The 'Dairy Nitrogen Fertiliser Advisor' - a web-based tool to assist farmer decisions

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Abstract
Decisions about using N fertiliser rely typically on rules based on expected average pasture responses to N applied. Such rules are mute on the economic limit to N use. In this paper, a new web-based application called the 'Dairy Nitrogen Fertiliser Advisor' (the 'N-Advisor') is presented. The tool uses marginal analysis and profit-maximising principles to inform dairy farmers and their advisors when they are considering how much N to apply to a particular paddock for a particular grazing rotation. The tool embodies response functions that have been derived from nearly 6,000 data sets from experiments in pasture yield response to N undertaken across Australia over the past 40 years. The response functions exhibit the diminishing returns required for marginal economic analysis. Recommendations about nitrogen fertiliser based on information from using the N-Advisor derive from (i) the expected marginal product of a response function for a particular Australian state and season calibrated to the paddock in question, (ii) the cost of the fertiliser (as spread) and (iii) the value of the extra pasture consumed. The N-Advisor enables users to perform 'what-if' analyses, exploring the effect on the profit maximising level of N of changing the cost of N fertiliser, or changing the value of the dry matter consumed. The N-Advisor also enables risk associated with production outcomes to be considered. The production and profit information that can be estimated using the N-Advisor has sufficient rigour and relevance to add value to decisions dairy farmers make about applying N.

Key Words
Urea, nitrogen fertiliser, dairy pastures, response function, decision-making, risk

Introduction
Using N fertiliser on grazing-based dairy farms in Australia is critical to producing pasture, and increasing, with implications for the wider environment (Stott and Gourley 2016). Nitrogen fertiliser is applied regularly after each grazing, with several hundred kilograms of N applied per hectare per year. The decision 'How much N to apply and when?' is made by dairy farmers numerous times for numerous paddocks.

Common recommendations about using N fertiliser are based often on the expected average extra pasture dry matter (DM) produced for the N fertiliser used (sometimes called the 'N response efficiency'). Such guidelines violate the law of diminishing marginal returns, which, if followed, result in higher N use than is warranted on economic grounds (Bishop and Toussaint 1958 p48). The operation of the law of diminishing marginal returns to added variable inputs (when other inputs are held constant), as is the case of increasing N fertiliser rates to dairy pastures, warrants respect. For this reason the 'Generalised Model of N Fertiliser Responses' for the Australian dairy industry (Hannah *et al.* 2016) has been incorporated into an economic framework, to create the 'Dairy Nitrogen Fertiliser Advisor'. This is a web-based tool to assist farmer decisions about N fertiliser in southern temperate Australia. The General Model was determined from nearly 6,000 data sets from experiments in pasture yield response to N, experiments done mostly across temperate southern Australia over the past 40 years. The response functions exhibit the diminishing returns necessary for marginal economic analysis.

The N-Advisor is an output of the 'Dairy Nitrogen for Greater Profit' project funded by the Gardiner Foundation in response to the increasing challenges being faced by dairy farmers to use N fertiliser efficiently and to reduce potentially adverse environmental impacts through over-application of N fertiliser.

The N-Advisor is accessible at http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/nitrogen-advisor.

Method

The profit maximising level of N

The decision rule to maximise profit from using a variable input, such as in an N fertiliser decision, is to apply the input up to where the revenue from an extra kilogram of N fertiliser applied just exceeds the cost of the extra kilogram of N fertiliser applied. Mathematically, this is the same as equating the derivative of the response function (d_y/d_n) to the inverse price ratio (p_n/p_y) (Bishop and Toussant 1958 p46). This profit maximising rule assumes full information, no constraints on capital, and all other inputs held constant.

In the N-Advisor, the price of the input (p_n) is derived from the market price for urea, delivered and spread. Urea is a single-nutrient fertiliser with a high N content (46%), hence it is the cheapest and most commonly used (about 80%) source of N fertiliser for pasture-based dairy farms in southern Australia. In an expansion situation, the correct and also most pragmatic way of valuing the extra pasture consumed by the lactating dairy cows (p_y) is to use an acquisition, or market replacement, value (Johnson and Hardin 1955). Feed barley is used as the reference replacement feed; and the barley DM price is adjusted for its metabolisable energy (ME) content relative to that of pasture - ME being the most important value determining attribute of pasture DM (Lewis *et al.* 2015).

The response function

The response function is the General Model developed by Hannah *et al.* (2016). It is exponential (Mitscherlich) with an asymptotic plateau:

$$y = \alpha(1 - e^{-\beta-\lambda N})$$

where

y is consumption from the added input N scaled as a proportion of maximum obtainable yield,

α is the maximum attainable pasture DM consumption set at 1,

β is an implicit measure of existing soil N and it varies with Australian state and season,

λ is a constant and it is a measure of the curvature of the response function.

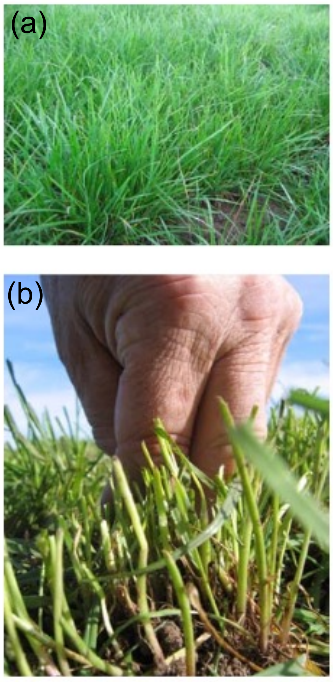

Figure 1. Pre (a) and post (b) grazing dry-mass. Picture shows post-grazing residual of 4-6 cm, equivalent to 1,500-1,600 kg DM/ha. Source: Dairy Australia (2011).

A kg DM/ha value is found for α so that the General Model can be used to determine the profit maximising level of applied N. We do this as simply as possible by asking the farmer or advisor to provide a subjective estimate of the dry mass that is expected to be consumed by grazing dairy cows in the next grazing for their typical application of N. To be specific, the N-Advisor requires information, for the area to be fertilised, about the:

a) observed post-grazing, pre-N application, dry mass (Figure 1b), and

b) most likely pre-grazing dry mass (Figure 1a), for the prevailing conditions with their typical application of N.

The DM consumption estimate (or 'utilisation') in kg DM/ha is determined by subtracting the post-grazing dry mass from the pre-grazing dry mass. We assume that the corresponding N application is reasonably close to the profit-maximising N rate for the long-term price ratio (p_n/p_y) – a robust assumption confirmed by testing, and not an unreasonable one as it is likely that farmers who know their own paddocks through long experience, and know the prices of urea and the value of their pasture, would already be getting the fertiliser decision about right.

Accommodating risk and uncertainty

In practice the pasture DM that will be consumed by dairy cows as a result of applying N fertiliser will differ from the best estimate that is made at the time of the decision. This is inevitably true regardless of the sources of information used to inform the N-Advisor, as the actual pasture DM that will be available for consumption, and will be consumed, cannot be predicted accurately, except by chance. Even if the response function that is applied to the paddock was accurately calibrated to the paddock for the average seasonal conditions which the General Model represents, the resulting production and subsequent pasture DM consumed will depend on future pasture growth conditions such as the extent and timing of subsequent rainfall and temperature events, as well as the management of animals at the time of grazing. This situation applies to all decisions about applying N fertiliser, made with or without the N-Advisor.

Hence, an important part of using the N-Advisor to inform farmer decisions is considering a reasonable range for pasture DM consumed. The approach adopted recognises that the decision-maker is well-placed to make a well informed 'bet' on achieving a return on marginal capital. To this end, the N-Advisor identifies the N application that is likely to be the most profitable for the cases where the actual pasture DM available to be consumed is 20% above or below the consumption that is considered to be 'most likely' (Figure 2). To inform the 'bet' more, the expected extra return on extra capital invested in N is identified for the range of possible applications of N. This point can be found by moving the pointer over the calibrated response curve (text box in Figure 2). The decision-maker can then invest in N fertiliser, subject to a required return on extra capital, adjusted for risk. For example, 'apply N fertiliser until the expected extra return reaches 30% on marginal capital, to allow for risk and uncertainty, and apply no more N beyond this level'.

Figure 2. The Dairy Nitrogen Fertiliser Advisor Interface

Worked example

The pasture DM consumed and the expected returns on extra capital invested in N fertiliser were determined for a Victorian perennial ryegrass pasture growing relatively rapidly during spring. The 'best bet' pre-grazing pasture DM is 2,500 kg DM/ha; and consistent with commonly recommended pasture management strategies (Dairy Australia, 2011) the post-grazing dry mass is 1,500 kg DM/ha. Prices used for urea and feed barley, respectively $630/t and $210/t DM, reflect annual averages (adjusted for inflation) for the past 32 years (ABARES 2015). More immediate grain prices can be sourced from Dairy Australia (2016). The DM price for feed barley was adjusted using the ME content for barley and pasture reported by Agriculture Victoria (2015 a & b, respectively).

The most likely pasture DM consumed, consumption for the last kilogram of N applied, and the marginal return on the last dollar invested in N, for the scenario described above and a range of N fertiliser application rates (including the optimum), is predicted by the N-Advisor and displayed on the N-Advisor interface in the text box that pops up when the pointer is hovered over the calibrated response curves. A fuller set of results is shown in Table 1. The 'best bet' profit maximising N is 40 kg N/ha (equivalent to 87 kg urea). At 40 kg N/ha, the marginal return on the last dollar invested in N expresses as a percentage is 0%. That maximum profit is earned when the last unit of input returns 0% sometimes causes people to wonder how it is that profit can be maximised when zero is made on the last unit of input. The producer has earned larger profits on all the earlier units, hence the sum of all the profits from each previous unit of input applied gives total profit from all units of fertiliser N used. A farmer wanting a minimum risk-adjusted return of say, 30% on marginal capital invested would apply 30 kg N/ha.

Table 1. Most likely pasture consumption and return on extra capital invested in N from a range of levels of N use: Victoria, spring.

N fertiliser applied (kg N/ha)	Pasture DM consumption (kg DM/ha)[1]	Pasture consumption from last kg of applied N (kg DM)[2]	Value of pasture consumed from last kg of applied N ($/kg N)	Cost of last kg of applied N ($/kg N)	Return from last kg of applied N ($/kgN)	Rate of return on last $ invested in applied N (%)
0	546	-	-	-	-	-
10	689	12.5	3.07	1.40	1.67	119%
20	799	9.6	2.36	1.40	0.96	69%
30	884	7.4	1.82	1.40	0.42	30%
40	950	5.7	1.40	1.40	0.00	0%
50	1,000	4.4	1.08	1.40	-0.32	-23%
60	1,039	3.4	0.83	1.40	-0.57	-41%
70	1,069	2.6	0.64	1.40	-0.76	-54%
80	1,092	2.0	0.49	1.40	-0.90	-65%

Notes: Estimated for the value of N in column 1 from (1) the calibrated response function, and (2) the derivative of the response function.

At 40 kg N/ha, the pasture consumed for the last kg of applied N (the marginal product) is 5.7 kg DM/kg N, equivalent to the inverse price ratio. Total expected pasture consumption with 100% utilisation is predicted to be 950 kg DM/ha.

Conclusions

The N-Advisor provides information about production and profit with sufficient rigour and relevance to add value to dairy farmer decisions by testing the intuition and judgments that they use currently in making their decisions about applying N. The information from the N-Advisor enables farmers and their advisors to use response functions for pasture that are derived from valid scientific experiments. The farm-specific information that is required is the farmer's 'best bet' on pasture growth and consumption in a particular paddock for a particular grazing rotation - as they do currently but without the benefit of information about the full response function showing diminishing returns. Risks and errors in estimates of the production that might result from applying the N are considered by varying expected pasture consumption by $\pm$20%, and seeing how this affects the profit-maximising N application. Users can perform 'what-if' analyses to examine the effects of changes in the cost of applied N fertiliser, or changes in the value of the dry matter consumed on the N rate that maximizes profit, and to weigh-up using marginal capital on N or elsewhere in the farm system, or beyond.

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