Nitrogen leaching implications of poor pasture persistence

K. BETTERIDGE[1], J. CRUSH[2], S. LEDGARD[2] and M. & S. BARTON[3]
[1]*AgResearch Grasslands, Private Bag 11-008, Palmerston North 4442*
[2] *AgResearch Ruakura Research Centre, Private Bag 3123, Hamilton 3240*
[3]*521 Hingarae Rd, RD 1 Turangi 3381*
keith.betteridge@agresearch.co.nz

Abstract

Farmers have indicated that perennial pastures sown in the Lake Taupo catchment revert to low quality species within 8 to 10 years. These may be renewed with perennial pasture species following an autumn then spring cropping regime, or resown pasture-to-pasture by direct-drilling into glyphosate-sprayed turf or following full cultivation. Vegetation which is desiccated and/or ploughed-under before sowing will decay and release mineral nitrogen (N). The mineral N from these sources is available for newly sown plants but can also be leached. In a large, replicated, rotationally cattle-grazed trial near Lake Taupo, new pasture was established with the high sugar ryegrass (HSG) *Aberdart* in one treatment only by direct-drilling, following glyphosate application in late summer. Existing pasture remained in Control plots. Renovated pasture leached 63 kg nitrate-N ha^{-1} in the 8 months following establishment compared 8 kg nitrate-N ha^{-1} in Control ($P<0.05$). There were no differences in the amount of leached N amongst treatments in the second year ($P=0.1$). Nitrogen leaching losses resulting from pasture renovation and forage cropping practices are discussed in relation to the impacts these have on future pasture management and renewal options and on the potential value of new germplasm in the Lake Taupo catchment, whose management is constrained by a N cap.

Keywords: nitrogen leaching, pasture establishment, Taupo

Introduction

Farmers in the Lake Taupo catchment require a resource consent to farm. They must develop a nutrient management plan that shows the annual farming operation will not leach more nitrogen (N), on average, than allowed by their nutrient discharge allowance (NDA; kg N leached ha^{-1} yr^{-1}). Most N leached from grazed pastures comes from urine (Ledgard 2001).

Perennial pastures that fail to persist in the long-term require resowing and many Taupo farmers say their pastures revert to browntop (*Agrostis capillaris*) dominance within 8 to 10 years. Poor performance in the years preceding resowing results in lowered pasture production and this increases the need for forage crops and N fertiliser to meet animal feed demands during winter and early spring.

To successfully establish pastures and crops, resident pasture is typically desiccated, buried, or both, to remove competition and unwanted pasture species. This plant litter breaks down to release mineral N which is available for plant uptake, incorporation into the soil organic matter pool, or loss through leaching.

Betteridge *et al*. (2007), in a 3-year cropping trial in the Lake Taupo catchment, measured from 80 to180 kg nitrate-N leached ha^{-1} yr^{-1} from annual cut & carry crops of triticale plus its annual ryegrass cover crop. In the one wetter-than-average year when greenfeed maize plus its cover crop was grown, 220 kg nitrate-N ha^{-1} yr^{-1} was leached. This compared to only 14 to 22 kg nitrate-N leached ha^{-1} yr^{-1} from perennial cut & carry crops of ryegrass (*Lolium perenne*) + white clover (*Trifolium repens*) or lucerne (*Medicago sativa*), sown in the first year only of that 3-year trial. Notwithstanding the different N fertiliser regimes, they concluded that cultivation of the crop stubble and the springtime desiccation and ploughing of the winter cover-crop were major contributors to the higher rates of leaching from annual, compared to perennial cropping regimes. In a concurrent trial on an adjacent farm, rotationally grazed cattle leached only 12 kg nitrate -N ha^{-1} yr^{-1} (Betteridge *et al.* 2007). Many research papers (e.g. Di & Cameron 2002; Francis 1995; Helyar *et al.* 1997) have reported high N leaching losses during pasture-crop-pasture and pasture-pasture management regimes, especially in the first year out of permanent pasture. However, these losses are rarely discussed in relation to managing pastures constrained by environmental regulations as farmers in the Lake Taupo catchment now experience.

In this paper we compare the leaching loss during the 2 years following establishment of new high-sugar ryegrass (HSG)-based pasture, with that leached from undisturbed Control pasture. This renovation was required as part of a large cattle grazing trial designed to compare four N leaching mitigation strategies with Control within the Lake Taupo catchment (Ledgard *et al.* 2007). Full results of that trial will be reported elsewhere. Results from the HSG-renovated and Control pasture treatments are discussed in relation to: (1) the impact of N leached during pasture renewal on a farmer's compliance with the NDA and; (2) why there is an urgent need for greater persistence of high yielding, high quality pastures, as environmental imperatives have the potential to impose constraints on future pasture management practice.

Materials and methods

In February 2007, on a private farm on the western shores of Lake Taupo, a grazing trial comprising 25, 0.5 ha paddocks on a yellow brown pumice soil (typic Vitrandept, sandy loam) of moderate fertility, was established. Grazing commenced on 5 May 2007.

Pastures

The base pasture was known to be more than 5 years old and comprised *L. perenne, Holcus lanatus, Dactylis glomerata, A. tenuis, T. repens, T. pratense* and a number of weed species.

One mitigation treatment required the establishment of the HSG *Aberdart* with AR1 endophyte. The elevated soluble sugar:crude protein ratio in this pasture species was expected to improve the utilisation of dietary N within the animal, compared to grass species without this characteristic (Pacheco *et al.* 2010), thereby reducing the amount of N excreted as urine (Moorby *et al.* 2006). Five replicate plots without pasture renovation were used as the Control. Three other mitigation treatments were also established but are not reported here.

In late February 2007, all pastures were heavily grazed by cattle and 1 week later, the five replicate 0.5-ha plots assigned to HSG were sprayed with glyphosate to kill resident grass and weed species. HSG was sown at 20 kg ha^{-1} using a Baker cross-slot seed drill, 7 days after spraying. On 15 May 2007, all HSG plots were sprayed with 2 L ha^{-1} Basagran® and 2 L ha^{-1} MCPB for weed control. There was no grazing of HSG or Control pastures between February and 5 May due to dry conditions. In mid-May, 15 kg urea ha^{-1} was applied to HSG plots only, in response to yellowing of the pasture, but no other N fertiliser was applied at any time during the trial.

Soil fertility In November 2007, Serpentine super 10K (24 kg P, 45 kg K, 31 kg S, 20 kg Mg ha^{-1}) was applied to replicates 1 & 2 and serpentine super 5K + Calmag (78 kg P, 45 kg K, 85 kg S, 20 kg Mg ha^{-1}) was applied to replicates 3-5 in response to October soil test results (Table 1). Maintenance fertiliser rates were applied thereafter.

All plots were grazed from 5 May 2007. Over 2 or 3 days, plots within each replicate were grazed concurrently, with cattle moving sequentially from Rep 1 through Rep 5. In the first 12 months, 20, 8-10 month-old heifers (ave. liveweight 274 kg) were assigned to treatment groups which grazed their respective treatment plots throughout the next 12 months. In April 2008, 12, 18-20 month-old cattle (460 kg) were introduced as replacements for the second year of the trial. The general guide for grazing management was to commence grazing when pasture mass was ~2500 kg DM ha^{-1} and finish when a residual of 1200-1400 kg DM ha^{-1} remained.

When pasture growth was high, cattle cycled through the plots continuously, but when growth was slow, cattle were removed from the trial, to simulate the longer grazing rotation used by sheep and beef farmers in the catchment. There were 24 grazing events during the 2-year period.

Table 1 Mean October 2007 and November 2008 soil test data within replicates.

	Rep				
2007	1	2	3	4	5
Olsen P (µg/ml)	26	25	16	16	16
Exchangeable K (QT)	5	5	5	5	5
SO_4-S (ppm)	13	18	18	14	17
2008					
Olsen P (µg/ml)	36	23	22	24	24
Exchangeable K (QT)	4	4	4	5	5
SO_4-S (ppm)	8	9	8	8	10

Measurements

Soil test: Approximately 20 soil cores (25 mm x 75 mm deep) were bulked within each plot and a subsample was analysed using MAF Quicktest procedures. Soils were sampled in spring and fertiliser applied in summer, with rates chosen to ensure Olsen P and exchangeable K levels did not limit pasture production.

Nitrate-N in soil water at 600 mm depth: Within each plot, 30 porous ceramic cups (Weihermuller *et al.* 2007) were established at 600 mm depth, using a stratified randomisation procedure to ensure one cup was located within each of the 30, 167 m^2 grid cells overlying each paddock. These were established by 20 April 2007 and first sampled on 14 June 2007.

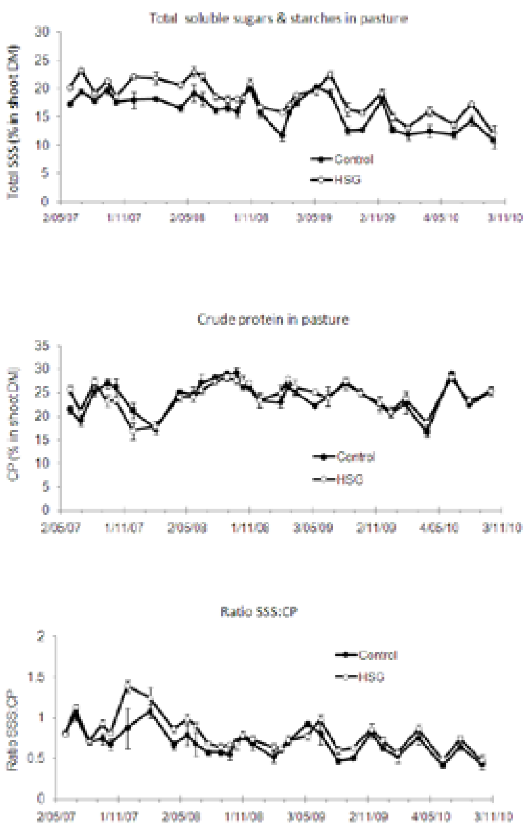
Soil water sampling was undertaken whenever approximately 50 mm of accumulated drainage had occurred. This was measured using one 300-mm-diameter by 500-mm-deep lysimeter adjacent to the grazed plots. These data were in close agreement with drainage volume determined by the model of Woodward *et al.* (2001) that used on-site meteorological data. Soil water at 600 mm was extracted by applying approximately 100 kPa suction to the cup and drawing the collected water from the apparatus for later analysis for nitrate-N. Leached N was the product of mean

Table 2 Mean botanical composition (% DM) in October 2008 of the *Aberdart* high sugar ryegrass (HSG) and Control pastures without pasture renovation.

	Pasture components				
Treatment	Ryegrass	Other grasses	Legumes	Weeds	Dead material
HSG	64	15	9	8	4
Control	47	21	16	11	4
	*	*	ns	ns	ns

*P<0.05

Figure 1 Mean concentration (SD) of a) soluble sugars+starches, b) crude protein and c) the ratio of [soluble sugars+starches]:crude protein, in samples plucked from high sugar grass (HSG) and Control pastures without pasture renovation, prior to grazing during the first 2 years of the trial.



nitrate-N concentration of all ceramic cups in the plot and drainage volume during the period prior to the sampling.

Analysis for nitrate-N concentration was by automated colorimetry using a FIAStar 5000 flow injection analyser (according to ISO standards 11732 and 13395).

Biomass and quality: Prior to and after grazing of each plot, pasture mass was measured with a rising plate meter to estimate herbage removal and to quantify the residual mass. Plate readings were obtained by walking random tracks around the paddock and measuring plate height at every 5th step, to provide a minimum of 50 readings within each paddock. No allowance was made to compensate for pasture growth over the 2- or 3-day grazing intervals for each individual plot. Pasture quality samples were taken from the HSG and Control plots before a new grazing rotation commenced. These were collected as 'plucked samples' from 10 random sites along a transect within each paddock and were immediately frozen in liquid N and kept frozen until they had been freeze-dried. Samples were milled to pass a 1-mm-aperture-mesh prior to analysis. Freeze-dried samples were analysed for water soluble carbohydrates and starches (NIRS)[1] and crude protein (N%*6.25). Separate plucked samples were also taken from all non-HSG plots and bulked within reps for NIR analyses for crude protein content. The latter samples were couriered to Ruakura and oven-dried 2-4 days later. The bulked oven-dried samples were also analysed for N content to enable the estimation of N intake by cattle in all treatments of the larger trial. Nitrogen content was determined by NIRS.[1]

Statistical Analyses

Treatment and Year effects of botanical composition, pre- and post-grazing pasture mass, and apparent DM and apparent N consumption variables were analysed by ANOVA using Genstat 11. Time trend effects were described by REML analyses using Genstat 11.

Results and Discussion

Pasture composition and quality: The *Aberdart* HSG established well as seen by the higher ryegrass content at 21 months after sowing, compared to Control (Table 2). Although *Aberdart* was not specifically identified, the sown rows were apparent throughout the 4-year trial which strongly indicates that the dominant ryegrass was the sown HSG. There was no difference amongst other botanical components in which other grass species comprised *A. capillaris* and *D. glomerata* species and *H. lanatus*. The dead material component was low.

[1] feedTECH, AgResearch, Palmerston North

In the frozen pasture samples, the spring and summer content of water soluble sugars+starches of HSG was higher than in Control (Fig 1a; P<0.01) but the crude protein content of the two pasture types did not differ (Fig 1b). The ratio of soluble sugars to crude protein was elevated in the HSG pastures over the spring/ summer period compared to Control (Fig 1c; P<0.05).

Pasture mass and utilisation (Fig. 2) HSG pre-grazing herbage dry matter (DM) mass was lower than in Control (P<0.01) and pre-grazing mass in Year 1 greater than in Year 2 (P<0.001). Time trend analysis showed HSG pre-grazing mass was lower than Control in May, June and July of Year 1 (P<0.01) reflecting the removal of all but the legumes when glyphosate was applied in February 2007 and the relatively slower growth of *Aberdart* seedlings. From August 2007, differences in pre-grazing mass between pastures were small and variable, indicating similar growth of pastures once *Aberdart* had established. Post-grazing mass showed a significant Date by Treatment interaction (P<0.01). This is attributed to Control cattle being unable to fully utilise the high mass of relatively low quality pasture (high dead matter content) until August in Year 1. This dense mat of pasture accumulated in Control between February and May while the trial was being established. In contrast, HSG litter resulting from chemical desiccation would have disappeared much sooner without impacting biomass measurements or cattle intake. It is also probable that the dominant *Aberdart* was more palatable than the grasses in the resident pastures. Averaged over both years, apparent DM consumption (difference between pre- and post-grazed covers) of Control cattle was 14% greater than of HSG cattle (P<0.01). There was no apparent intake difference between years. These Control cattle also had a 10.6% higher apparent consumption of N (42.6 kg ha^{-1}) than HSG (38.5 kg N ha^{-1}) (P<0.01; Table 3).

The lower apparent N intake combined with the hypothesis that N is utilised more efficiently in the rumen by animals on HSG, both predicted that excreted urinary N and, therefore, leached N should have been lower than by Control animals, but this was not found.

Nitrogen leaching The cattle-grazed renovated HSG pastures leached 55 kg more nitrate-N ha^{-1} than the Control pastures in 2007-8 (P<0.01), but a similar amount was leached in 2008-9 (Table 4). Considerably more N was leached in the second year, possibly due to the switch from R1 to R2 cattle in 2008-9. After the first four soil water samplings in June-July 2007, 70% of the total nitrate-N that leached from HSG in that year had been accounted for. By contrast only 43% of the annual nitrate-N that leached from Control had been measured during this time.

This finding is consistent with other research in the Lake Taupo catchment where large amounts of N were leached following pasture-to-pasture renovation or pasture-to-annual forage crops in a cut and carry trial (Betteridge *et al.* 2007) and in grazed plots of winter forage on similar soils adjacent to the Taupo catchment (Shepherd *et al.* 2009).

The high rate of N leaching from HSG-sown pastures seems to have been a consequence of the elevated mineralisation of N from decayed pasture residues and enhanced mineralisation of soil organic matter associated with direct-drilling. Nitrogen mineralisation is greatest in the first year out of pasture (Di & Cameron 2002; Francis 1995; Helyar *et al.* 1997). Therefore, the high rate of N leaching is likely to be due to accelerated

Figure 2 Mean (SD) pre-grazing, post-grazing and apparently-utilised biomass of Control and *Aberdart* (HSG) pastures sown in March 2007 in the first 24 months of the trial. *Aberdart* was.

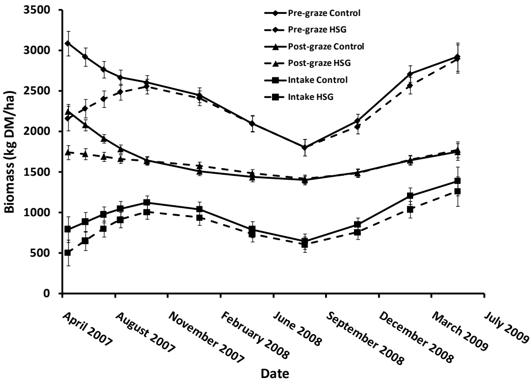


Table 3 Mean apparent nitrogen intake (kg N ha^{-1} day^{-1}) of steers grazing HSG and Control pastures in 2007-8 and 2008-9.

Pasture type	2007-8	2008-9
HSG	39.0	38.1
Control	44.4	40.9
	$LSD_{0.05}$ Year 5.4	$LSD_{0.05}$ Treat 2.6

Table 4 Mean nitrate-N leached (kg ha^{-1}) in 12 months during 2007-8 and 12 months during 2008-9 from pasture renovated with *Aberdart* following chemical desiccation and direct drilling in March 2007, compared to all other treatments where pastures were not renewed.

Pasture type	2007-8[1]	2008-9
Renovated	63	25
Control	8	22
	LS $ratio_{0.05}$ 2	$LSD_{0.05}$ 10

[1] Back transformed means adjusted for bias following analysis of Log-transformed data. Error terms cannot be back-transformed so LS ratio is needed. Transformation was not required in 2008-9.

mineralisation during pasture renewal than to *Aberdart per se*. This study highlights the challenge of introducing new germplasm with minimal disturbance, to take advantage of new traits that enhance economic and environmental benefits.

Practical implications

The NDA that has been imposed on farmers in the Lake Taupo catchment effectively prevents any increase in a farm's stocking rate that leads to increased N leaching losses, unless the farmer can integrate N mitigation practices or buy N credits from another farm within the catchment. The high N leaching losses associated with pasture renovation in this trial and forage cropping in general, seriously limits this management option and, by default, the potential value of new germplasm in this environment.

The NDA is estimated using the Overseer® nutrient budget model. Currently, the model does not include the effect of pasture renovation on N leaching because such effects were thought to be small and would typically involve only a small part of the farm in any one year. Hence, pasture renovation would have very little impact on the calculation of the long-term N balance. Further research is needed to understand the drivers and magnitude of the effects of pasture-pasture renovation on N leaching for it to be integrated into Overseer®.

If the increase in N leaching from pasture renovation is representative and if its effects were accounted for in NDA calculations, then the possible implications can be evaluated. We used a 120-ha Taupo case study farm with an NDA of 23 kg N ha^{-1} yr^{-1}. It carries 200 weaners, 80 R1 and 140 R2 beef finishing animals (3.5 head ha^{-1}), and this permits the leaching of 9.5 kg N $head^{-1}$ yr^{-1}, or 2900 kg N over the farm. Assuming 10% of the farm is regrassed each year, as is typical on many farms in this region, and assuming that an additional 54 kg N ha^{-1} is leached during pasture-to-pasture renovation, an extra 648 kg N yr^{-1} will be leached when renewing pasture. To stay within the NDA of 23 kg N ha^{-1} yr^{-1}, cattle numbers would need to be reduced by 68 (68 x 9.5 = 682 kg N leached). With fewer animals farmed there is less urinary N leached, but there is also less need for additional high quality feed. Whereas the stock will grow better with the new pasture, it is likely that there will be insufficient animals to control pasture growth at some times of the year and quality will deteriorate. This will likely accelerate reversion to lower quality and lower yielding pasture species - a potential Catch 22 situation for Taupo farmers working under an N cap. The high N leaching cost associated with resowing and cropping has rarely, if ever, been considered in New Zealand until now. Acknowledgement of the effects of mineralisation of organic matter related to pasture renewal is required.

Most telling is that if these high leaching losses are confirmed and built into Overseer®, to comply with their NDA, farmers undertaking pasture renewal would need to farm fewer cattle, their income would fall and farming, in its present form, may not be viable.

In this study, herbicide spraying, followed by direct-drilling, was the method used to introduce the new grass species. A full cultivation might have increased the rate of N leaching in the first year due to the greater oxidation and mineralisation compared to that from the less-disturbed soil with direct drilling (Dowdell *et al.* 1987; Rasmussen 1999), although a lower rate of leaching has also been reported (Catt *et al.* 2000; Goss *et al.* 1993; Stein *et al.* 1987). Still others report no difference in N leaching between the two methods of seed-bed preparation (Ellington & Reeves 1990; Hansen *et al.* 2010). Irrespective of these relative differences in N leaching, the apparently large amount of N leached with pasture renewal indicates the need to implement N loss mitigation practices such as: use of DCD to inhibit nitrification, refraining from applying N fertiliser during pasture renewal, and sowing pastures when potential leaching losses are low (spring rather than autumn).

Managing N emissions from farms applies to few New Zealand farmers at present but, as the Resource Management Act and Dairy Accord are more widely and rigorously implemented, all farmers will face similar environmental constraints on their farming operations. Therefore, whole-farm modelling and field trials relating to pasture renovation need to be undertaken to provide greater knowledge, and to test mitigation options for farmers that will enable them to optimise farming operations within these environmental constraints. The importance of improved pasture persistence to reduce the need for pasture renovation must be recognised. System improvements on farm have to be measured against the amount of N, or any other pollutant, emitted. For Taupo farmers there is no improvement unless the farm's gross margin per kg N leached is higher than the *status quo*. Improved pasture persistence will contribute towards this goal.

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