levels of nitrate present in ground and surface waters have been linked to several serious health problems in both humans and livestock. These include methaemoglobinaemia (blue baby syndrome), various cancers in humans and similar nitrate poisoning symptoms in animals.
http://www.cahe.nmsu.edu/pubs/_m/m-114.pdf

Other research however, states that there is no proven link between the incidence of stomach cancer and blue baby syndrome in humans and increased levels of nitrate in drinking water (Addiscott and Benjamin, 2004).

In addition, high concentrations of nitrate in surface water, such as lakes and rivers can have adverse effects on water quality and as a result lead to fish kills. As a consequence of these findings, it was considered necessary to evaluate methods of protecting both surface and groundwater from nitrate contamination.

4 Research

Studies by Di and Cameron (2002a) at Lincoln University to examine the factors influencing nitrate leaching to the soil, included the examination of various management practices and the development of future strategies, including the adaptation of nitrification inhibitors, as a means of reducing the occurrence of nitrate leaching.

Management practices were reviewed under various systems as follows:

4.1 Grassland

One of the areas least affected by nitrate leaching is mowed or cut grassland, due to a low level of N application and incorporation of N fixing white clover in the pasture. Lack of cultivation of the land during autumn reduces mineralisation of N compared to arable systems, where the ground may be left fallow with no ground cover to use any available nitrate, increasing the risk of nitrate leaching. However, the degree of nitrate leaching from grazed pasture is greater, mainly due to the application of organic effluents, with the largest proportion being produced from animal urine. Up to 70% of N returned to grazed pasture is in the form of animal urine (Haynes and Williams, 1993). According to Jarvis *et al.* (1995), a cow may urinate between 10-12 times per day and the N loading rate under a cow patch has been estimated to be equivalent to 100 kg N/ha.

Due to the rapid expansion of dairy farming in New Zealand, further studies were undertaken to measure N leached to grazed pasture from cow urine and dairy farm effluent (Di *et al.,* 2002). Results showed a significant increase in the amount of N leached from both urine and urine plus farm effluent lysimeter treatments, with the most significant increase occurring with urine application (Table 1).

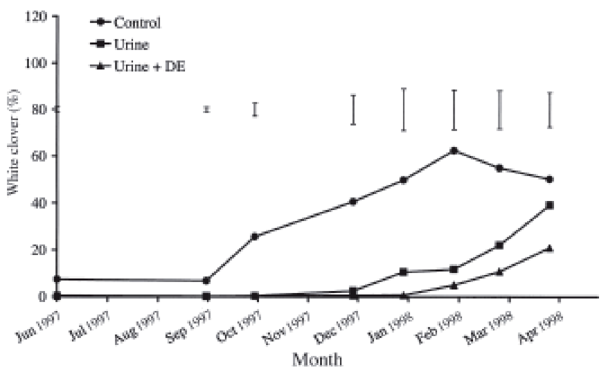
Table 1 Annual total NO_3^- leached, herbage dry matter and N offtake measured using lysimeters

Treatments	**NO_3^--N Leached (kg N/ha)**	**Dry matter yield (t/ha)**	**N offtake (kg N/ha)**
Control	1.5[a]	9.2[a]	282.5[a]
Urine	77.0[b]	17.1[b]	489.4[b]
Urine + dairy effluent	90.0[b]	21.2[c]	605.2[c]

Figures followed by the same letters within a column are not statistically different ($P<0.05$)

An evaluation of the pasture showed reduced levels of white clover were recorded after the application of urine and urine plus farm effluent. In the control treatments, levels of clover increased over the season from June to February to greater than 60%, but were significantly lower for the other treatments, being below 10% for much of the season (Figure 2).

Figure 2 Percentage of white clover in pasture-Vertical bars indicate LSD (0.05)



Di *et al.* (2002)

4.2 Arable cropping

Arable systems have been shown to be prone to nitrate leaching (Francis *et al.,* 1995) due to periods when the soil has no cover vegetation and there is a greater drainage from the soil. As a consequence vulnerable periods would occur at harvest time and during the autumn and winter months. Ploughing of permanent pastures can also increase the level of nitrate leached from the soil, due to an increased mineral N status in the soil. This has been a common practice in the UK since 1930, with estimates of more than 450 kg N/ha being released after the first years ploughing (Whitmore *et al.,* 1992).

4.3 Horticultural systems

Vegetable production can result in a high level of nitrate leaching due to the level of irrigation, high input of N fertiliser and frequent cultivation. In some cases, crop residues remaining after harvesting can cause an increase in N levels (up to 100 kg N/ha) (Whitmore 1996), with levels of nitrate leaching often exceeding the European Union safe drinking level of 11.3 ppm.

4.4 Organic farming

Nitrate levels in organic farming systems can vary according to the quantity of animal manure applied to the land, with levels of nitrate leaching being similar to some conventional farming systems. Researchers in Denmark (on soils with a depth of 0-75 cm), Kristensen *et al*. (1994) recorded a mean nitrate content of 31 kg N/ha on an organic farm, compared with 29 kg N/ha on a conventional farm where manure was applied. However, the level of nitrate on the organic farm was greater than a conventional farm, when manure was not applied (22 kg N/ha). In a Scottish study, where nitrate leaching on organic farms was assessed, data on levels of nitrate leaching on organic farms varied between 25 kg N/ha during the winter months, to 70 kg N/ha after ploughing (Watson *et al*., 1993).

4.5 Forest systems

Forest systems generally have lower quantities of nitrate leaching than other systems. In some cases, only 5-15 kg N/ha have been documented (Juergens-Gshwind, 1989). Forest soils are highly acidic and this can reduce the activity of the nitrifying bacteria, slowing down nitrification.

4.6 Application of animal manures

The extent of nitrate leaching is dependant on the N content of the manure, the rate at which the N is mineralised and the conditions of storage. Levels of mineral N in effluent varied from 60-85% from pigs, 15% from dairy pond sludge and 25% from dairy shed effluent (Cameron *et al.,* 1996). Nitrogen in the different forms of effluent can be present in both mineral and organic form, with organic N undergoing the process of mineralisation before being utilised by plants or leached into the soil. Applications of fresh effluent will mineralise quicker than those with recalcitrant N compounds.

4.7 Soil
Nitrate leaching is usually less from fine textured rather than coarse soils, due to slower drainage and a greater potential for denitrification. Elements of the soil structure such as depth, cracks and root channels also contribute to the level of leaching (Silva *et al.*, 2000).

4.8 Weather
Weather is a major factor affecting the level of nitrate leaching, with levels being higher in autumn and winter. Dry summers can affect the leaching that occurs over the winter months, probably due to the low uptake of N by plants, lower denitrification loss and greater mineralisation at the end of the dry season (Scholefield *et al.,* 1993).

4.9 Fertiliser application
Nitrate leaching occurs if N application levels exceed plant uptake. Studies show that nitrate losses increase rapidly when fertiliser application rises above 400 kg N/ha (Barraclough *et al.,* 1992). To maintain recommended levels of nitrate in drinking water, application should not exceed 200 kg N/ha in grazed pasture systems and 400 kg N/ha in cut ryegrass systems in New Zealand (Di and Cameron, 2000).

4.10 Post-harvest management
Planting of cover crops after harvesting can prove useful in reducing the level of nitrate leaching, with ryegrass being more effective than beans or lupins. The planting of winter crops could reduce leaching by 25 kg N/ha (Shepherd, 1999). Delaying ploughing times to late autumn or spring can also have a beneficial effect (Djurhuus and Olsen, 1997). Early ploughing can result in an extended fallow period, increasing the potential for mineralisation to occur. Francis *et al.* (1995) measured the effect of ploughing time on soil N accumulation. Data demonstrated N accumulation rates of 107-131 kg N/ha for March ploughing and 42-45 kg N/ha for May ploughing, indicating that late ploughing can result in a reduced accumulation of mineral N in the soil, with a concomitant reduction in the level of nitrate leaching.

5 Nitrification Inhibitors

Nitrification inhibitors delay the conversion of ammonium to nitrate by microorganisms. Inhibitors can assist in a controlled slow, continuous release of nitrate to agricultural soils. Nitrate is a mobile form of N and therefore the chemical action of inhibitors could reduce the level of nitrate leaching, and greenhouse gases such as nitrous oxide.

5.1 Recorded positive effects of Nitrification Inhibitors

- Reduction in nitrate leaching
- Reduced nitrous oxide emissions
- Increased plant growth

} Stelly (1980); Klein *et al.* (1996)

5.2 Possible negative effects of Nitrification Inhibitors

- Increase in ammonia volatilisation (Giocchini *et al.,* 2002)
- Priming effect on mineralisation of soil organic N (Prasad and Power, 1995)
- Senescence of leaves caused by dicyandiamide (DCD) (Macadam *et al.,* 2003)
- Defoliation, decreased growth of stem and root tissue (Reeves and Trouchton, 1986)
- Reduction in clover yield of 16% with DCD (Macadam *et al.,* 2003)

Nitrogen deposited in the soil from animal urine rather than from fertiliser application appears to be the main source contributing to nitrate leaching. This has led researchers at Lincoln University to extend their research to methods of reducing the losses of N from urine, using nitrification inhibitors. Consequently, Di and Cameron (2002b) conducted studies to investigate the effect of nitrification inhibitors on nitrate leaching, using the passage of ^{15}N – labelled N in cow urine and dairy effluent.

Ledgard (2001) recorded the N loss by denitrification, volatilisation and nitrate leaching from legume-based pastures. Data indicated that N losses resulted in costs of up to £30/ha for an average dairy farm and £9/ha for a sheep or beef farm, figures being based on a cost of N at 32 p/kg N. These findings highlighted a requirement to investigate methods to alleviate the problems of nitrification.

There are three nitrification inhibitors currently available on a commercial basis, Dimethylpyrazole-phosphate (DMPP), Dicyaniamide (DCD) and Nitrapyrin (N-serve). Dimethylpyrazole-phosphate requires fewer applications than DCD but cost is prohibitive to its use, DCD has higher water solubility and can be applied in liquid form and is also less volatile and can be used in conjunction with solid fertilisers, acting as a slow release fertiliser. Three different DCD products are currently available or are to be marketed shortly in New Zealand, namely:

1. **N-care** Granulated urea-based product, containing DCD and applied as a fertiliser (Balance Agrinutrients Ltd)

2. **Eco-N-q** A suspension preparation, which is sprayed onto soil (Eco-N costs approximately NZ $65/ha for each application) (Quin, 2004)

3. **Taurine** (Tail activated urine injection of nitrogen extender). An animal mounted mechanism to deliver DCD directly onto urine patches (not yet on market). Work on prototypes of the device is close to completion and it is estimated that the device will be commercially trialled in 2005. One of the problems associated with the application of a nitrification inhibitor is that the whole pasture has to be sprayed in order to treat urine patches adequately. To reduce nitrate leaching, it would be more effective to treat urine patches as opposed to the whole pasture and the development of the Taurine device may help to address this problem (Blennerhasset, 2004).

The development of another new product by AgResearch (Ruakura Centre, Hamilton) has been announced recently (4th November 2004), which is claimed to reduce nitrate leaching by 60%. (www.acri.cri.nz/media/98973acb7162f09a39f97ec6ce8d4968.html). This new treatment will allow the inhibitor to pass through the urine, delaying the conversion of N to nitrate. Further development of the product will be in the form of a bolus that can be administered to cattle in late autumn, allowing the inhibitor to be slowly released over the winter period.

Other research in countries such as India by Sahrawat (2003), focused on the identification of natural sources of inhibitors to reduce cost. Essential oils from mint *Mentha arvensis* and *Mentha spicata* displayed potential inhibitory activity, as did Neem seed (*Azadirachta indica. L.*). Sahrawat (2003) also demonstrated that the cost of production can be restrictive on the use of these materials. Furthermore, the effectiveness of mint and neem seed as nitrification inhibitors has been shown to vary (Prasad and Power, 1995).

Researchers at Lincoln University (Di and Cameron, 2002b) conducted trials (where DCD was applied in liquid form) to soil samples in lysimeters (cylinders of soil 50 cm diameter x 70 cm depth). In this study, 100 ml DCD was applied at a rate of 7.5 kg/ha. Urea was applied in 8 treatments at a rate of 200 kg N/ha, to represent a higher level of fertiliser application and subsequently applied in 4 treatments to represent a reduced level of fertiliser application. Urine was applied to lysimeters on two occasions, to represent urine deposits by cows in spring and autumn. Data demonstrated that there was an increase in herbage yield and N uptake upon DCD application, compared to no DCD application (Table 2).

Table 2 Herbage yield and N uptake with DCD application

Measurement	**DCD**	**No DCD**
Herbage yield (t/ha/year)	15	11
N uptake (kg N/ha/year)	406	352

(Di and Cameron, 2002b)

These authors concluded that DCD application in liquid form could be beneficial in reducing nitrate leaching in a grazed dairy cow system. Researchers at Lincoln University collaborated with Ravensdown Fertiliser Co-operative to produce the nitrification inhibitor Eco–N. Data indicated that Eco-N reduced nitrate leaching from 85 to 20-22 kg N/ha/year, representing a reduction of 74-76% (Di and Cameron, 2002b).

Ravensdown Fertiliser Co-operative recommended that the product should be applied in spray form twice yearly, which would reduce nitrate leaching by 60%, with the potential to reduce the level of nitrous oxide, a by–product of nitrification, using Eco–N. (www.ravensdown.co.nz/Newsletters/Summer0304/). Researchers at Lincoln University are conducting further research on the reduction of nitrous oxide by Eco-N.

A report by the Waikato Regional Council in New Zealand (2004) suggested that additional research was required to examine the effectiveness of nitrification inhibitors because research conducted in New Zealand to date had concentrated on one area, namely the Canterbury region. Furthermore, such research was largely based on lysimeter studies, with a requirement to extend such studies to normal farm conditions.
(http://www.ew.govt.nz/newsandevents/agendas/documents/env935602.pdf)

Internationally, other studies have been performed to evaluate the effectiveness of dimethylpyrazole–phosphate (DMPP) as a nitrification inhibitor (trade name ENTEC, produced by BASF in Germany). Wissemeier *et al.* (2002) reported that DMPP performed better in lighter soils and remained more effective after heavy rainfall than DCD. Other researchers indicated that DMPP had greater plant compatibility than other nitrification inhibitors such as DCD (Macadam *et al*., 2003) and required fewer applications. However, Macadam *et al*. (2003) also reported that DMPP was too expensive. At present, DMPP is marketed mainly in Europe at the moment, in Germany, Spain, Italy and Austria by Dalgety Ltd under the trade name ENTEC.
(http://www.dalgety.co.uk/common/uploaded_files/7150002/6700017_7150002_ENTECsummary.pdf?page_id=6700017).

Ryan (2002) evaluated the effectiveness of the nitrification inhibitors DCD, N-serve and DMPP. This author suggested that DMPP a more recent product, showed potential for further investigation having displayed favourable results in tests at low application rates of 0.5-1.5 kg/ha. DCD was considered to be too expensive for large-scale agricultural use and N-serve was used almost exclusively with ammonia.

Suggestions have been made that the adoption of good management practices such as controlling the level, timing and form of fertiliser application, rate of effluent application, stocking levels and cropping systems could be equally as viable as the use of nitrification inhibitors. Many of these management practices are outlined in government documents.
(www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/climate/green-house.)

6 Northern Ireland

Nitrate leaching is an area of importance to local agriculture, with regard to the implications for water quality arising from the introduction of both the Water Framework Directive (2000/60/EC) and the Nitrates Framework Directive 91/676/EEC. The Water Framework Directive came into force from 22 December 2000 and requires each member state to establish a framework to protect their natural waterways. The Nitrates Directive was introduced to reduce the level of pollution of natural waterways by nitrates as a result of agricultural practices. The legislation states that levels of nitrate must not exceed 50 mg/NO_3/l.

Initially, several areas of Northern Ireland were declared Nitrate Vulnerable Zones. However, considering the impact of agriculture on the environment, DARD and DoE have now opted for a total territory approach to nitrate pollution rather than one of designated zones. With the legal requirement to improve water quality in Northern Ireland, the use of nitrification inhibitors could have potential in reducing the level of nitrate leaching. Other areas of potential interest could be the use of natural sources of nitrification inhibitors, such as essential mint oils, as mint is a plant that could easily be grown in Northern Ireland. Watson (2005) examined the potential of urease inhibitors for Northern Ireland and concluded that they are very effective at low concentrations, with levels of 0.05% by weight of the active ingredient reducing ammonia loss by 80%.

Additional research on the use of nitrification inhibitors and the adoption of good management practices could prove useful to address the problem of nitrate leaching and pollution of water in Northern Ireland.

7 Conclusions

1. Nitrification inhibitors can be effective in reducing levels of nitrate leaching, but this varies with time (decreasing after application to soil), soil conditions, temperature, moisture content and pH.
2. A problem associated with the majority of research to date in New Zealand which examines the usefulness of nitrification inhibitors, is that studies have largely been conducted on a small-scale experimental basis with field lysimeters. Researchers have subsequently extrapolated such data to yield field results. Further research in this area is currently underway through PhD studies at several universities, in collaboration with Summit-Quinphos, Ravensdown and Balance AgriNutrients. Further long-term full-scale farm research is required to examine the effect of DCD on plant toxicity, soil type and climatic variation.
3. Good management practice may be as effective as nitrification inhibitors in reducing nitrate leaching.
4. Nitrification inhibitors alone will probably not provide a complete solution to the problem of nitrate leaching, but they could be incorporated as a useful tool in conjunction with the adoption of good management practices.
5. A concern regarding toxicity to plants is a potential drawback to the use of nitrification inhibitors such as DCD. No research evidence indicating toxicity of DCD or nitrification inhibitors *per se* to other flora, fauna or animals was reported.
6. Factors limiting the use of nitrification inhibitors include cost and the period of time (3 weeks) for which their application remains viable. Dicyandiamide retails at approximately $78/ha (New Zealand) per application, being equivalent to £29/ha (sterling).
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8. Smaller scale laboratory studies have indicated that the effectiveness of DCD is temperature dependant and its half-life was reduced from 114 days to approximately 20 days, with an increase in temperature from 8°C to 20°C.
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12. Nitrification inhibitors could offer potential for use in Northern Ireland agriculture. However, they will not provide the complete answer to the problem of nitrate leaching. An adoption of good management practices and the use of nitrification inhibitors to reduce the level of nitrate leaching may offer potential in addressing the local nitrate problem.
13. Dimethylpryazole-phosphate (DMPP) is a much superior nitrification inhibitor to DCD and is effective at lower concentrations.
14. It has not been possible to obtain information on the current scale of usage of DMPP in Europe.

15. Further work in Northern Ireland should be based on DMPP rather than DCD.

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