GROUNDWATER NITRATE LEVELS UNDER GRAZED DAIRY PASTURES RECEIVING DIFFERENT RATES OF NITROGEN FERTILISER

S. F. Ledgard[1], N. Selvarajah[2], D. Jenkinson[2], and M.S. Sprosen[1]

[1]AgResearch Ruakura Research Centre, Private Bag 3123. Hamilton. [2]Environment Waikato. P O Box 4010. Hamilton.

Abstract

Nitrate-N concentrations in groundwater are being measured under grazed pastures at the Dairying Research Corporation Number 2 dairy near Hamilton. Three farmlets are receiving N fertiliser at 0, 200 or 400 kg N/ha/yr (as 8-10 split applications through the year) and are stocked at 3.2 cows/ha. A fourth farmlet receives 400 kg N/ha/yr, and has 4.5 cows/ha which also gets maize grain at 3-5 t/ha/yr. Piezometers (3/farmlet) were inserted to a depth of 5.5-6 m in the free-draining soil derived from volcanic ash. Depth to the groundwater vanes seasonally from about 2 m in spring to 4 m in autumn/early winter.

Nitrate-N concentrations in groundwater well initially similar in all farmlets at about 10 mg/L. During the following two years, the nitrate-N concentrations in the 0 N farmlet fluctuated around 5-10 mg/L whereas they showed a cyclical pattern in the 400 N farmlets reaching a peak in spring of between 20 and 30 mg/L. There was no significant difference between the two 400 N farmlets despite an increase in stocking rate from 3.2 to 4.5 cows/ha, although results were probably confounded by the large input of grain at the high stocking rate. The nitrate-N concentration in the 200 N farmlet tended to show a small increase over that in the 0 N farmlet. Thus, application of N fertiliser at 400 kg N/ha/yr to these farmlets led to an increase in the nitrate-N concentration in groundwater to well above the recommended maximum for drinking water in New Zealand of 11.3 mg/L.

Introduction

Underground sources of water are widely used throughout New Zealand and groundwater is the sole source of water for a range of communities including the cities of Napier and Christchurch (Burden 1982; Selvarajah et al. 1994). Thus, the contamination of groundwater by nitrate is of concern because of potential direct impacts on human health and indirectly through movement to surface water bodies where eutrophication can occur. The maximum acceptable nitrate-N concentration set as the New Zealand drinking water standard of 11.3 mg nitrate-N/L (Ministry of Health 1995) is similar to that of many other countries and is based on a level which is considered safe for young infants who are most predisposed to methaemoglobinaemia (eg. Weisenburger 1991).

There have been a range of ad hoc surveys of nitrate in groundwater throughout New Zealand, mainly carried out by regional water authorities in the 1970s and 1980s, and these have been summarised elsewhere (Burden 1982; Ledgard 1993; Smith et al. 1993). These summaries have indicated that the areas with significant enrichment of groundwater by nitrate due to non- point sources, are associated with intensive farming systems on free-draining soils. The main contamination in pastoral fanning systems was observed in intensive dairying areas in Taranaki and Waikatio. For example, a 1987 survey of dairy farms in the intensively-managed south Taranaki area showed that over 40% of the groundwater samples from wells had nitrate-N concentrations exceeding 10 mg/L (Taranaki Catchment Commission 1987).

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During the past ten yean there has been a marked increase in use of nitrogen fertiliser on New Zealand dairy farms. In Taranaki the use of N fertiliser on dairy farms has increased from about 1000 t/year m 1988/89 to over 12000 t/year currently (Kidd and Howse 1994). The on-farm rates of application vary widely from 0 to about 400 kg N/ha/year.

To date, there has been no published research in New Zealand on the effects of increasing N fertiliser use on nitrate levels in groundwater. Selvarajah et al (1994) showed that application of very high rates of N (1200 kg N/ha/year) in dairy factory waste water increased nitrate-N in groundwater from 10 to 40 mg/L within three years, and up to 70 mg/L after 8 years. Thus very large N inputs can have a marked impact on nitrate in groundwater.

This paper reports on the concentrations of nitrate in groundwater under dairy cow farmlets in a long-term grazing experiment conducted by the Dairying Research Corporation (DRC), with treatments varying in the rate of N fertiliser application.

Methods

In June 1993, a long-term dairy cow farmlet trial was established at the DRC Number 2 near Hamilton (Harris et al. 1994). This trial includes the following four treatments:

1. Nil N fertiliser. 3.2 cows/ha.
2. 200 kg N/ha/yr. 3.2 cows/ha.
3. 400 kg N/ha/yr. 3.2 cows/ha.
4. 400 kg N/ha/yr. 4.5 cows/ha. plus regular feeding of maize grain (3-5 t/ha/yr)

The N fertiliser was applied as urea in 8-10 split applications throughout the year, except during dry summer conditions.

The farmlet layout consisted of a series of four consecutive 0.4 ha paddocks of the same treatment. Overall, there were 16 paddocks in each farmlet. with 4 series of 4 paddocks. Three paddocks from within one series were selected from each of the above 4 treatments, for piezometer placement. These groups of paddocks were all located in a similar area of a common soil type. The free-draining soil was derived from volcanic ash and is classified a mottled orthic brown soil (Silverdale silt loam).

Piezometers were installed centrally in each of the twelve selected paddocks in March 1994 using a Gemco hollow stem auger rig. The piezometers range in total depth from 5.5 to 6.0 m. All piezometers were constructed from 40 mm diameter Class C PVC standpipes with 3 m machine slotted screen sections (0.5 mm slot aperture). The 100 mm annular space surrounding the PVC standpipes was back-filled with clean sand to 1 m above the screen section, sealed with 0.5 to 1 m of bentonite, and back-filled to ground level with material extracted during drilling. At the ground surface, the piezometers were capped with PVC end caps, and further protected by a short length of 100 mm diameter capped PVC pipe.

Ground water levels were recorded and samples collected from each piezometer at approximately monthly intervals. Samples were collected using a small surface vacuum pump with 10 mm diameter clear non-toxic hose. Prior to sample collection, each piezometer was purged of five casing volumes of water in order to gain a suitably representative sample.

Sample containers were triple rinsed with sample water before filling, and transported to the laboratory within two hours of collection. Each sample was analysed for nitrate and ammonium concentration using a flow injection analyser.

Rising head permeability tests were performed on the piezometers using a closed 37 mm O.D. alkathene pipe as a “slug”. The slug was inserted into the piezometers to their total depth and left to stand to allow re-equilibration of the static water level. Due to rapid water level recovery, water level probes were set in epoxy resin at the bottom of the slug pipe. Water levels could thus be measured as the slug pipe was withdrawn to avoid delay in water level measurement during the first few seconds of recovery. Individual slug tests were repeated two to three times as necessary to provide sufficient data for analysis.

Hydraulic conductivities were calculated from the rising head test data using the Bouwer and Rice method (Bouwer 1989). This method assumes the following:

- porosity of 30% for the sand occupying the annular space surrounding the piezometer screen sections,
- the aquifer surrounding each of the piezometers is homogeneous and isotropic,
- the piezometers penetrate the full thickness of the aquifer.

This last assumption has little impact on the hydraulic conductivity (≈15 % decrease for a hypothetical impermeable basement at 15 m depth).

Results

At all samplings, the concentration of ammonium-N in groundwater was low (< 0.8 mg/L), with no significant difference between treatments (Fig. 1). Similarly, there was no clear seasonal pattern to the small variations in ammonium-N concentration over time.

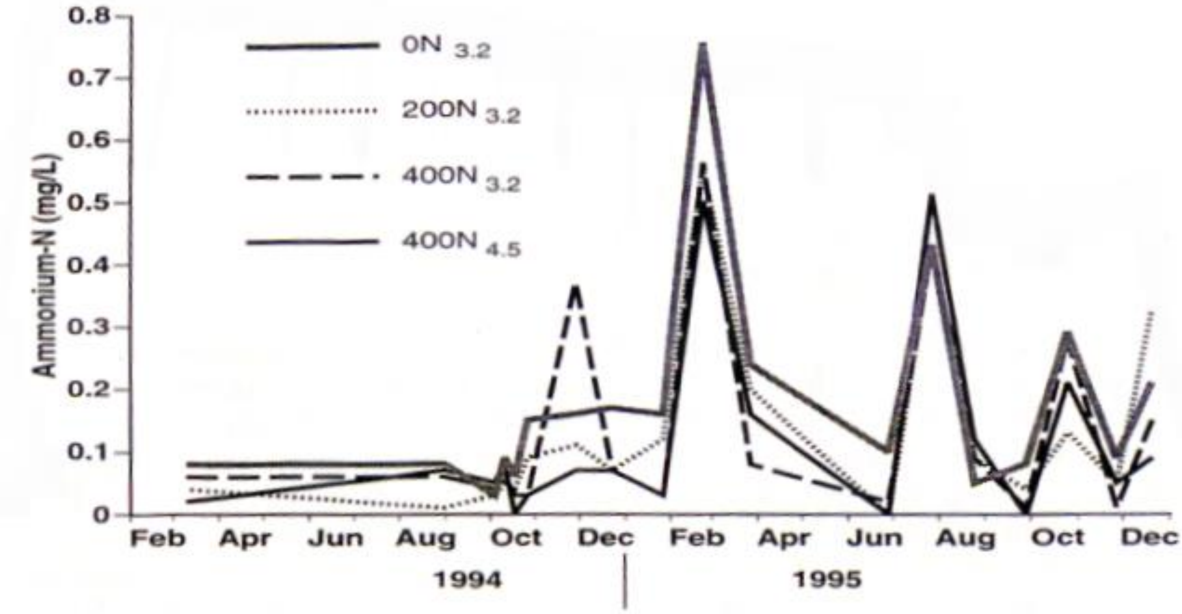

Figure 1 Concentrations of ammonium-N in groundwater under farmlets varying in N fertiliser input (0, 200 or 400 kg N/ha/yr) and stocking rate (3.2 or 4.5 cows/ha). The average SED was 0.05 mg/L (range 0.01 - 0.10).

The mean nitrate-N concentration in groundwater was initially similar for all farmlets at approximately 10 mg/L, but differences had developed by summer 1994/95 (Fig. 2). Between December 1994 and April 1995, the nitrate concentrations in the two 400 N treatments were higher ($P<0.05$) than those in the 0 and 200 N treatments, and there was little difference between the latter two treatments. However, after August 1995, differences between the three N fertiliser rates were apparent with 400 N > 200 N > 0 N.

There was no clear temporal variation in nitrate-N concentration in the 0 N treatment. Similarly, there was little variation in the 200 N farmlet. although an apparent increase occurred during spring 1995. In contrast, the 400 N farmlets showed greater seasonal variation in nitrate-N concentration with peaks evident in summer 1994/1995 and in spring 1995.

The depth to the groundwater also showed clear seasonal variation, being least in spring and greatest in autumn (Fig. 3). The spring peak was closer to the ground surface in 1995 (1.6 m) than in 1994 (2.4 m) due to greater early winter drainage in 1995. The drainage during June and July was 270 and 350 mm for 1994 and 1995 respectively, as measured from 1 m deep lysimeters.

Hydraulic conductivity values derived from the rising head tests ranged from 0.1 to 1.9 m per day. These values correspond to those for silts to fine sands (Driscoll 1986). The estimated mean hydraulic gradient at the site is 0.0016. Based on an assumed effective aquifer thickness of 4 m, a throughflow of 0.3 to 4.8 cubic metres per day would be estimated over a cross sectional width of 400 m. Thus, a groundwater velocity of 5.2×10^{-4} to 1.0×10^{-2} m per would be expected, assuming an effective porosity of 0.3.

Discussion

Concentrations of ammonium-N in groundwater were low (< 0.8 mg/L) and were unaffected by N fertiliser application. The experimental soil has a high nitrification rate which favours rapid conversion of ammonium to nitrate in soil. It also has a relatively high cation exchange capacity and ammonium is retained by adsorption. In a survey of groundwater in the Piako region, measurements of ammonium-N concentration in the free-draining ash soils around Matamata were also low at less than 0.1 mg/L (Hadfield 1993).

The concentrations of nitrate-N in groundwater under the farmlets were within the range of (<1 to 35 mg/L; approximate mean of 13 mg/L) measured in a 1981 survey of bore water in nearby Hamilton-Cambridge area (Hoare 1986). However, the present study has indicated that increased N fertiliser use can lead to an increase in the nitrate-N concentration in groundwater. While there was an increase in nitrate-N concentration with N fertiliser use up to 400 kg N/ha/year, there was no significant difference between the two 400 N farmlets which varied in stocking rate. Greater leaching losses might be expected at the higher stocking rate due to increased return of potentially-leachable urine-N (Ledgard 1993; Jarvis et al. 1995). However, the 4.5 cows/ha treatment received a significant component of maize grain which has a very low N concentration compared to that in pasture, and this will tend to reduce N excretion in urine relative to that in dung.

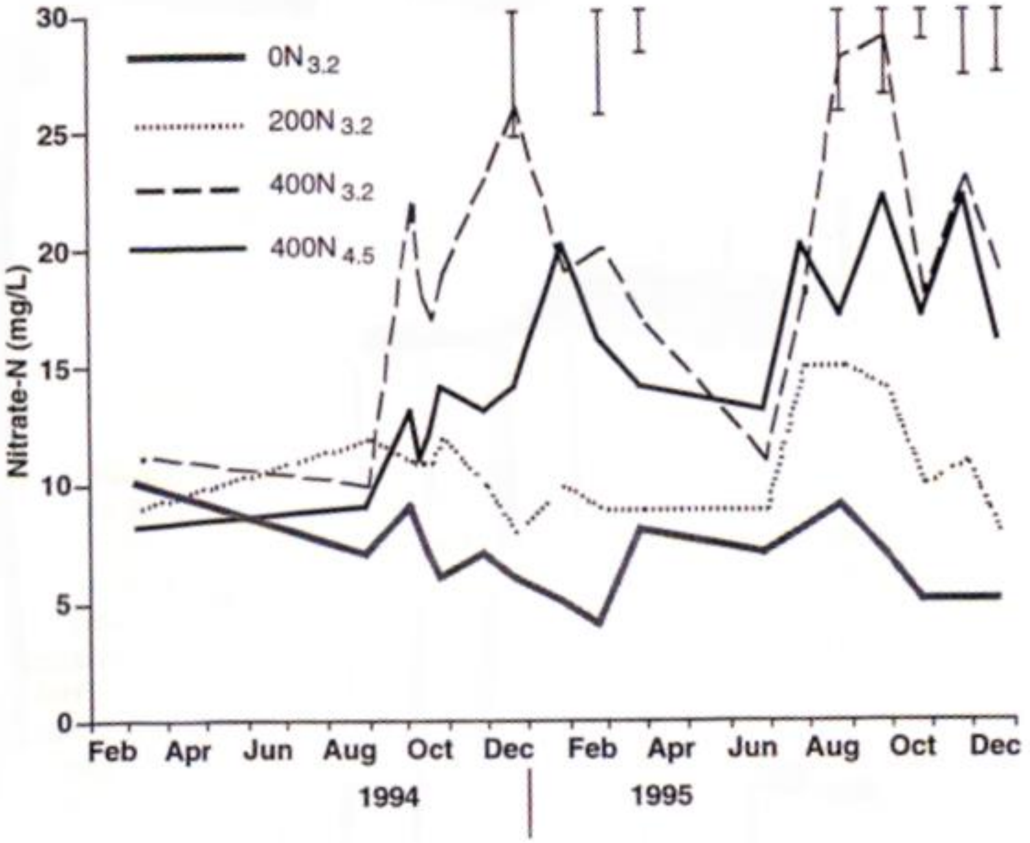

Figure 2 Concentrations of nitrate-N in groundwater under farmlets varying in N fertiliser input (0, 200 or 400 kg N/ha/yr) and stocking rate (3.2 or 4.5 cows/ha). Bars represent SED's.

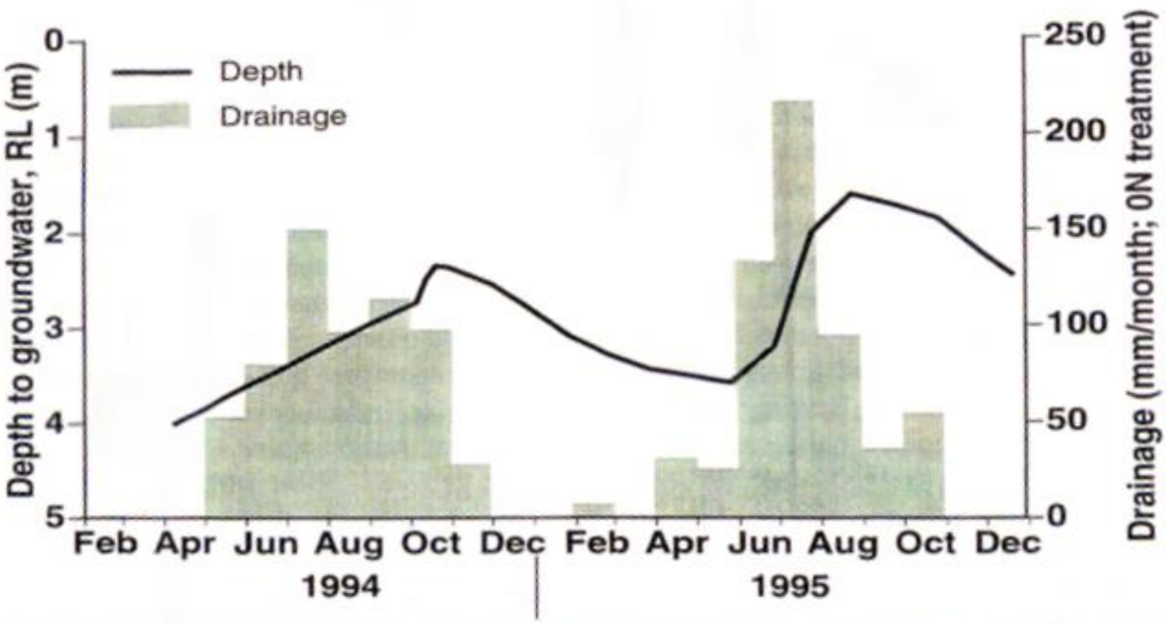

Figure 3 Temporal pattern of depth to groundwater and monthly drainage. Data for depth to groundwater is the average for the four farmlets.

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Farmlet differences in nitrate-N concentration of groundwater had developed by 18 months after commencement of the grazing trial, with significantly higher concentrations in the farmlets than in the 0 N farmlet. The relative differences between treatments were similar to those observed in the measurements of soil solution at 1 m depth (Ledgard et al. 1996). However, the peak nitrate-N concentrations of groundwater in 1994 were approximately one-half of those in solution at 1 m depth, whereas in 1995 this relative difference in the N-fertilised farmlets was 60-80%. The measurements of soil solution at 1 m depth represent nitrate moving with the percolating water and therefore readily reflect the effect of treatments. However, there are a number of factors which will affect the concentration of nitrate-N in groundwater including nitrate concentration will clearly be influenced by that in percolate, as well as the dilution effect from resident groundwater, and lateral flow from outside the measurement area. If flow rates were very rapid, there would have been little or no difference between treatments because of the relatively small land area (1.6 ha) associated with each treatment. However, preliminary research on groundwater velocity, based on estimates of hydraulic conductivity, indicate a slow lateral flow of less than 4 m/year. This estimate will be conservative because it ignores dispersion by preferential flow pathways within the aquifers. Further research is being carried out to better estimate the time-frame for possible ‘cross contamination' between neighbouring farmlets. Nevertheless, the measurements to date indicate that the aquifers below the experimental site have low dispersion characters and that the groundwater data has shown differences in nitrate concentration between treatments.

There have been no other long-term experiments in New Zealand which have examined the effects of dairy farming intensity or N fertiliser use on nitrate in groundwater, although a short-term study by Sharpley and Syers (1979) showed an increase in nitrate-N concentration of tile-drainage water following a single application of N fertiliser in winter. In a long-term experiment in England, Scholefield et al. (1993) measured an increase in nitrate-N concentration in water from tile drains with increasing rate of N fertiliser application to ryegrass-only pastures grazed by beef cattle. In their study, the long-term average peak nitrate-N concentrations in drainage water were 2, 22 and 55 mg/L from areas receiving 0, 200 and 400 kg N/ha/year respectively.

The temporal pattern of nitrate-N concentration in groundwater during 1994 was similar to that observed in the measurements of soil solution at 1 m depth (Ledgard et al. 1996), except that the rise and fall in nitrate-N concentration in the 400 N treatment occurred 6 months later in the groundwater. However, during 1995, this lag in observed peak in nitrate-N in the N-fertilised farmlets was only about 2 months. This can be attributed to differences in the rate and timing of drainage between years. During 1995, the peak monthly drainage of 220 mm occurred in July, thereby resulting in rapid early winter leaching, whereas in 1995 the peak monthly drainage of 170 mm occurred in October and there was a prolonged leaching period. The temporal pattern of nitrate-N concentration in groundwater and depth to groundwater were similar, with both peaking in spring/early summer and reflecting recharge by percolating water.

Results from the first two years of measurement of groundwater in this study indicate that the concentrations of nitrate-N have increased with increasing rate of N fertiliser application to the farmlets. Further measurements are required to obtain a more accurate indication of the long-term effects of N use on nitrate-N concentrations, and on the effects of groundwater flows on the results obtained. However, the nitrate-N concentrations under both of the farmlets receiving 400 kg N/ha/year were clearly well above the recommended maximum for drinking water of 11.3 mg/L (Ministry of Health 1995), while those in the 200 N farmlet were near this value. Groundwater in the Hamilton Basin drains into surface water and there is also concern about groundwater high in nitrate leading to eutrophication of surface waterways. Furthermore, if we aimed to meet the EC Directive, then dairy farmers would also be required to use farm water of potable water quality (i.e. < 11.3 mg nitrate-N/L). At the trial site, groundwater under the 400 N farmlets would not have met

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any of the above criteria. Clear definition of a maximum rate of N fertiliser use on dairy farms from a human health and environmental perspective requires more data from other sites and soils, in conjunction with N modelling research, to account for interacting effects of key determining factors.

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