FERTILISER ADVICE – WHAT PROGRESS CAN WE MAKE?

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Introduction

New Zealand pasture systems have traditionally relied on clover to fix nitrogen (N) but fertiliser N use has increased in recent years, especially in the dairy sector. As the pastoral sector strives for productivity gains with smaller environmental impact, efficient use of N fertiliser inputs becomes a part of the challenge. Efficient use of N fertiliser benefits both the farmer (more effective conversion to saleable products) and the environment (smaller losses to water and air). The aims of this paper are to provide a stock take of current knowledge, and to identify areas of possible improvement in N fertiliser recommendations for pasture.

Minimising losses to the environment

Grazed pastoral systems have inherently low N efficiencies when compared with cropping systems (Domburg *et al*., 2000). However, even within pastoral farms there can be a wide range of N efficiencies (Wheeler & Power, 2011). The effects of increasing N inputs to dairy and beef systems were clearly demonstrated by Rotz *et al*. (2005). They assembled data from European studies and showed that for these systems, losses of N to the wider environment (volatilisation, denitrification, runoff and leaching) increased with increasing N inputs, whether as fertiliser or feed. A similar relationship holds between N inputs from a range of sources and subsequent N leaching and N inputs when data are assembled for New Zealand farms (S. Ledgard, Pers. Comm.).

The role of nitrogen fertiliser on N losses from the farm system can be considered as ‘direct’ or ‘indirect’. By indirect, we mean the effects that fertiliser N application has on pasture dry matter production and consequent N consumed and N excreted per ha by the grazing animals, which will then determine the farm N losses. By direct, we mean losses that arise after application of the fertiliser; as ammonia volatilisation, nitrous oxide emissions (and N_2 gas) and by nitrate leaching. The goal is to use fertiliser N more efficiently to reduce losses from the system both as direct and indirect losses.

The real challenge is perhaps tackling indirect losses because of the complexities of the pastoral farming system and the interaction of N fertiliser with many parts of this system, not least stocking rate (Ledgard *et al*., 2006), but also pasture N content and resultant urinary N content. There is considerable research effort to improve the N efficiency of pastoral systems through a wide range of management practices (e.g. Shepherd & Chambers, 2007; Monaghan *et al*., 2007; De Klein *et al*., 2010). In this paper, we focus on the potential to decrease direct losses of fertiliser N.

Risk of loss of N fertiliser by leaching can, to a large extent, be managed by good fertiliser practice; avoiding application in the winter months when growth rates are slow and drainage through the soil can leach fertiliser N. This advice is well documented (Ledgard, 1986). If not followed, losses potentially can be large and reported to be as much as 30-50% of N fertiliser (Ledgard, 1989; Cookson *et al*., 2001) from winter applications (May-July).

Urea is the most commonly used form of N fertiliser in pasture-based systems within New Zealand but is at risk of ammonia volatilisation during urea hydrolysis and conversion to ammonium-N. Losses can vary but may be as much as 20% of applied N under some circumstances. One way to potentially improve fertiliser N use efficiency, therefore, is to use a urease inhibitor to slow urea hydrolysis. N-[n-butyl] thiophosphoric triamide (NBPT) is one such inhibitor. The effectiveness of NBPT to decrease ammonia volatilisation from urea is well documented (Watson, 2000), with a halving of NH_3 losses having been reported (Zaman *et al*., 2008).

Nitrous oxides are of less agronomic importance, being only a small proportion of applied N, but are clearly important as a potent greenhouse gas. The use of dicyanamide (DCD) has been shown to decrease nitrous oxide losses from urea by slowing nitrification (Zaman *et al*., 2008).

The benefits that should accrue to the farmer are derived through smaller losses of the applied N fertiliser, with greater scope to turn applied N into pasture dry matter.   When operating at N applications of 35 kg N/ha, savings of, say, 10% of applied N (for example, through savings from reduced ammonia volatilisation) should provide yield benefits: equivalent to 3.5 kg N/ha in this example. Although present, yield benefits from the additional 3-4 kg N/ha might be difficult to measure, and become easier to demonstrate at higher application rates (Martin *et al*., 2008). If greenhouse gas emissions become accountable at a farm level, this will be a further driver to decrease losses from N fertiliser applications.

Fertilising for feed

Strategic vs tactical decision making

Fertiliser plans need to be made at both the strategic and tactical level. At the strategic level, farms should understand their pasture production limits (basically, the farm's site potential determined by climate, pasture species and soil-properties) and are able to design their farm system accordingly. Tools such as Farmax (Bryant *et al*., 2010) help to identify times of feed shortage and the solutions to address these shortages will include use of fertiliser and/or supplements.

However, with the strategy in place, farms continually need to make tactical decisions around the next N fertiliser application in response to weather conditions and DM production requirements. It is the tactical decision-making around fertiliser application that is the challenge. When deciding on N applications, sources of risk for a farmer include production, price fluctuations, and financial risk to the business (Parker *et al*., 1994). The greatest risk for the farmer revolves around production because of the pattern and variability of pasture growth and animal utilisation. The key sources of risk in production are: site conditions, weather (rainfall and temperature), season, and animal utilisation (Parker *et al*., 1994) and decision support is needed to help manage this risk.

For example, in terms of risk, Figure 1 shows the range of pasture growth rates (simulated with EcoMod) based on over 30 years of climate data from AgResearch's Tokanui research farm (W King, Pers. Comm.). It is clear that there are certain seasons that have a greater production risk than others. For example, the range of growth rates in spring is much narrower than in summer where soil moisture is likely to be more variable; the modelled growth rate in January ranged from 0 to >60 kg DM/ha/day, which leaves the farmer with much uncertainty about how he will manage feed stocks during that time.

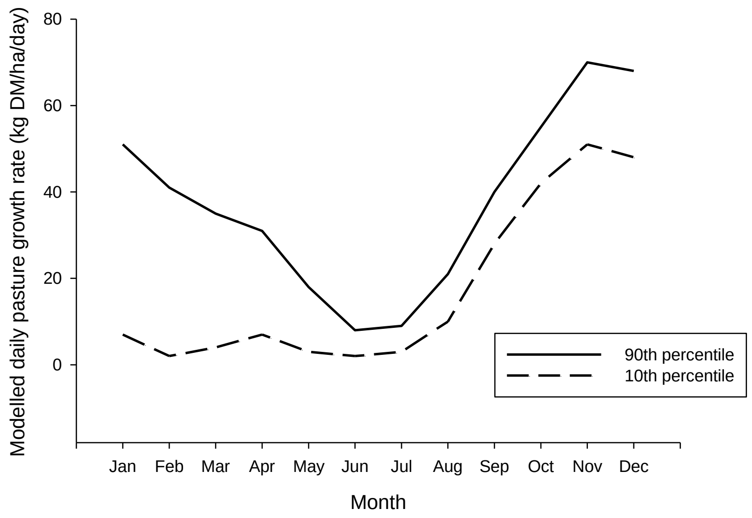

Figure 1. *Modelled daily pasture growth rates at Tokanui, based on 34 years of weather data. Lines show the 10th and 90th percentiles for growth rates each month over the 34 years (Data provided by Warren King).*

State of scientific understanding of fertiliser N response

The challenge is that many factors affect pasture growth and response to N (e.g. Murray *et al*. 2007; Zhang & Tillman 2007) including: rainfall and temperature (or radiation); season; slope and aspect; basal soil fertility; clover content; sward management; and sward composition.

However, what drives pasture response is largely understood, at least qualitatively if not always quantitatively; the interactions between soil and climatic factors are complex. Simply put, the greatest response in DM production to the addition of N fertiliser is when pasture growth is limited solely by the supply of N from the soil. How great that response is depends on the pasture growth rate, weather and soil fertility. In general, the greatest response to N fertiliser is in the spring; when grasses are at the start of the vegetative growth phase and when plant demand for N outstrips supply.

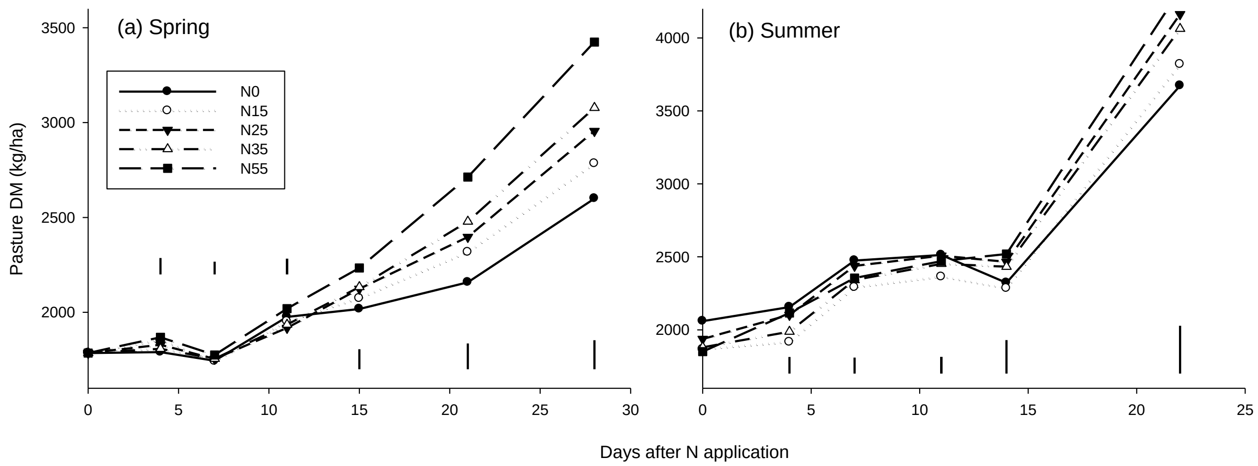

Figure 2*. Examples of pasture growth curves related to different rates of N fertiliser application at the same site in spring and summer. Vertical bars represent LSD at P<0.05.*

Figure 2 is an example of a growth curve in the spring where moisture is not limiting growth. The recovery time after grazing/mowing was approximately 7 days before growth began. It also shows how the application of fertiliser can bring forward the target covers (2700 kg DM/ha) by 10 days compared with no additions of fertiliser. In comparison, the response to fertiliser in the summer at the same location was affected by moisture shortage. There was a small rainfall event (24 mm) a week after application, but consequently the growth slowed due to water limitations. It was not until after a large storm at day 11 (143 mm) that growth took off, but the similarity between N rates hints that either some applied N may have been lost from the system or mineralisation of soil N was sufficient to sustain adequate growth at all N levels.

Packaging of advice/knowledge transfer

The substantial New Zealand research base of pasture N response trials (see later) has provided the industry with a good understanding of the key factors that affect N fertiliser response. Shepherd (2009) confirmed that a sample of farm advisers generally followed a formalised process when determining the need for a N fertiliser application to a paddock and recognised the key decision points. These included: does the farm need the feed; is the paddock likely to respond to N; are conditions ok for spreading; how much and what type; likely response, cost-benefit and comparison with alternative feed sources.

The challenge is providing the quantitative component of this advice, i.e. what is the likely pasture growth response to applied N if it is applied now? Again, the industry has been able to provide generalised 'rules of thumb' or typical response ranges for different times of the year (e.g. Table 1). This is also backed up by a range of sources of general advice on N fertiliser use. An analysis of some of these sources is shown in Table 2.

Table 1. *Typical pasture N response rates according to season (adapted from Anon., 2008).*

Season	**Months**	**Typical response (kg DM/kg N applied)**
Late winter/early spring	July-Sept	10-15
Mid-spring	Oct-Nov	20
Summer	Dec-Feb	unpredictable
Autumn	Mar-Apr	5-10
Early winter	May-Jun	4-8

In addition to the sources given in Table 2, there are tools that can be used to calculate feed budgets and predict pasture growth like Farmax (http://www.farmax.co.nz/) and Q-Graze (http://www.beeflambnz.com) but these do not account for additional DM grown from N inputs.

Table 2 shows there is no shortage of information and advice available regarding N fertiliser application in New Zealand. However, although some of this advice tries to provide specific tactical fertiliser recommendations, the information is given for the country as a whole and it is difficult at that scale to give more precise recommendations. The question, therefore, is whether there is scope for providing more specific recommendations?

Table 2*. A summary of some of the main sources of N fertilizer advice with a brief analysis of pros and cons of each source.*

NZ advice	Reference	Pros and cons
Dairy NZ Farmfact(s)	Anon. (2008)	+ Concise information by subject. Includes how application rates relate to N leaching and drinking water nitrate levels. Table with response rate in relation to growth rate and time for full response - no margin of error for response rate stated
Fertiliser use on NZ dairy farms	Roberts & Morton (2009)	+ Explains environmental risks of leaching and runoff. Includes target ranges for soil tests and guidelines for building up and maintaining soil fertility - Only a few pages dedicated to N fertilisers
Code of practice for nutrient management	Anon. (2007)	+ Best practice for fertiliser use and legal requirements. Planning; nutrient budget and follow-up of results. Environmental risks considered and fertiliser handling and storage. - Not much about response rate or specific N information
Milk production from pasture	Holmes *et al.* (2002)	+ Production focused. In-depth pasture balance with growth rate and consumption. Includes grazing management, practical examples and calculations - little specifically about N
Wise N Use project	http://www.wisenuse.co.nz/	+ Best management practices, N fertiliser and stock health - Only general information

Case studies from other countries
In order to assess this, examples of advice for N fertiliser use on pasture in two countries was investigated.

In the UK, it is our assessment that the level of available advice is similar to New Zealand. The Fertiliser Manual (or Reference Book 209; Defra, 2010) includes a ‘Checklist for decision making’, which is a framework for making fertiliser decisions. At the strategic level, grass growth potential is determined from soil type and average summer rainfall for the site. An added refinement in the UK system is that the soil N supply status (low, moderate and high) is factored into decision making, determined using lookup tables based on previous paddock management and N use. All of these parameters then are used to determine the average annual N application rates for the desired level of production.

Equal N applications are not recommended, but that spring application should receive the greatest share. However, at the tactical level of decision making, the split and timing of application are left to the discretion of the user. The recommendations are given with a caveat that they apply only when moisture, temperature, pH and other nutrients are adequate and balanced. When the conditions are not met N inputs are to be reduced or omitted, but more specific advice is not given. There is also scant support for how to split the recommended annual fertiliser and the cost of fertiliser relative to other feeds is not addressed at all.

Perhaps the best working model for a NZ approach comes from Victoria, Australia. The Target 10 Program (Anon., 2005) has compiled lookup tables included in their "Fertilising Dairy Pastures Manual" for regions in Victoria which give the average N response (in kg DM/kg N) and response time for each month based on a defined pasture index with additional responses for certain pasture species and irrigation (Table 3). The Tables are also offered in a spreadsheet version (http://www.nitrogen.unimelb.edu.au/index.htm). The spreadsheet version includes options for evaluating N cost compared to other feed alternatives. This system is straightforward and states a NFUE (N fertiliser use efficiency; kg DM/ha per kg fertiliser N applied) and the time to reach the response for each month of the year. However, again the drawback is that there is little advice for when conditions deviate from average.

Table 3. *Nitrogen lookup table for average N response in Gippsland, Victoria (adapted from Anon., 2005).*

	Average N Response (kg DM/kg N)											
Pasture index	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Low	7	3	4	7	5	5	6	8	9	9	8	7
Medium	8	4	6	10	9	7	10	13	16	13	12	9
High	9	5	8	14	12	10	15	18	22	18	16	12
Flood Irrigated Ryegrass	10	10	11	14	12	10	15	18	22	18	16	12
Typical response time (Days)	28-35	28-38	28-35	21-35	21-35	35-90	28-42	18-28	14-28	14-21	14-28	21-32

Our conclusion is, therefore, that other countries are able to provide generalised recommendations for 'average' climatic conditions, although they are packaged in different formats to New Zealand advice; but all are still faced with the challenge of providing better quantitative advice when conditions veer from the average. Our question still holds: whether there is scope to further improve N fertiliser recommendations?

New Zealand Research

Nitrogen trials database

Pasture response to N has been measured in a number of trials around New Zealand. The N fertiliser database collates data from 1,272 fertiliser trials conducted during the past 80 years. It was put together as a first step towards creating a decision support system that would make use of relationships between N response and a number of measured variables. However only weak relationships were found between climatic factors and N response (Rajendram *et al*., 2009) possibly due to the number of confounding site effects, and possibly because the trials had different specific aims and methodologies. However, once the data were separated into regions, some significant relationships emerged. Unfortunately, separating the data resulted in few regions with enough trials to draw significant relationships between N response and other factors. In addition to the poor spatial distribution of trials, there was also a poor representation of trials made during the summer, autumn and winter months, with most of the trials run in the spring. This means that in spite of the large data set that we can access, there are still gaps in the research that need to be filled.

One example from the N trials database is presented in Figure 3, showing the average base growth rate for Hamilton and Invercargill, together with the additional growth from 50 kg N/ha. It can be seen from this example how the average N response varies between regions and also how it varies between months at each site.

Although the spread of the data within the database provides some limitations as discussed above, it does provide an invaluable resource moving forward for testing hypotheses and models.

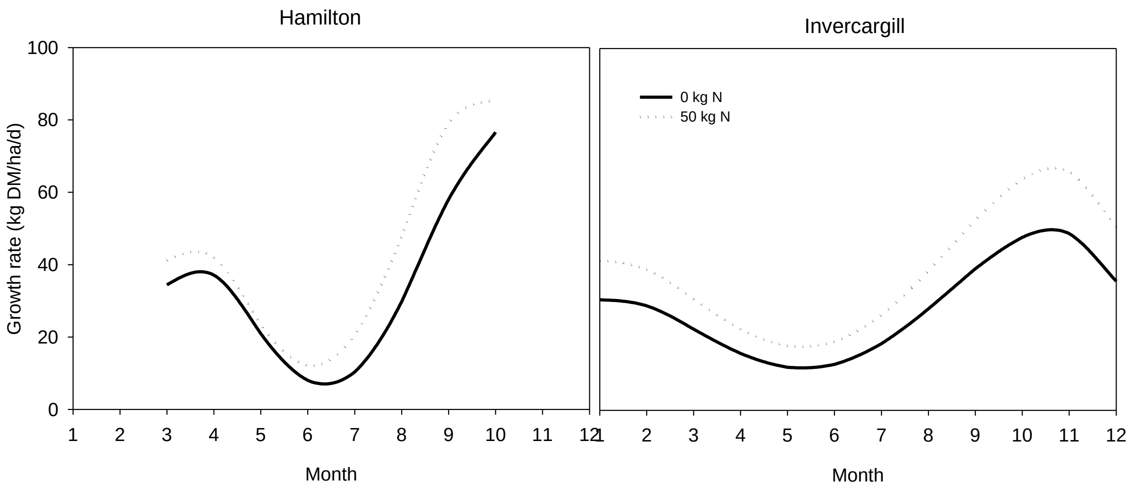

Figure 3*. Average growth rate for N trials in Hamilton (left) and Invercargill (right). The black line represents the growth rate with nil N fertilizer added, and the dotted line is the growth rate when 50 kg N is added.*

Improving decision support

So, is it possible to build on the understanding that we have? Approaches to data analysis and decision support for pasture growth and N response have included the development of mechanistic models of pasture growth (e.g. Sheehy *et al*., 1996) and a range of empirical modelling approaches (Zhang *et al*., 2005). Mechanistic models can reveal the causal factors determining pasture productivity and, because of their strong theoretical base, they are more widely applicable than empirical models. However, they are generally complex and not good predictors of pasture N response.

Empirical modelling (often based on multiple regression analysis) has been used to simulate pasture productivity and investigate inter-relationships between pasture and environmental factors (e.g. Zang & Tillman, 2007). This approach has the advantage over mechanistic models in terms of better predictive capacity for areas where the model has been developed. However, even this approach, based on multiple regression may not be able to cope adequately with the complexity of pasture growth and response to applied N. In particular, the derived models are best placed to work on sites similar to the training dataset used.

By way of an example of the potential use of empirical modelling approaches, Zhang *et al*. (2005) created a decision tree that modelled pasture production on hill farms. The most important factor in influencing productivity was spring rainfall, followed by hill slope. It is worth noting that the model was better at predicting annual pasture productivity than it was for seasonal productivity. Zhang & Tillman (2007) then applied the decision tree to NFUE (N fertiliser use efficiency; kg DM/ha per kg fertiliser N applied) and found that the month of application (August and September vs. rest of year) was the most important factor influencing NFUE (which is not surprising as responses are greatest in the spring). In the early spring, applications of P fertiliser, Olsen P levels and rainfall were the other parameters influencing NFUE. At other times of the year the rainfall, temperature and slope most often determined NFUE.

We believe there is a strong case for the continuing roles of both mechanistic and empirical modelling in improving N fertiliser response understanding, and developing improved decision support. This is clearly illustrated by the fact that, despite the enormous resource represented in the N trials database, there is still insufficient trials data to formulate widely applicable relationships for pasture N response. Therefore, 'more of the same' is unlikely to bring about a step-change in decision support for pasture N fertiliser response; a combination of hypothesis-led, targeted, research combined with modelling is likely to be a more effective approach. Mechanistic models continue to improve and the APSIM simulation model (Keating *et al*., 2003) is one example which could be used to underpin the advancement of understanding in fertiliser N response and extrapolation of experimental datasets to other circumstances.

Other tools available?

Rajendram *et al*. (2009) reported that environmental conditions (temperature and soil moisture) need to be favourable for pasture growth before N fertiliser application is justified. Advisers tend to recognise this in their decision making, although the decision rules around temperature appear to vary between advisers (Shepherd, 2009). Technologies for on-farm measurement of key environmental factors such as temperature and soil moisture status are becoming available. There is scope, therefore, to install and use these tools (for example, in 'indicator paddocks') to guide decisions on fertiliser application.

Nevertheless, the science has to provide sound decision rules around temperature and moisture thresholds. In terms of soil moisture, this would also be better linked to weather forecasts for prediction of rain in the days after application.

We also need to consider how this information might be used. Thresholds can be used to identify when soils are prohibitively dry or cold so that pasture will not grow and there will be no response to N fertiliser. But what happens when conditions are sub-optimal but adequate for some growth? Farmers might choose to apply fertiliser because some growth response might be better than nothing if feed supplies are short. Factoring in environmental conditions might allow a better estimate of expected return on applied N so that the farmer can determine if fertiliser N is more cost-effective than buying in feed.

Conclusions

The goal of N fertiliser use is to use the input as effectively as possible to meet pasture production targets. Industry-funded research has shown that tools are becoming available to decrease N losses after application by reducing risk of ammonia volatilisation, nitrous oxide emissions and N leaching. Decreasing these losses will increase the amount of dry matter produced per kg N applied but the uptake of these fertiliser treatments (such as DCD or NBPT) will depend on the cost-benefit.

Untangling the role of fertiliser N on indirect losses of N from the farm, usually via N in excreta, is more complex because of the range of interactions between N fertiliser and the farm system and structure. However, part of the solution is similar to dealing with direct loss: ensure that the N fertiliser input is used as effectively as possible to produce the target level of pasture production. This requires robust advice on timing and rates of N fertiliser at a tactical level.

Our assessment is that pasture response to applied N fertiliser, and the factors that drive it, are well understood but it is difficult always to convert this into farm-specific, quantitative advice other than for the average situation. Thus, advice is readily available to farmers through a number of providers but tends to be necessarily general. The question is whether there is scope for providing tools for making this advice more specific to a farm in a particular season. The factors that influence N fertiliser response are many and their interactions are complex. The spread of previous fertiliser response experiments is uneven and does not cover all seasons or sufficient locations; nor is it ever likely to, given the resource required to undertake such experiments. These challenges are not unique to New Zealand alone, but are important to address in a major industry that is based around pasture production. Our suggestions for making further progress towards more specific advice are therefore as follows.

There will always be a role for expert opinion to extend the empirical data from N fertiliser response to other circumstances. However, this needs to be underpinned with modelling. The emphasis to date appears to have been on the use of regression models to understand key drivers for N response and for developing relationships to extend prediction to other circumstances. This is ok, but with considerable resource being invested in mechanistic models such as APSIM, we believe there is now scope to use these types of models to extend our understanding and to underpin the development of decision support tools for tactical N fertiliser advice. This would need to be supplemented with targeted, hypothesis-led research on N response to ensure that the mechanistic models are giving the right answers for the right reasons.

In addition, we wonder if there is scope for better packaging of the advice that is already available. Examples of the tools developed within Victoria make us wonder if such approaches should be developed for farms here in New Zealand.

Furthermore, the industry needs to explore whether there are advantages to using real-time monitoring of environmental data (e.g. temperature and soil moisture status) to inform fertiliser application decisions. These technologies are readily available and could be used to trigger decisions on when it is and isn't appropriate to apply N fertiliser (i.e. where moisture and/or temperature are limiting the likelihood of response). This still requires good understanding of the science such that robust threshold values can be set and it would need to be further supplemented by reliable weather forecasting.

Thus, in summary, advice surrounding pasture response to N fertiliser is available and is underpinned by a good research base. Further improvement on N fertiliser use efficiency is likely to be incremental and via a number of routes: better packaging of advice; use of environmental monitoring to support decisions; continue development of scientific understanding, particularly by the use of models; and technological developments (e.g. fertiliser additives).

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