# An assessment of the implications of timing and soil nitrogen dynamics during and after summer drought on Waikato Allophanic soils

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## Abstract

Recommendations for farming when coming out of a drought are to apply fertiliser nitrogen (N), but when a drought breaks late in the season (i.e. mid to late autumn), the release of soil N has the potential to compound fertiliser N loads at a time when pasture N demand is low. Using the APSIM model, based on measurements made on a Waikato dairy farm and using data from the drought of 2007/8, an accumulation of 20 kg $NO_3$-N/ha in the top 50 cm of soil post-drought was predicted, and therefore any fertiliser N applied during the drought would have added to the available N pool. Where a total of 70 kg N/ha fertiliser was applied during the drought, 35 kg $NO_3$-N/ha was leached during the following winter. A glasshouse trial was subsequently run to observe N dynamics under controlled conditions. The pot trial confirmed that a substantial amount of available N was released (40–60 kg N/ha; 0–15 cm) upon rewetting after a "severe" drought, which may be sufficient to promote growth. The ability of pasture to grow and utilise soil/fertiliser N and the subsequent risk of N leaching will depend on how late in the season drought soils are returned to field capacity and when drainage commences.

**Keywords:** pasture, nitrogen, nitrate leaching, nitrogen fertiliser, drought, ASPIM

## Introduction

Many regions in New Zealand experience a period of drought during summer. There is little published information available on appropriate nitrogen management at these times, but extension agencies (e.g., DairyNZ 2012; Ballance 2010) recommend the application of nitrogen fertiliser as soon as there is significant rain after a drought. Fertiliser is one of the larger expenses on farm, and a single application can cost around $62/ha, (35 kg N/ha at $1.78/kg N) or $7500 for a blanket application across an average sized North Island dairy farm (120 ha; LIC 2011), not including spreading costs. Our hypothesis is that, following a drought and the rewetting of a soil under pasture, the mineralisation flush will supply a substantial quantity of mineral N for the recovering sward. The flush of mineral N on rewetting occurs because of new sources of N and C becoming available such as dead cell and plant material, and excreted osmolytes (Birch 1964). The consequences of this could be that fertiliser N is not essential post-drought in some situations, and significant savings could be made at a time when financial demands on the farm are significant.

Apart from financial concerns, fertiliser N added on top of the N flush released post-drought could, depending on the severity of the drought, timing of the drought break, and return to field capacity, significantly raise soil mineral N content and then increase N leaching over the following winter. The objectives of this paper are to 1) use a process-based model to investigate soil N dynamics and the potential for N loss post-drought, and 2) to undertake a glasshouse study to estimate the effect of the drought period (i.e. severity of drought) and soil type on the release of mineral N following rewetting of the soil.

## Methods

### APSIM drought modelling

The APSIM model (Keating *et al.* 2003) was used to investigate nitrogen dynamics in the soil during and after a drought. The drought of 2007/8 was chosen as a good example of a long dry period, followed by rapid rewetting of the soil in autumn. Measurements (soil mineral N, soil moisture, pasture dry matter (DM) and N content (%N)) made at the Tokanui dairy farm (Waikato) were used to test the model for this exercise. The specific modules used in this simulation were the SoilN and SurfaceOM modules (Probert *et al.* 1998) that describe N and C dynamics; AgPasture (Li *et al.* 2011) to simulate pasture growth and N uptake, and SWIM2 (Verburg *et al.* 1996) to model soil water processes. Daily weather data (2007–2008) for Ruakura was accessed from the NIWA Virtual Climate Station network (VCS; Tait *et al.* 2006).

The model was run as a 2 × 2 factorial experiment: ± irrigation (i.e., with and without drought conditions), and ± N fertiliser (35 kg N/ha × 5 applications in mid-September, November, December, February, and March). To look specifically at the interaction of drought with soil N release in the absence of urine, the pasture was managed as a cut and carry system with

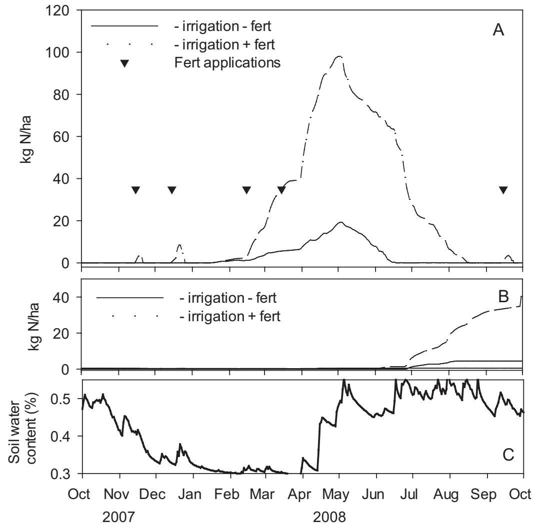


**Figure 1** Simulated response in the soil to 50 cm depth of (A) soil nitrate and (B) cumulative nitrate leaching, with and without fertiliser (fert) additions and irrigation; and (C) soil moisture content. The black triangles represent the timing of N fertiliser applications (35 kg N/ha as urea).

cutting at a fixed interval of 21 days to a residual DM of 1700 kg/ha. Irrigation started when the soil water deficit in the top 500 mm of soil fell below 20 mm, in which case 20 mm was applied with a minimum return period of four days.

## Glasshouse experiment

The glasshouse experiment was designed to estimate the quantity of N released from soil and how that is effected by drought length under controlled conditions. Undisturbed soil cores (8 cm diameter × 15 cm deep) were taken from Otorohanga and Horotiu soils on dairy farms in August 2012, within 1 week of rain, and brought into the glasshouse 2 days before the start of the trial (23 August 2012). Both soils are classified as Typic Orthic Allophanic Soils (Hewitt 1998) and had not been recently grazed. We assumed that the soils were at, or close to, field capacity at the time of sampling, given that we sampled in early spring after recent rainfall and when evaporative demand was low. A total of 240 cores were taken: 120 of each soil. Ten cores per treatment were destructively sampled at each 3-week period (up to 12 weeks, Table 1). Selected soil properties are shown in Table 2. The following treatments were randomly assigned to cores: control (field capacity); 3-week drought (field capacity for 3 weeks, drought for 3 weeks starting on week 3); and 6-week drought (drought for 6 weeks starting on week 0; Table 1). All droughted soils were rewet after week 6. Because these cores were kept in the glasshouse, and because of their limited size and the absence of soil moisture encroaching from below, the effects of the drought periods will likely be more severe than in field conditions.

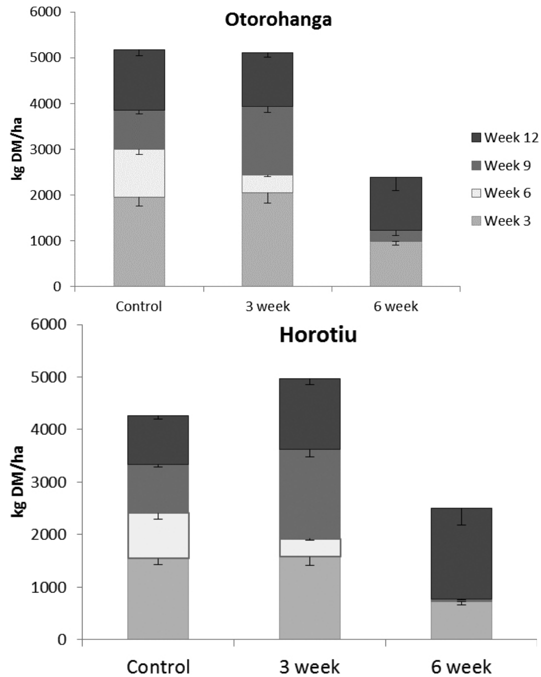


**Figure 2** The dry matter (DM) yields harvested at each 3-week period, for the Otorohanga and Horotiu soils.

We assumed that the soils were at, or close to, field capacity at the time of sampling because they were sampled in early spring after recent rainfall. The initial weight of each core was recorded on day 0. All moist treatments (Table 1) were watered with the average volume of water lost from 10 randomly selected control cores at 2–4 day intervals. Every 3 weeks, each core of the non-drought treatments was individually weighed and watered back to field capacity (water content at week 0). Droughted soils were rewetted at week 6 and then maintained at field capacity for another 6 weeks. No N was added to any of the treatments.

At the start of the experiment, and then every 3 weeks

**Table 1** Sampling regime and drought treatments. Grey cells denote treatments at field capacity or watered to maintain field capacity, and white cells are dry or drying. Ten cores were destructively sampled for soil moisture and mineral nitrogen (denoted "S") at the end of the given period for each soil.

| | Weeks from start | | | | |
|---|---|---|---|---|---|
| | 0 | 3 | 6 | 9 | 12 |
| Control | S | S | S | S | S |
| 3 week drought | | | S | S | S |
| 6 week drought | | S | S | S | S |

thereafter, 10 replicate cores from each treatment were destructively sampled (Table 1). Pasture (>2.5 cm) was harvested, dried and weighed from all cores. Soil was analysed for soil moisture content, bulk density and mineral N content, the latter extracted using $K_2SO_4$ (Blakemore *et al.* 1987). All data were analysed in GenStat v.12. Mineral N data were analysed using an Analysis of Variance and the difference between soils and treatments are reported using the least significant difference (LSD) at the 5% level of significance.

## Results

### Modelling results from 2007/8

The Waikato drought in 2008 was characterised by an extremely dry December–April period followed by a rapid rewetting of the soil profile in mid-April, with drainage starting 2 weeks later (Figure 1C). Fertiliser applied to the irrigated treatments resulted in only temporary spikes in soil nitrate, as the N was quickly utilised by the growing pasture (data not shown). However, fertiliser applications made during drought conditions in February and March accumulated in the soil, due to low uptake of soil N by the pasture, as growth rates were <1 kg DM/ha/day from February to March (data not shown). Nitrogen applications during a drought are not recommended, but may occur if rain is forecast. However, this rainfall may fail to be of the magnitude expected. Nitrogen inputs during a drought may also be indirect in the form of supplements fed out during the drought and N returned as urine. The model output suggests that when drainage began in May 2008, there was approximately 20 kg available N in the top 50 cm of the soil where no N was applied, and over 100 kg N/ha where fertiliser was applied (Figure 1A).

As a consequence of the conditions described above, APSIM estimated nitrate leaching losses of 35 and 5 kg N/ha over the following winter in the drought treatments, with and without fertiliser additions, respectively (Figure 1). In contrast, the modelling suggested no N leaching in either of the irrigated treatments (data not shown). Therefore these results suggest that the main effect of the drought on leaching arises from "unused" fertiliser N applied during the drought.

### Experimental Results

Under glasshouse conditions, pasture production was greater on the Otorohanga than the Horotiu soil (Figure 2), although the relative effects of the drought on pasture production were the same. During the 3 weeks of drought on the 3 week treatment, pasture production was approximately half of that on the watered control. There was no growth at all between the third and sixth weeks for the 6-week drought treatment. For both soil types, the pasture quickly recovered from the 3-week drought, and growth was about 80% greater than the control, probably from a flush of N from the soil. This additional growth made up for the depression of growth that occurred during the 3-week drought. However, no such response was observed after rewetting the 6-week drought plots on the Otorohanga soil. This could be because it took longer for the pasture to regrow and respond to the N flush, and the response was spread out over a longer period than was measured.

The 3-week drought caused no statistically

**Table 2** Properties of the two soils (0–15 cm) used in the glasshouse experiment. Field capacity (FC) was measured on day 0.

| Soil | N | C | pH | Olsen P | $SO_4$ -S | K | Ca | Mg | Na | Bulk Density | FC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | --%-- | | | µg/mL | ppm | ----MAF QT---- | | | | g/cm³ | vol/vol |
| Horotiu | 0.75 | 7.6 | 6.0 | 33 | 15 | 3 | 6 | 24 | 6 | 0.83 | 0.48 |
| Otorohanga | 0.77 | 7.7 | 5.9 | 28 | 78 | 4 | 5 | 22 | 4 | 0.71 | 0.55 |

**Table 3** Soil mineral nitrogen (ammonium + nitrate) levels measured at each destructive sampling event (kg N/ha). Droughted soils were rewet after week 6. (Grey cells denote wet soils; vertical line denotes when drought treatments were rewet).

| | Weeks from start | | | | |
|---|---|---|---|---|---|
| | 0 | 3 | 6 | 9 | 12 |
| Otorohanga | | | | | |
| Control | 8.4 | 2.0 | 3.8 | 2.3 | 0.0 |
| 3 week drought | - | - | 7.5 | 3.6 | 0.0 |
| 6 week drought | - | 9.8 | 18.4 | 59.7 | 24.4 |
| Horotiu | | | | | |
| Control | 5.9 | 2.9 | 3.7 | 2.4 | 0.0 |
| 3 week drought | - | - | 11.7 | 5.3 | 0.0 |
| 6 week drought | - | 10.0 | 19.5 | 86.9 | 16.4 |
| LSD (5%) soil × drought | 2.6 | 3.9 | 5.8 | 16.2 | 13.5 |

significant change in soil mineral N levels (mainly as nitrate-N, ($NO_3$-N)) compared with the start of the trial (Table 3). In contrast, after another 3 weeks of drought, the mineral N levels almost doubled in both soils (an additional 15–16 kg N/ha) because there was no growing pasture to utilise soil N during this time, and the microbes, which are more tolerant of dry conditions (Griffiths *et al.* 2003), continued to mineralise N. After rewetting the 6-week drought treatments (week 9), the mineral N levels were three times greater than the end of drought (week 6) in the Otorohanga soil (60 kg N/ha), and over four times greater in the Horotiu soil (87 kg N/ha; Table 3). Even 6 weeks post-rewetting, the mineral N in the 6 week drought soils was significantly greater than the control.

## Discussion

The results highlight two main mechanisms affecting soil mineral N accumulation and the potential for N leaching in the winter season following a drought: soil N release and interaction with pasture N uptake. The results from the APSIM modelling, based on the drought of 2008, show the potential for nitrate accumulation (20 kg N/ha) in the soil during a drought. Soil nitrate levels were compounded when fertiliser N was applied. The glasshouse experiment confirmed soil N accumulation (15 kg N/ha) during an "extreme" (6-week) drought, and a substantial amount of additional N released ("N flush") upon rewetting (40–60 kg N/ha; 0–15 cm). These results have to be set in the context of a cut and carry system, i.e., no urine deposition was included in the simulations or glasshouse experiment, and would probably result in greater losses. The N flush from the Horotiu soil was greater than from the Otorohanga soil and shows that, even for similar soils, N flushes can vary in magnitude because of different mineral and biological sources mobilised upon rewetting. Sparling & Ross (1988) found that the total N or C content of 20 New Zealand grassland soils explained 50–60% of the variation in mineral N flush. This was a positive relationship suggesting that soils with high N or C will have greater flushes of N upon rewetting.

The second important mechanism is the interaction of soil N with the pasture. As we observed in the glasshouse trial, the duration and severity of drought will affect the time it takes for pastures to resume growth and begin removing N from the soil. The pasture recovered much more quickly after the 3-week drought and had little effect on total cumulative yield and soil N levels. Pasture subjected to 6 weeks of drought took 3 weeks to recover, and total yield (and N uptake) was only about half of that in the control treatment over the 12-week period. There were 16–24 kg N/ha of available N remaining in the soil 6 weeks after rewetting, suggesting that physiological rather than N limitations were the cause of slow re-growth (Colman & Lazenby 1975). This shows that after a severe drought, pastures may take a long time to recover and assimilate available N, which should be part of any decisions made around N fertiliser and feed planning.

## Conclusions

A "moderate" drought (e.g., the 3-week treatment) was insufficient to perturb the soil-plant system, and pasture growth and N uptake recovered immediately upon rewetting. In more extreme droughts, measurements indicated a mismatch between the flush of soil mineral N and pasture uptake that could potentially increase N loss through leaching. After a late-breaking drought, leaching could be further exacerbated by fertiliser N additions. The outcomes depend very much on the severity and timing of drought. The timing of the start of drainage in relation to the end of the drought will strongly influence N leaching. The 2008 drought was an example of a rapid rewetting of the soil profile and a chance of leaching before pasture could recover. In other years rewetting can be more gradual, resulting in good growing conditions and uptake of N. More work is needed to refine advice and strategy for fertiliser management that is tailored to soil properties and drought development, so as to meet production and environmental goals.

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## REFERENCES

Ballance 2010. Post-drought nitrogen use. Ballance Research Fact Sheet. Accessed: 12 June 2013. http://www.nrc.govt.nz/upload/11524/Post-drought%20Nitrogen%20Use.pdf

Birch, H.F. 1964. Mineralisation of plant nitrogen following alternate wet and dry conditions. *Plant and Soil 20*: 43-49.

Blakemore, L. C.; Searle, P. L.; Daly, B. K. 1987. Methods for chemical analysis of soils. New Zealand Soil Bureau Scientific Report 80.

Colman, R.L.; Lazenby, A. 1975. Effect of moisture on growth and nitrogen response by *Lolium perenne*. *Plant and Soil 42*: 1-13.

DairyNZ 2012. Nitrogen use after a dry summer. DairyNZ Farmfact 7-17. Accessed: 24 May 2013. http://www.dairynz.co.nz/file/fileid/43742

Griffiths, R.I.; Whiteley, A.S.; O'Donnell, A.G.; Bailey, M.J. 2003. Physiological and community responses of established grassland bacterial populations to water stress. *Applied and Environmental Microbiology 69*: 6961-6968.

Hewitt, A.E. 1998. New Zealand soil classification. Manaaki Whenua, Landcare Research, Lincoln. 133 pp.

Keating, B.A.; Carberry, P.S.; Hammer, G.L.; Probert, M.E.; Robertson, M.J.; Holzworth, D.; Huth, N.I.; Hargreaves, J.N.G.; Meinke, H.; Hochman, Z.; McLean, G.; Verburg, K.; Snow, V.; Dimes, J.P.; Silburn, M.; Wang, E.; Brown, S.; Bristow, K.L.; Asseng, S.; Chapman, S.; McCown, R.L.; Freebairn, D.M.; Smith, C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy 18*: 267-288.

Li, F.Y.; Snow, V.O.; Holzworth, D.P. 2011. Modelling the seasonal and geographical pattern of pasture production in New Zealand. *New Zealand Journal of Agricultural Research 54*: 331-352.

LIC 2011. New Zealand Dairy Statistics 2010/11. Report Livestock Improvement Corporation.

Probert, M.E.; Dimes, J.P.; Keating, B.A.; Dalal, R.C.; Strong, W.M. 1998. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agricultural Systems 56*: 1-28.

Sparling, G. & Ross, D. 1988. Microbial contributions to the increased nitrogen mineralization after air-drying of soils. *Plant and Soil 105*: 163-167.

Tait, A.; Henderson, R.; Turner, R.; Zheng, X. 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology 26*: 2097-2115.

Verburg, K.; Ross, P.J.; Bristow, K.L. 1996. SWIMv2.1 User Manual. Divisional Report No 130. CSIRO Division of Soils: Canberra, Australia,