The feasibility of nutrient leaching reductions (N leaching) within the constraints of minimum impact on the profitability and production of five dairy farms in the Horizons Region

A Report for

horizons regional council

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An additional in-depth analysis of Horizons Farms with emphasis and discussion on model structure as related to marginal economics and ability to determine nitrogen abatement costs.

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Technical Forward

Explanation of marginality and profit maximisation

This report makes extensive reference to marginal analysis - so it is vital the reader has a working understanding of the concepts employed - otherwise large sections of the report will sound - at best - counterintuitive and - at worst - 'just plain wrong'.

A useful starting point is considering a simple 'accounting' view of profit (π**)**, which conceptualises profit as a residual; or what is 'left over' when total cost (TC) is subtracted from total revenue (TR).

This can be expressed thus:

π = TR - TC (or 'profit equals what you earned less what you spent to earn it')

Economics goes a step further, and distinguishes between a firm that 'makes a profit' versus one that is 'profit maximising'; with marginal analysis being the key to determining the latter.

In microeconomics, the term 'marginal' simply means 'one more' or 'one less' - so 'marginal cost (MC) is simply the cost associated with producing one more 'widget' (i.e. a widget is some type of good or service), whereas 'marginal revenue[1]' is the revenue generated from selling one more widget.

Widgets are made by 'firms' (where a dairy farm is analogous to a firm if the widget in question is milk). The standard assumption is firms will maximise profits, which occurs when marginal costs equals marginal revenue: or 'when the last dollar *spent* equals the last dollar *earned'*.

At this point the marginal (or extra) profit (Mπ) from producing an extra widget is **zero** - implying no further gains can be made.

The result is akin to a 'tipping point', where:

- if marginal cost is *less* than marginal revenue then it is profitable to *increase* production and thereby *increase* profitability (as the last dollar spent is less than last dollar earned - so 'add cows'); however
- if marginal cost is *greater* than marginal revenue then it is profitable to *decrease* production to *restore* profitability (as the last dollar spent is more than the last dollar earned - so 'reduce cows').

Marginal analysis is especially useful when making decisions to increase or decrease production - which is something dairy farmers do all the time.

A practical example neatly illustrates the theory.

[1] For the mathematically inclined, MC and MR are merely the first derivative of TC and TR.

Let's assume a hypothetical farm is currently producing 900 kgMS HA (which is a little under the national average). The farmer is therefore considering increasing production; so is targeting 1100 kgMS HA production over the same land area via greater intensification. As planning figures, let's assume:

- Farm gate milk price is $5 kgMS
- Fixed costs (FC) are $4 kgMS
- Variable costs (VC) range from 20 cents to $2.50 kgMS depending on intensity
- Current farm working expenses [FWE] are $4.50 kgMS
- Whilst the farm is currently doing 950 kgMS HA, the possible range is 700 kgMS HA - 1,200 kgMS HA.

The results are summarised in the table below.

Table A: *Hypothetical farm profitability analysis*

KgMS HA	FC $	VC $	AC $	TC per HA $	MC $	TR $	MR $	π per HA $	M π $
700	4.00	0.25	4.25	2975.00	-	3500	-	525.00	-
750	4.00	0.25	4.25	3187.50	212.50	3750	250	562.50	37.50
800	4.00	0.20	4.20	3360.00	172.50	4000	250	640.00	77.50
850	4.00	0.25	4.25	3612.50	**252.50**	4250	**250**	637.50	-2.50
900	4.00	0.30	4.30	3870.00	277.50	4500	250	630.00	-7.50
950	4.00	0.50	4.50	4275.00	**385.00**	4750	**250**	475.00	-155.00
1000	4.00	1.00	5.00	5000.00	725.00	5000	250	0	-475.00
1050	4.00	1.75	5.75	6037.50	1037.50	5250	250	-787.50	-787.50
1100	4.00	2.00	6.00	6600.00	**562.50**	5500	**250**	-1100.00	-212.50
1150	4.00	2.25	6.25	7187.50	587.50	5750	250	-1437.50	-337.50
1200	4.00	6.50	6.50	7800.00	612.50	6000	250	-1800.00	-562.50

Colour code

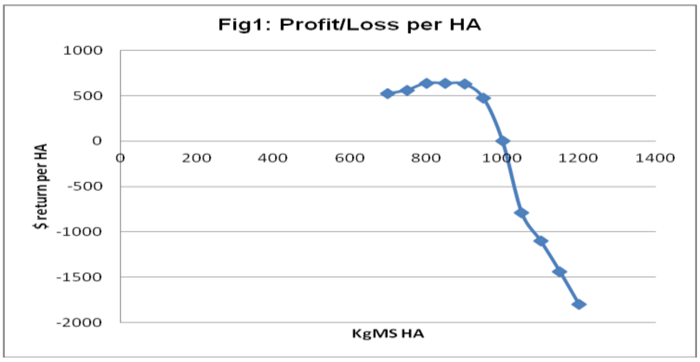
Profit maximising output	Actual or targeted production	Loss making production

The table illustrates the following:

- At an expected milk price of $5 kgMS, any level of production above 1000 kgMS HA will be unprofitable - so that targeted expansion should be abandoned
- Current production of 950 kgMS HA, whilst profitable, is not optimal - as MC is greater than MR - so the farm will benefit from *reducing* production.
- Profit maximising production is almost exactly 850 kgMS HA, so in this case a 21% drop in production leads to a 34% increase in profitability
- The column denoting profit per HA achieves a maximum before reaching a 'tipping point' and declining; whereas the marginal profit approaches zero at the maximum - and is negative thereafter.

The fundamental problem with an output or production based objective is there is no consideration given to profit maximisation - with the result typically being systemic overstocking. This implies a farm essentially has 'two herds': the first is the profit maximising herd (so makes money); whereas the second is a 'parasitic' herd that generates net costs (and thereby *reduces* the profitability of the entire farm).

In the example above, the cows producing the marginal 100 kgMS per HA (between 850 and 950 kgMS HA) are the parasitic herd. Profitability per HA at different production levels is represented in figure 1 (below).



A counter argument is often expressed thus: 'well, that's fine when the milk price is down, but more intensive farms will make plenty of money when the milk price is higher'. As table B shows, this is also flawed thinking. In table B the milk price assumption is increased to $6.00 kgMS but the cost structure remains unchanged. As can be seen:

- the 1100 kgMS production target is now at breakeven (compared to an $1100 HA loss) so is still nowhere near optimal
- the existing 950 kgMS level of production has improved; but is also not optimal - as profit maximisation is closer to 900 kgMS HA (so at 950 kgMS the farmer is just starting to rebuild a parasitic herd)
- A 20% increase in milk price only resulted in only a 6% increase in output from the previous optimum (and a 5% reduction from status quo).

Table B: *Revised farm analysis*

KgMS HA	FC $	VC $	AC $	TC per HA $	MC $	TR $	MR $	π per HA $	M π $
700	4.00	0.25	4.25	2975.00	-	4200	-	1225.00	-
750	4.00	0.25	4.25	3187.50	212.50	4500	300	1312.50	87.50
800	4.00	0.20	4.20	3360.00	172.50	4800	300	1440.00	127.50
850	4.00	0.25	4.25	3612.50	252.50	5100	300	1487.50	47.50
900	4.00	0.30	4.30	3870.00	**277.50**	5400	**300**	1530.00	42.50
950	4.00	0.50	4.50	4275.00	385.00	5700	300	1425.00	-95.00
1000	4.00	1.00	5.00	5000.00	725.00	6000	300	1000.00	-425.00
1050	4.00	1.75	5.75	6037.50	1037.50	6300	300	262.50	-737.50
1100	4.00	2.00	6.00	6600.00	562.50	6600	300	0	-252.50
1150	4.00	2.25	6.25	7187.50	587.50	6900	300	-287.50	-287.50
1200	4.00	6.50	6.50	7800.00	612.50	7200	300	-600.00	-312.50

In reality, it is not possible with a biological system like a farm to obtain the level of precision outlined in the tables - but one can closely approximate. However, very few farmers actually employ any type of profit maximising analysis - and models like Farmax (and the plethora of industry benchmarks) are incapable of profit maximising as they are based on averages, whereas markets clear 'at the margin'. For example, Farm Working Expenses (FWE) is basically a total cost/total revenue approach with average cost analogous to FWE. However, on its own FWE is merely a point estimate - so while FWE can confirm whether a profit is made (or not), unless you have *all* the FWEs for each level of production for the specific farm in question, it is impossible to profit maximise.

A further reason why profit maximising analysis is almost never employed is many farmers erroneously assume that higher production must equate to higher profitability - so the result, is essence, is a form of 'output maximisation' ('productionism') rather than profit maximisation.

The productionist assumption of 'more production means more profit' only occurs if there are economies of scale (EoS) where a farm is struggling to achieve minimum efficient scale. In this case average costs are falling - so all a farmer needs to do is keep expanding until average costs stabilise (at which point there are constant returns to scale - or if an additional 20% of resources are added then widget production should likewise increase by 20%).

However, all systems are ultimately bound by diminishing marginal returns (which occurs when at least one input is fixed - so that becomes the system constraint). For example, the number of cows, the amount of fertiliser applied, and volumes of bought in feed (BiF) can all be increased; but if land area is fixed then that becomes the constraint within a pastoral farming system. Beyond constant returns one has diseconomies of scale due to decreasing marginal returns, so it is marginal costs - rather than average costs - that are critical.

This is illustrated in figure 2.

Figure 2: NZ Dairy Industry – Scale economies over time

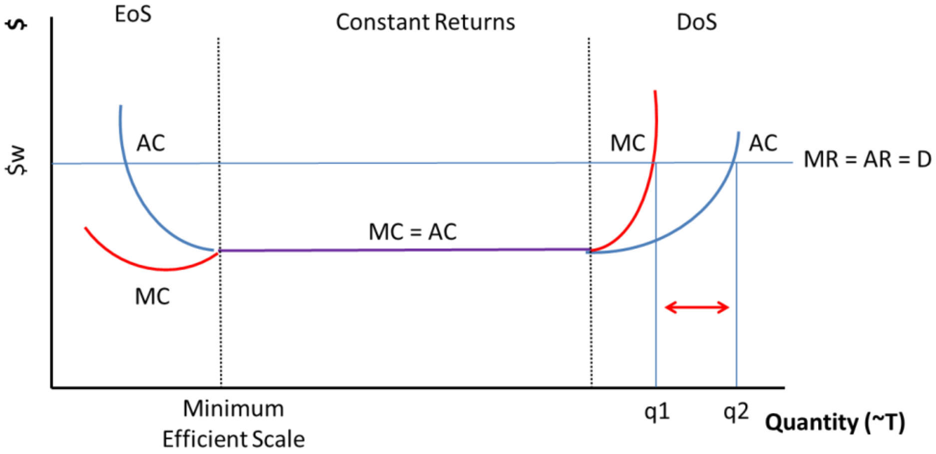


Figure 2 assumes a constant world price for dairy commodities - labelled $w. With a constant price over the production range the result is marginal revenue and average revenue (AR) are identical, and together form the demand curve (labelled D).

A firm's supply curve is merely its marginal cost curve (which is why a supply curve slopes upwards - this is due to diminishing marginal returns) but, as noted above, most farms produce based on average costs; which is represented by quantity q2. However, the profit maximising output is where marginal costs match marginal revenue - and this is represented by point q1. The difference between q1 and q2 is the cost to the farm (or industry) of parasitic cows.

In summary, from an economic perspective all that is required to optimise a system is a thorough understanding profit maximisation; but one cannot profit maximise without knowing a farm's marginal cost and marginal revenue.

Overview of GSL and explanation of why it is different

The explanation above regarding diminishing marginal returns, profit maximisation and the concept of a parasitic herd is an excellent segue into understanding how GSL is fundamentally different from other farm models (such as *Farmax* or the *Whole Farm Model*). In simple terms, GSL is an economic model that uses linear programming (LP) techniques[2] to undertake marginal analysis. GSL can thereby ascertain both where a farm 'is' (i.e. what is the base case) but also where a farm can 'be' (i.e. its individual Y or point of profit maximisation - or alternatively, loss minimisation).

A real strength of LP is its ability to handle constraints: for example, to profit maximise subject to a nitrogen (N) leaching constraint by 'crunching' alternative resource combinations. For example, in terms of energy production the application of N and the purchase of BiF are substitutes - albeit with significantly different cost structures. However, the entire issue of energy production becomes irrelevant if an alternative strategy: reducing stocking rates - is also considered.

In essence, once a constraint is identified GSL will calculate the least cost method of addressing that constraint subject to an overall objective of profit maximisation - and in doing so will 'de-clutter' the analysis by seamlessly eliminating a myriad of inferior outcomes.

The analytical power of GSL becomes apparent when one considers the use of benchmarks within the dairy industry. The rationale for benchmarks is simple: given an inability to maximise numerous variables subject to one or multiple constraints on a 'farm by farm' basis the simplifying assumption is made that farms are, on the whole, homogenous in nature (so are akin to standardised multisite processes such as a McDonald's Restaurant). This assumption is critical as it permits the application of simple benchmarks (e.g. comparative analysis such as kgMS/HA, kgMS/cow, cows/HA, milk production targets, per cow production targets, production at X percentile etc.) that are - at best - irrelevant (as they do not provide the information farmers require to make informed decisions) and - at worst - misleading or erroneous (as the averaging processes masks useful farm specific information).

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2 Linear programming is defined as a mathematical technique used in computer modelling (simulation) to find the best possible solution in allocating limited resources. An example of LP is solving the best assignment of 70 people to 70 jobs. The computing power required to test all the permutations to select the best assignment combination is vast; the number of possible configurations exceeds the number of particles in the observable universe. However, it takes only a moment to find the optimum solution by posing the problem as a linear program. The theory behind linear programming it that it drastically reduces the number of possible solutions that must be checked (see: https://en.wikipedia.org/wiki/Linear_programming).

In comparison, GSL can analyse a farm 'as is' to provide a base case that alternative strategies can be considered. For example, in the material that follows for farm 1, run 1 is the base case whereas runs 2 and 3 are the application of existing industry 'wisdom'. This is essentially a standard template or 'cookie-cutter' approach to farming where stock numbers are held constant and an energy deficit that was previously filled by the application of N is substituted via the purchase of BiF.

In all farms assessed, this approach led to a significant decrease in farm profitability compared to the base case, with a marginal cost of N abatement of up to $1,225 per kg/HA. **From a public policy perspective, this implies that N abatement cannot be achieved without imposing significant economic harm on farmers**.

In comparison, in runs 4-7 the templated prescription is progressively abandoned and other resource options are considered (i.e. grazing off, reducing stock numbers, optimising stock numbers) - albeit within the overall objective of profit maximisation.

In stark contrast with runs 2 and 3, resource re-allocation via GSL not only significantly reduced N leaching (more so than the industry solutions), but results in an increase in profitability compared to the base case. However, there is a warning here: each farm had an N 'tipping point' where further reductions made the farm in question economically infeasible.

The public policy implications of these findings are also stark: compared to status quo is it possible for almost all dairy farmers to make substantial reductions in N leaching at little or no economic cost - indeed, in most cases, farmers would be *better off* (implying a Pareto-safe policy outcome - and positioning farmers for any future move to bring agriculture in the emissions trading scheme [ETS]).

However, for a Pareto safe outcome to occur each farmer needs to know what his or her base case is, and what are the specific combination of changes necessary to profit maximise. Moreover, in the absence of such knowledge policy makers run the risk of:

- Imposing significant - and unnecessary - economic harm on farmers
- 'Locking in' the status quo (via grand parented allocations providing a 'license to pollute') whilst at the same time penalising efficient farmers (who would get comparatively small allocations) whilst rewarding gross polluters (who would get large allocations).

Summary

Executive Summary

1. Existing industry approaches to N mitigation provide relatively modest reductions in leaching, albeit at the cost of imposing significant economic harm on farmers. This is completely unnecessary.

2. The starting point matters - in that all farms surveyed were overstocked so are therefore carrying a 'parasitic herd'. The difference in outcome between industry approaches and GSL is simply that GSL identifies and eliminates the parasitic herd - and therein lies the ability to reduce negative externalities (such as N leaching and GHG emissions) whilst also improving farm profitability. This implies that the marginal cost of abatement is either positive or zero over a key part of the desired abatement range.

3. Based on five case studies of dairy farms within the Horizon's region, it is possible for New Zealand dairy farmers to make significant reductions in N leaching at little or no economic cost compared to the status quo - though beyond certain levels a 'tipping point' emerged where further N reductions made the farm financially unviable (NB: these findings are entirely consistent with GSL analysis generally).

Detailed Points

- All farms could allocate resources more efficiently: but these changes are dependent on the opportunity for marginal increases in efficiency vs. the marginal N leach reduction required.
    - N leach limits create differing levels of constraint that are more dependent on soils and climatic influences than efficiency of resource use.
    - The imposition of set “caps” on farms fails to acknowledge the distinction between efficient and inefficient resource allocation.

- There are options for mitigation which will *reduce N leach and reduce profit* (i.e. the current industry based approaches) and others that will *reduce N leach but improve profit* (i.e. those identified by GSL based on profit maximisation).
    - Current industry recommendations for reducing N may reduce N leach but reduce profit (Refer Tables 1A and 1B Farm 1 analyses; 72 ha).
    - GSL model resource allocation progressively reduces N leaching with least impact on profit (Compare model Runs Farm 1 Runs B-H).
    - Reducing herd number, grazing off and no winter cropping provide the best options if available and acceptable.
        - Acceptability may not be a factor for some of the farms as they have combinations of soil type and rainfall that combine to make dairying unacceptable both financially and environmentally with current costs, prices and N leach caps.

- Depending on response rate, nitrogen provides the best and cheapest additional feed when applied correctly (date and rate); however, Overseer® penalises nitrogen applications at the times when most economic benefit can be extracted (spring and autumn).

    - On all soil types, as Overseer® approaches a lower limit of N leach, the N leach reduction "curve" flattens.
    - **This can increase the marginal cost of any additional N leach reduction required to a point where the farm system becomes unviable.**
    - This may require a change in stock type or perhaps a "hybrid" system of dairy and beef (Example Farm 4.).

- Several of these farms have intensified (or plan to intensify) and will incur large decreases in overall profit and increased N leaching. These increases are possible due to soil and rainfall interacting "favourably" with Overseer criteria (Farms 2 and 3).

    - Much of the decrease in profit is due to unrecognised non-cash costs (depreciation), maintenance costs associated with intensification (infrastructure and machinery), and costs that are now "fixed variable costs" due to use of new infrastructure (insurance, labour, interest, feeds) i.e. the costs associated with intensification.
    - Use of marginal analysis may have prevented this level of intensification where in one case, almost $3.5 million of added capital has been spent for a net increase of about 50,000kgMS (about $70/kg additional MS.)

      A better investment may have been to buy more land.

    - Such intensification is not only unprofitable, it also increases Nitrates to soil.

- Marginal analysis identifies such intensification as being unprofitable. Gross Margin and cash budgets average costs equally across all production income. The marginal cost associated with specific actions are therefore hidden within all-encompassing accounting "categories".

    - This makes any reliance on Gross Margins, averages, benchmarks and ratios fraught with misinterpretation and leads to erroneous "causal relationships" when used for analysing between systems, mitigating nutrient loads or as a basis for policy decisions.
    - If the concept of marginal analysis was more widely understood (Appendices 3, 4 and 5 provide the means for understanding this concept) both farmers' profits and the environment would benefit.

- Existing debt levels impact by altering the point at which resource use reaches a 'tipping point' with reduced profits. Optimisation techniques provide a means to distinguish how critical each debt level may be for any resource combination. N leaching caps impose an added constraint which supersedes that of maximising profit.

- A more co-ordinated National approach that encompasses N leaching "bands" and associated CO_2 emissions combined with specific resource input taxes (bought in feeds, fertilisers, additional fuel) will penalise the less efficient producers proportionately more than efficient producers, create an overall more profitable agricultural industry and provide funds for the environmental improvement now required.

Five farms were selected from a short list of dairy farms in the Horizons Regional Council area which provide insight of these points.

Project Objectives

Service description: Overview

The work is to understand feasibility of nutrient leaching reduction (N leaching), by modelling a small sample of farms' responses to different system changes and changes in assumptions (e.g. debt, product price scenarios), within the constraints of minimum impacts on:

(a) Farms' profitability, and
(b) Farm production

What opportunity do the sample farms have, to achieve N leaching reductions?

More specifically: modelling of 5 case study examples

Objective 1.0 – Initialise and optimise each farm to illustrate the marginal and overall response to progressive decreases in nitrate leaching values

> Based on the knowledge gained from the initial runs, the contractor will modify the underlying assumptions in order to test the sensitivity of results to various assumptions.

Objective 1.1 – sensitivity testing around the optimum. The contractor will also test a range of costs and milk solids prices for a range of scenarios to provide an understanding of what remains achievable and affordable for farmers under more recent dairy price scenarios.

> This will provide additional insight into the impact of constraining N leach under differing product price and cost scenarios.
>
> The impact of debt on such scenarios will also be explored in order to better describe the impact the required N leach reductions will have on final farm profit.

Analysis

To investigate ways to reduce N loss whilst retaining profitability.

The relevant Farm details are contained within the following Tables. Each Table provides not only a number of related resource use options but also provides a structured farm implementation strategy that can be applied by managers to achieve required N leach targets. All the Runs are based on the same resources but with constraints either being removed (for optimisation) or applied (for N leaching reductions).

Each column and row can be mathematically linked to the Base farm data and farm system through the relationships (animals and feeds) associated with resource allocation. By comparing between Columns and Rows, the extent and type of resource changes can be accurately tracked to provide validation for each change.

Each farm is different and optional computer model runs have been completed on these farms to analyse various management options. For each Farm, Run "Base" uses data for each individual farm as supplied in files provided by Horizons Regional Council. These did not include pasture growth, quality and utilisation data nor responses to nitrogen applications.

The GSL model process adequately generates such data from equations used within the model, all of which require to be balanced. This varies from other models used in Agriculture where such imbalance remains undetected until implemented.

➢ ***Farm 1***

Size: [redacted]
Run 1 is the Base farm.
Runs 2 and 3 illustrate N leaching mitigation protocols that have been suggested by industry.

Run 2: **Maintain herd number** (and production) but reduce Nitrogen applications. Buy lower crude protein maize silage to replace the N boosted pasture.

Run 3: **Maintain herd number**, cease all Nitrogen applications and replace with only lower crude protein maize silage.

Run 4**: Reduce herd number** and minimise N application. Continue buying in maize silage. (Link Run between industry protocols and GSL defined resource allocation.)

Run 5: **Maintain herd number** but **Allow grazing off herd** in winter with original N application of 112 kgN/ha. GSL dominated resource allocation that buys silage as currently used. Illustrates effect of grazing off on N leach and $surplus. Maize silage rejected as too costly and less effective than reducing herd size.

Run 6: **Reduce herd number**. Cease all N application to [redacted] effluent area. Reduce N to autumn application of 40 kgN/ha March and irrigated area. Shows effect of no N applied to effluent area and decrease in herd number closer to "natural" pasture production levels.

Run 7: **Reduce herd to GSL model determined level** with herd graze off allowed. No N applied to [redacted] effluent area but 40 kgN/ha autumn to 34 ha pasture and normal 112 kg N to irrigated area. The GSL model has established the best herd number to "fit" the natural resources and rejected any inputs (plus associated costs) that are making less return than they cost.

(i.e. Marginal Cost is greater than Marginal Return; MC>MR).

Feed barns were not considered on the basis of capital required for barn and associated intensification. However, previous GSL modelling on barn-based systems is that the cost structure is such as to make them uneconomic in a NZ context.

The resulting economic and leaching outcomes are summarised in Table 1 below which include inputs required to produce an N leach figure from the Overseer ® program.

Table 1: Farm 1 Economic and N leach outcomes to resource allocation protocols

Run no.	**1. Base**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**
No. Cows	215	215	215	195	215	170	154
kgMS/cow	430	430	430	430	430	430	398
KgN/hatotal	112	45	0	16	112	33	33
Supplmade	0	0	0	0	0	0	0
discard							
Total BIF [g]	275,000	328,000	360,000	228,850	165,000	78,000	0
MSprodn	92,162	92,162	92,162	83,585	92,162	72,871	61,233
$Income	439,944	439,944	439,944	399,020	440,470	348,278	293,952-33
$costs	318,835	330,214	348,226	281,363	288,232	192,729	144,240
$Surplus	**121,109**	**109,730**	**91,718**	**117,656**	**152,236**	**155,548**	**149,713**
CO2 tonne	906	887	874	820	854	760	714
N excreted	32,935	31,966	29,476	28,288	31,148	27,340	24,993
Total kgDM use	1,032,660	1,042,360	1,051,100	939,290	939,600	801,073	719,300
N leached kg/Ha~	[redacted] **66**[a]	[redacted] **55**[b]	[redacted] **42**[c]	[redacted] **40**	[redacted] **59**[d]	[redacted] **40**[e]	[redacted] **37**[f]
Change in $/kgNleach	**Compare To Base**	**-$1,035 / kgNleach**	**-$1,225 / kgN**	**-$132 / kgN**	**+$4,450 / kgN**	**+$4,060 / kgN**	**+$990 / kgN**

Colour code

Base | **Industry derived runs** | **GSL Runs**

Overseer input notes:

[a]*Effluent areas received 2 x 70 kg urea/ha Aug-Sept. Irrigated areas 4 x 70 urea/ha July-Sept & March. Total farm 109 kg N/ha*

[b]*All areas received 2 x 70 kg urea/ha March & May. Maize silage fed on feed pad.*

[c]*No urea; extra maize fed in the paddock.*

[d]*100% of cows were on the feed pad for 7 hours in June-July; this mitigation is negated by having all cows off. 55 cows on in July because Overseer doesn't accept 'part' months for stock numbers.*

[e]*All silage fed on the feed pad. Effluent area increased from 10 to 38 ha. No N on Effluent area, and 80 kg urea in March over rest of the farm.*

[f]*Effluent area increased to 38 ha.*

[g] *BIF = bought in feed*

Overseer operation: Runs 6 & 7 include an increase in the effluent area, which reduces N-leaching more than the other scenarios that didn't increase the effluent area.
If the Base file Effluent area is increased to 38 ha (same N applied) it decreases N-leaching from 66 to 58 kg N/ha.

Table 2a Delta analysis

Run comparison	***Run 1 v Run 3***	***Run 1 v Run 7***	***Run 3 v Run 7***
No. Cows	*No change*	*-28%*	*-28%*
kgMS/cow	*No change*	*-7%*	*-7%*
KgN/hatotal	*Eliminated*	*-70%*	*Run 7 +33kgs*
Supplmade discard	*0*	*0*	*0*
Total BIF	*+31%*	*Eliminated*	*Run 3 +360,000kgs*
MSprodn	*0*	*-33%*	*-33%*
$Income	*0*	*-33%*	*-33%*
$costs	*+9%*	*-55%*	*-58%*
$Surplus	***-24%***	***+24%***	***+63%***
CO2 tonne	*4%*	*-21%*	*-20%*
N excreted	*10%*	*-24%*	*-15%*
Total kgDM use	*+2%*	*-30%*	*-31%*
N leached kg/Ha~	***-36%***	***-44%***	***-12%***
Change in $/kgNleach	***Harm imposed -$1225kgN***	***No harm imposed +$990kgN***	***No harm imposed +2215kgN***

Summary points from table:

- This farm currently has a 61 cow parasitic herd.
- If the policy objective is the lowest N leach/HA then run 3 and run 7 are the two cases to use.
- Compared to 'base':
  - the 'industry template' focused on maintaining production and stocking rate - with N removed completely and replaced with BiF. This resulted in a 36% reduction in N leach, but a 24% *decrease* in farm surplus.
  - The GSL run focused on 'right sizing' the herd, which allowed for BiF to be eliminated, which permitted a much reduced level of N application. The result was a 44% reduction in N leach but a 24% *increase* in farm surplus.
- When comparing the industry solution v the GSL solution GSL had a 12% lower N leach but a 63% higher farm surplus.

Farm 1 discussion points

These results illustrate the impact differing protocols used to decrease nitrogen leaching may have for this farm system:

- Run 2 where Nitrogen application is partly replaced with maize silage reduces Base farm profit.

- Run 3 has greater profit reduction as ALL N application is replaced with maize silage.

    - This shows that while N and BiF can be considered as substitutes, N is the least expensive way to provide extra feed (though Overseer penalises N).

- Run 4 allows the GSL model to constrain herd number between 195 and 215 cows producing 430 kgMS/cow. GSL chooses 195 cows, uses minimal nitrogen, reduced maize silage (the only form of BIF offered) and improves profit.

- Run 5 shows the effect of grazing off both for N leaching and profit with original herd of 215 cows. This Run compares to Base run with same N used, cows grazed off and subsequent reduction in N leach (66 to 59 kg N leach/ha) but a large improvement in profit (+$31,000) due to grazing off being more cost efficient than purchasing BIF and associated feeding costs.

    - Again, grazing off and BiF can also be considered as substitutes, with grazing off being the cheaper option.

- Run 6 allows model to allocate resources more efficiently and chooses 170 cows at 430 kgMS/cow with no graze off allowed and Nitrogen limited to 33 kgN/ha. This reduction in herd number increases profit to +$34,400 above Base farm.

- Run 7 assumes reduction in production per cow and herd number. Despite all being grazed off, **profit reduces due to reduced efficiency with lower per cow production.** (Conversely, many farmers can increase /cow production as herd numbers reduce. 460kgMS/cow reduces total MS by only 20% and increases profit BUT Overseer will increase N leach to about 43 kgN/ha.)

Points to note:

- Nitrogen is most cost efficient input to provide extra feed.
- Feeding BiF to replace Nitrogen and maintaining production reduces profitability as N is the cheaper alternative.
- Feeding all maize silage to reduce crude protein while feeding BIF is even less profitable due to higher cost /MJME (megajoule of metabolisable energy.)
- Reducing herd number provides opportunity to increase profit by reducing input costs (BIF and per cow costs) and also reduces N leach.
- Grazing off (even at $4.50/kgMS and $18 per cow per week) results in better profit and reduced N leach.
- Any reduction in per cow production has an impact on efficiency of the system. (See Appendix 5.)

Per cow performance was reduced to 398kgMS/cow as some DairyNZ staff and farmers argue that reducing herd number will cause a reduction in pasture quality and per cow production. However, recent long term trials by Chris Glassey of DairyNZ have shown this to claim to be incorrect. Reducing MS/cow has a large impact on $surplus due to being less efficient use of feeds (Appendix 5).

Herd number reduced to 154 cows with no BiF (at $4.50 /kgMS BiF is uneconomic).

Critically, N leach is reduced by 44% and $surplus is up 24% compared to Base.

At current levels of input costs, product prices and system performance, the marginal cost of adding BiF to support more cows is uneconomic. **However, adding supplement (of the required quality and quantity and price) for short periods to overcome underfeeding will be profitable.**

The above examples show that some current industry N protocols are misguided in terms of "investigating ways to reduce N loss whilst retaining profitability."

Table 2 illustrates GSL generated outcomes can be far more profitable as the LP function progressively constrains the amount of nitrogen excreted (Nx) as more efficient resource allocations are identified from the final GSL LP iterative analysis.

Table 3 Farm 1 Reduction in N leach and impact on $surplus

Run no.	**B**	**C**	**D**	**E**	**F**	**G**	**H**
No Cows	195	195	175	165	152	141	127
kgMS/cow	417	428	428	419	428	430	440
KgN/hatotal	112	96	23	Irrgn 14	0	0	0
Supplmade	0	0	0	13,000	38,000	0	0
discard						55,000	108,000
Total BIF	135,000	198,000	111,000	46,200	0	0	0
MSprodn	81,427	83,585	74,815	69,100	65,190	60,552	55,950
$Income	389,304	399,020	357,220	330,310	311,190	289,064	266838
$costs	259,466	268,352	212,182	183,715	160,229	158,820	152,552
$Surplus	**129,838**	**130,667**	**145,038**	**146,594**	**150,960**	**130,244**	**114,286**
Total CO_2 Tonne	840	833	770	735	708	676	598
N excreted GSLmodel constrained.	30,000	30,000	27,500	26,000	24,600	23,000	21,500
Total use kgDM	914,290	932,056	827,090	766,435	713,973	659,947	613,356
N leached kg/Ha.	[redacted] **54**	[redacted] **50**	[redacted] **39**	[redacted] **37**	[redacted] **36**	[redacted] **32**	[redacted] **30**
Marginal $ change /kgNleach	**+$730 Base vs. Run B**	**+$210 Run B vs. C**	**+$1310 Run C vs. D**	**+$780 Run D vs. E**	**+$4360 Run E vs. F**	**-$5125 Run F vs. G**	**-$7980 Run G vs. H**

Farm 1 important aspects

- Efficient use of resources with least N leach is between Runs F-G with a herd of about 140-150 cows and no nitrogen applied.
- Ability to decrease N leach and increase profits by reducing bought in feed and the cows that eat this. (See Appendices).
- The impact of removing Nitrogen applications (112 kgN Run B compared to 96 kg in Run C) despite increases in milksolids (81,430 compared to 83,585 kg MS) and feed consumed (914,290 kg DM compared to 932,056kg DM) still reduces N leach from 54 to 50 kgN leached /ha.
- Decreasing N application from 96 kgN/ha in Run C (50 kgN leach/ha) to 23 kgN/ha and BIF by 87,000 kgDM. in Run D drops N leach 11 kg to 39 kgN/ha leached. Both these Runs indicate impact of N application on N leach in Overseer.
- But as a lower N leach limit is reached in Overseer, the reduction in kilograms of Nx required (Nx is nitrogen from crude protein excreted from feeds) compared to reduction in Overseer kgN leach, increases (Runs F and G).
- This makes reductions in N leach past a critical level increasingly more difficult and expensive as seen from Marginal $ change/kgN leach of -$5125 then -$7980 per kg of additional N leached Runs F-G and G-H.
- **This "tipping point" will vary between individual farms due to combinations of resource efficiency, soils and rainfall that apply to each.**
- For this farm, the tipping point is somewhere between Run F and G as the farm system can no longer consume the pasture that has been grown (no nitrogen or BiF inputs are used) and must reduce production and $surplus below even the current less than optimal $surplus..
- **Despite the same amount of Nx reduction in each of Runs C to Run G, Overseer no longer reacts to these reductions in a linear fashion.**
- **This is logical as it should not be a linear progression, however many involved in this work seem not to recognise the reality of the increasingly severe financial reductions that will occur when setting nitrogen leaching caps.**
- Despite Nitrogen no longer being used from Run E to F and BiF now reducing from 46,200kgDM to none, Overseer only reduces N leach from 37 to 36 kgN leach /ha /year.
- Runs D, E and F are more efficient resource use than Base Farm with lowered N leach and higher $surplus.
- Run G shows the tipping point (as $surplus begins to reduce at an increasing rate) yet still provides similar financial outcome but with an almost 50% decrease in kgN leach/ha/year, (32 vs 66).

NOTE: When production per cow is increased, if Overseer works on a "ratio" rather than more accurate energy relationships, Overseer may still penalise them as much as less efficient farmers.

Take the diagram in Appendix 5 as an example.

- Herd producing 100,000 kg MS at the ratio of 16:1 (286 cows @ 350 kgMS/cow and 25% RR), will eat 1,600,000 kgDM.

- But herd producing 100,000 kg MS at the ratio of 13:1 (220 cows @ 455 kgMS/cow and 18% RR) will eat 1,300,000 kgDM.

This is 300,000 kgDM less eaten and N excreted from this feed but if a standard ratio of KgDM / kgMS is used, this efficiency gain is not recognised and the amount of leach will be larger than it should.

Relative to the series of Nx reductions, the N leach for Run F should be about 34 kgN leach (not 36) as Run G has 32 and Run F 30 kgN leach /ha.

This may seem a minor point but becomes critical if a N leaching cap of 32 has been set as it reduces $surplus by about $20,000 or 15% and may be the difference between bank action or not if farm debt is at a critical level.

This emphasises the importance of being able to identify accurately the rapidly diminishing "mitigation curve" and the level of N leaching at which it begins to "flatten" with respect to the N cap imposed.

GSL is a full systems model that requires all mathematical relationships to balance. This therefore provides more transparent and comprehensible links between all resources, the manner in which they relate to each other and the system as a whole.

➢ *Farm 2*

Size: [redacted]

Plan is greater intensification and increase herd size from 512 cows to 600 cows and increasing per cow production from 420 MS/cow to 492 kgMS/cow through [some] improved pasture utilisation but mainly from more BiF fed using specialised feeding equipment and facilities.

All cows will be wintered on. The additional costs of the intensification are included in expansion herd costs in terms of additional added costs (MC) of interest, depreciation, maintenance and insurances, are then able to be compared with the additional income (MR) from additional product (milk and meat) products.

Table 4 Farm 2 Economic and N leach outcomes for planned intensification

Run no.	**1. Base**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**
No Cows	512	600	600	600	600	280
kgMS/cow	420	420	476	492	492	440
KgN/hatotal	166	155	154	154	154	69
Supplmade	0	0	0	0	0	0
discard						
Total BIF	1,340,000	1,380,000	1,728,000	1,795,000	1,924,000	10,000
MSprodn *(Winter)*	179,115 35,740	215,600 35,740	245,000 40,550	253,270 42,000	253,270 42,000	123,665
$Income	1,115,253	1,302,164	1,459,496	1,504,092	1,504,092	618,068
$costs	1,057,894	1,210,407	1,306,720	1,334,036	1,364,580	309,925
$Surplus	**57,359**	**91,757**	**152,776**	**170,057**	**139,514**	**308,143**
CO_2 tonne	999	1,070	1,095	1,100	1,125	770
N excreted	61,457	74,880	77,867	78,714	81,610	39,800
Crop area	17	17	17	17	17	20
Total *kgDM use*	2,482,080	2,859,593	3,093,156	3,159,400	3,279,930	1,276,458
N leached ***kg/ha***	[redacted] **20 kg N**	[redacted] **22**	[redacted] **22**	[redacted] **23**	[redacted] **23**	**2,433** **13**

Farm 2 important aspects

- Run 6 allocation of resources with results in least N leach. 280 cows with no additional infrastructure costs and nitrogen application of only 69 kgN/ha applied. Improved pasture management, observation and implementation will be required.
- More efficient resource allocation using a value of marginal product approach will provide almost double the economic surplus ($308,000) even when the now largely redundant "sunk costs" of the new intensification are fully accounted.

- Winter milking is neither economically nor environmentally beneficial. It also complicates an already complex system.
- Although ***income*** will improve by about $390,000 between current Base and Run 5, BIF will increase by 584,000 kilogram dry matter (kgDM) and this, plus costs associated with feeding an increased number of cows producing at a higher level in facilities that have been substantially upgraded to cater for this intensified feeding system, will reduce MR to about $113,000.
- Much of the additional "profit" from the intensified system is due to improved per cow production (producing 492 kgMS/cow rather than 420 kgMS/cow) and predicted increase in utilisation of pasture (which itself contributes almost 30,000kgMS of the additional 80,000kgMS between Run 1 Base and Run 5). Intensification costs are therefore about $70/kg additional MS.
- Achieving these improvements involves additional risk in terms of debt finance, management understanding, implementation and control, and the impact of these on cow health and performance.
- Despite increasing feed consumed by 800,000 kgDM (about +32%) from "improved utilisation of pastures and feeds" plus BiF, and no real reduction in Nitrogen applied, soil type, feeding systems, effluent disposal changes and rainfall negate much of the expected additional leaching when entered into Overseer®.
- Changes to effluent area (expanded to 150 ha. of the 179 ha. of land) feeding BiF on feeding area with waste filtered so that all liquids are irrigated and solids applied as slurry all mitigate N leach through Overseer, but at a marginal cost higher than alternatives provided initially by more efficient resource allocation
- In this case, very poor resource efficiency in terms of economics is made environmentally possible as the impact of additional feeds and cows on these soils is very small and falls within the limits imposed.
- However if the farm moved to a more economically efficient system similar to Run 6, total N leach would reduce from 4,224 kgN to about 2,450 kgN or a total reduction of about 1.8 tonnes N.
- If a carbon tax was introduced at $10 per tonne, the intensified system would incur a total of $11,250 extra cost.
- In 2009 results from GSL indicated that input penalties on feeds and fertiliser would likely curb the increasing surge in many of the marginally unprofitable but environmentally damaging inputs. None of the recommendations to MAF Policy were instigated.
- Many of those inputs are even more unprofitable now due to an averaging rather than marginal approach still being used by those managing, advising or financing the wider agricultural industry.

Key points from the delta table:

- ➢ This farm currently has a 232 cow parasitic herd.
- ➢ Compared to 'base':
    - cow numbers are reduced by 45%, which leads to a similar percentage drop in income (despite slighter higher per cow production).
    - However, costs fall by a whopping 71% - in large part to a dramatic reduction in BiF (which was almost eliminated). This increased $surplus by a staggering 437%.

- N leaching dropped by roughly a third - to levels normally associated with a drystock farm.

Table 5a - Delta analysis Base v. Run 6

Run no.	**1. Base**	**Run 6**	**Delta**
No Cows	512	280	-45%
kgMS/cow	420	440	+5%
KgN/hatotal	166	69	-58%
Supplmade	0	0	No change
discard			Nil
Total BIF	1,340,000	10,000	-99%
MSprodn *(Winter)*	179,115 35,740	123,665	-
$Income	1,115,253	618,068	-45%
$costs	1,057,894	309,925	-71%
$Surplus	**57,359**	**308,143**	**+437%**
CO_2 tonne	999	770	-23%
N excreted	61,457	39,800	-35%
Crop area	17	20	+18%
Total *kgDM use*	2,482,080	1,276,458	-49%
N leached ***kg/ha***	[redacted] **20 kg N**	[redacted] **13**	**-32%** **-35%**

➢ *Farm 3*

Farm 3 provides opportunity to allow the GSL resource allocation model to provide a stepwise decrease in Nx and N leach and assess the economic consequences. The analysis is extended to 16 Runs to provide the opportunity to construct a "mitigation curve" for this farm. (Appendix)

Again, the basic farm data is included in the Table as a Base Run, constrained until Run 5 where Herd number is optimal. The model is then constrained (Table 5) to limit expected N leach (Nx **output limited**) until N leach decreases to 15kgN/ha (Nx 52,000 kg.)

Table 6 Farm 3 Economic and N leach outcomes as Nx output is reduced

Run no.	**1. Base**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**
No Cows	500	505	485	460	445	437	423
kgMS/cow	413	486	486	486	486	486	486
KgN/hatotal	126	126	106	106	106	102	102
Supplmade	110,000	0	0	150,000	185,000	200,000	230,000
Total BIF	570,000	785,000	620,000	432,500	328,000	287,000	115,200
MSprodn	206,430	245,200	235,960	223,800	216,430	212,466	206,000
$Income	1,034,213	1,209,990	1,164,373	1,104,353	1,068,047	1,048,481	1,016,682
$costs	689,242	824,160	749,652	667,568	629,316	611,945	584,032
$Surplus	**344,971**	**385,827**	**414,721**	**436,786**	**438,731**	**436,536**	**432,650**
CO2 tonne	987	1024	988	964	946	882	867
N excreted	**79,694**	**84,814**	**82,256**	**78,783**	**76,233**	**74,300**	**72,000**
Crop areas ha	16 maize 5 turnip	16 maize 5 turnip	20 maize 5 turnip	10 maize 5 turnip	15 maize 10 turnip	15 Maize 10 Turnip	12 Maize 10 Turnip
Total kgDM use	2,678,290	3,011,360	2,874,083	2,719,770	2,626,020	2,578,750	2,500,720
N leached kg N/ha#	[redacted] **26**	[redacted] **26**	[redacted] **25**	[redacted] **25**	[redacted] **23**	[redacted] **23**	[redacted] **23**

Table 7 Farm 3 Summary of effects when Nx is reduced

Run No.	Herd No.	$ Surplus	**Nx kg**	Total Eaten kg DM	BIF total Kg DM	N appl Total kgN	Total kgMS	N leached kgN/ha.	Total Overseer N leached
1 Base	500	$344970	**79694**	2678294	570000	25761	206430	26	6,855
2	505	$385827	**84814**	3011360	785000	32364	245200	26	7,014
3	485	$414721	**82256**	2874083	620000	32364	235960	25	6,531
4	460	$436786	**78783**	2719773	432000	25761	223800	25	6,534
5	445	$438731	**76233**	2626023	328000	25761	216430	23	6,229
6	437	$436536	**74300**	2578750	287000	25761	212466	23	6,201
6a	429	$434344	**73000**	2534641	247000	25761	208826	23	6,189
7	423	$432650	**72000**	2500716	216000	25761	206020	23	6,119
7a	412	$429245	**70000**	2432888	154000	25761	200400	23	6,120
8	400	$425493	**68000**	2365438	93000	25761	194810	23	6,016
9	389	$420774	**66000**	2300600	41000	24951	189365	21	5,606
10	382	$415260	**64000**	2259550	0	23738	186020	21	5,601
11	371	$407657	**62000**	2190615	0	17790	180373	20	5,329
12	360	$397396	**60000**	2133400	0	12813	175275	19	5,148
13	345	$362090	**58000**	2038245	0	12380	167734	18	4,790
14	330	$328050	**56000**	1949390	0	12060	160706	17	4,645
15	315	$291600	**54000**	1877593	0	0	153383	16	4,168
16	298	$255984	**52000**	1768260	0	0	144850	15	4,010

Refer to Appendix for N leaching vs. Profit Graphs based on this data.

Discussion of Farm 3 Table 5

- Run 5 system provides the highest $surplus and is $93,760 higher than Base.
- Runs 6, 6a and 7 produce similar $surplus to Run 5 but with reducing herd number and Nx but not to N leaching from Overseer.
- Bought in Feeds (BiF) are reduced first as they are least cost efficient (storage, handling, feeding, utilisation, relative MJME factors) despite being lower in CP% than most pasture.
- When BiF is eliminated, subsequent reduction in Nitrogen applications means less pasture growth and therefore reduced production per animal or (better option) a reduction in animal numbers. This reduces N loss to gas (direct EFI to N2O or Frac Gas to NH3/NO3 and then N2O) and N loss to water (FracLeach to NO3 then N2O depending on whether direct to pasture or via animal waste system; AWS) through fewer cows. Although milk and meat export N from the farm, far more of the total crude protein ends up as Nitrogen excretion onto soils – from direct or indirect applications, which adds to N leaching.
- The decrease in feeds that supply CP and subsequently, Nitrogen excretion, requires herd number to decrease (or for cows to produce less per cow - a poor economic choice).

- As this process occurs, the inputs that cost more than they return (MC>MR) are eliminated first (maize silage for example despite a lower crude protein % and reduced N leach potential to higher CP% feeds such as nitrogen boosted pasture.)
- This provides an increase in overall profit as two functions have occurred: herd number and therefore associated costs have decreased and feeds that are costing more than the product produced from returns in product value (Marginal Cost greater than Marginal Return; MC>MR) have also been reduced.
- These two factors combine to provide higher net income but lowered N leaching.
- This marginal analysis process occurs during continuing iterations of the GSL model until the inputs (and herd number) have reduced to a point where the additional costs now equal the additional returns (MC=MR) Run 5.
- Beyond this "tipping point" any inputs removed are at a cost. Profitable (MC<MR or MR>MC) resources must now be reduced. This point is below where most efficient firms would wish to operate as there are lost economic opportunities being forced into the efficient system due to a non-economic constraint – the N leaching cap. This will lead to increasingly large inefficiencies in resource allocation.
- The iterative process of reducing loss making inputs now focuses on those inputs making the least profit (rather than the greatest loss).
- This results in increasingly larger negative marginal changes to overall $surplus which may be minor initially (as many inputs may still be close to MC=MR) but as fewer resources are able to be used, even the more profitable ones must eventually begin to be rejected in order to lower crude protein use and therefore consequential nitrate leaching.
- This leads to an increasing rate of loss (depending on when each input substitution or elimination occurs and by how much) but, as no resource use (value) remains constant (due to the changing system dynamics) this reduction will not exhibit a classic diminishing return "curve". (See Appendices for example using Farm 3.)
- When non-pasture inputs have been eliminated (BiF, Nitrogen, cropping), further N leaching constraints provide no opportunity to consume all the pasture currently grown.
- Therefore the model's only option is *not to consume* farm grown feed by reducing herd numbers and "*discarding*" the now surplus feed.
- If this can be sold at a profit, this may mitigate the now increasingly inefficient resource use.
- At this point, the variable costs (VC) of the farm are minimal but the fixed costs (FC) remain (depending on opportunities to also "discard" lumpy inputs such as machinery and labour) and these contribute an increasing proportion of the total farm costs.
- Depending on debt levels, the farm $ surplus is now in a downward curve and the farm becomes unable to function in its current state.
- Options may be to sell feed (unlikely), plant trees (appears feasible until analysed more closely) change to different stock type (may not be capable of debt repayment) and some sheep and beef farms may still not meet N leach requirements depending on soil and rainfall.

For this particular farm however, soils and rainfall allow even inefficient resource use to continue. Combinations of economics (input costs vs. output price) may eventually force the same search for a more efficient dairy system or alternative enterprise use.

Table 8a Delta analysis - comparing Runs 5, 13 and 16 to Base

Run No.	Herd No.	$ Surplus	**Nx kg**	Total Eaten kg DM	BIF total Kg DM	N appl Total kgN	Total kgMS	N leached kgN/ha.	Total Overseer N leached
1 Base	500	$344,970	**79,694**	2,678,294	570,000	25,761	206,430	26	6,855
5	445	$438,731	**76,233**	2,626,023	328,000	25,761	216,430	23	6,229
13	345	$362,090	**58,000**	2,038,245	0	12,380	167,734	18	4,790
16	298	$255,984	**52,000**	1,768,260	0	0	144,850	15	4,010
5	-11%	+27%	**-4%**	-2%	42%	0	+5%	-12%	-9%
13	-31%	+5%	**-27%**	-24%	Eliminated	-52%	-19%	-31%	-30%
16	-40%	-26%	**-35%**	-34%	Eliminated	Eliminated	-30%	-42%	-42%

Table 9B Delta analysis - comparing Runs 13 and 16 to run 5

Run No.	Herd No.	$ Surplus	N leached kgN/ha.	Total Overseer N leached
5	445	$438,731	23	[redacted]
13	345	$362,090	18	[redacted]
16	298	$255,984	15	[redacted]
13	-22%	-17%	-22%	-23%
16	-33%	-42%	-35%	-36%%

Key points:

- This farm currently has a 55 cow parasitic herd.
- Compared to 'base':
  - Run 5 (the profit maximising run) reduced heard size by 11%, improved $surplus by 27% and reduced leaching by 12%
  - Run 13 (the Pareto safe run in terms of $surplus) reduced herd size by 31% and increased profitability by 5%. Leaching was also reduced by 5% - with the result being a 'profitable', rather than profit maximising farm
  - Run 16 reduced herd size by 40% but resulted in a 26% drop in $surplus. N leaching decreased by 35%.
- Run 16 illustrates the marginal cost of abatement compared to base - $surplus is reduced by 26% (basically the mirror image of run 5). The N abatement cost is $8,089 per kg abated.
- However, if compared again run 5, the abatement cost associated with run 16 soars to $22,843 per kg abated.

➢ *Farm 4*

Size: [redacted]
"The permissible nitrogen loss limits for the property has been calculated at **19 kg N/ha/year** for year one, and dropping to 14 for year 20"

The Base farm has some of the planned improvements included and larger effluent area. Winter oats and summer turnip rotation was included initially then excluded to reduce N leach.

The model examined the impact of the changes suggested within the report provided by Horizons. It was then optimised to allow alternative systems to improve performance and economic outcomes plus the "bonus" of further reductions in N leaching (Win Win). Such change will require the farmer objectives to become more flexible than those stated above (e.g. cows grazed off for both economic and environmental reasons).

- Economically due to ability to better balance pasture covers into and out of winter (dry off and calving).
- Less BiF required.
- Environmentally due to less urine, less BIF feeding and soil damage over the winter months.

Some early culling also enhanced the ability to milk better producers longer.

Decrease in herd number would also maintain better feed balances without the need for as much BiF.

The model was used to examine a change of stock policy from all cows to a cow/beef mix that could be sourced from utilising cull calves from the herd and rearing then finishing for slaughter at 18-20 months. Later Runs investigated how well the Milking block and Runoff block could be integrated for such a system.

Although not included in the following Table (although changes to herd number and beef finishing are examined) the data and implications for economic and environmental outcomes are presented.

Table 10 Farm 4 Economic and N leach outcomes as N leach is reduced

Description	**Base**	**400 cows Fix**	**No crop**	**Repl. on Optimal**	**85 bulls**	**Higher MS/cow**	**Allow120 Bulls**
Run no.	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7
No Cows	450	400	400	354	326	320	300
kgMS/cow	322	333	333	334	326	350	348
KgN/hatotal	40	10	0	0	0	0	0
KgN spr	2 x 29	10 (86ha)	0	0	0	0	0
KgN aut	0	0	0	0	0	0	0
Supplmade	0	0	40,000	170,000	68,000	63,000	55,000
PKE	100,000	0	65,000	0	0	0	0
Total BIF	133,000	0	65,000	0	0	0	0
MSprodn	145,120	133,300	132,900	118,362	109,040	112,315	104,530
$Income	782,308	721,578	719,870	649,360	662,489	673,488	682,477
$costs	515,366	405,600	412,108	330,326	335,086	330,373	334,292
$Surplus	**266,942**	**315,878**	**307,762**	**319,034**	**327,403**	**343,115**	**348,185**
CO2 tonne	1400	1254	1253	1224	1225	1225	1225
N excreted	58,938	53,917	53,777	51,942	52,073	52,131	52,194
Crop areas ha	10 Oats 10 turnip	10 Oats 10 turnip	0	0	0	0	0
Total kgDM use	2018900	1809430	1806840	1749530	1749205	1748980	1748700
Bulls	40	40	40	40	85	85	120
kgCW/bull	395-310	395-310	395-310	395-310	395-310	395-310	395-310
Date kill	20Mar-Apr	20Mar-Apr	20Mar-Apr	20Mar-Apr	20Mar-Apr	20Mar-Apr	20Mar-Apr
N leached KG/Ha	[redacted] **47**	[redacted] **15**	[redacted] **13**	[redacted] **23**	[redacted] **20**	[redacted] **20**	[redacted] **20**

Discussion of Farm 4 Table 6

- Run 1 is based on current farm inputs. (Some calving date sensitivity analysis indicated a calving date of August 10th better suited pasture flows and improved $surplus).
- Run 2 herd was fixed at 400 cows and allowed option of all cows grazed off at $18/ week for 6 weeks.
- The model was allowed to apply nitrogen at best economic (rather than what may be thought best response) periods and application rates. This resulted in N applied only in 2 periods September and late October/November
- Fewer cows allowed better areas of farm to be grazed by the herd and walking was reduced. This meant less energy used for walking and more for milk and per cow production increased by about 11 kgMS/cow. This is most economic use of extra feed. Increasing per cow production rather than feeding and milking more cows.

- Run 3 fixed 400 cows and retained other changes to graze off but now reduced nitrogen applications to 0 applied. Supplement was now made on the farm (as no crop area so more pasture all year) but some BiF needed to fill in autumn and early spring feed gaps with 400 cows despite grazing off.
- Run 4 allowed herd size to optimise but bulls remained fixed at 40. The model chose 354 cows which again provided a rebalance of feed grown to that required. No BiF was required, replaced instead by farm made silage. This kept flatter pastures in good growing condition. No Replacements grazed off farm increased N leach. None were grazed off for Runs 5, 6, 7 and 8 either but changes to bulls finished and killed prior to winter did reduce N leach from 23 to 20 kgN/ha/year.
- Run 5 allowed the model to choose split of cows (MS $4.50/kg) compared to bulls ($4 / kg carcass weight (CW)) but a maximum allowable of 85 bulls. The model chose to reduce herd number and increase bulls to 85 which produced an increase in profit to $343,000 compared to Base of $267,000 (but some alterations to cash flow). The model ensured LWG and sale date integrated to sell all bulls before the critical autumn months for Overseer® N leaching. As the herd was now reduced, only the better areas were grazed by the herd and the better pastures plus less walking allowed a once a day (OAD) production of 350 kgMS /cow from 320 cows.
- Run 8 allowed the model to rear and finish up to 120 bulls. The model chose bulls over cows as this again balanced feed more efficiently and $surplus increased to a high of $348,000.
- The issue of “lumpy inputs” such as labour and machinery were not addressed but could lead to better economic outcomes if adjusted within this new system.
- Note that although the amount of feed used (Total kgDM row in Table) and the associated N excreted row (Nx) show little change from Run 4 to Run 7, the proportions of feed consumed in each month alters and should provide a reduction in N leach yet provide also a higher $surplus.
- If the Nx is constrained to 45,000 kg Nx (compared to 52,200 Run 7 see following Table 4B) herd number drops to 245 cows but retains 120 bulls. Although $surplus drops to $290,000 (as feed must now be wasted rather than eaten to meet the lower Nx required) the farm makes more $surplus than currently.
- This indicates that: currently resources are being used inefficiently and that bull beef is more profitable than milksolids given the input and output figures for feed, milksolids production, meat production, costs and product prices used.
- This illustrates how inefficient resource use can be simply improved and the beneficial results that can accrue.

A series of additional runs were completed to investigate the need to “discard” feed and the impact on $surplus. The GSL model was constrained to reduce the Nx figure (related to N leach) in a stepwise manner but the model otherwise allowed to optimise the best combinations of feed produced, supplements made, increase in excess pasture (as Nx constrains use) herd number and bulls to provide best $surplus. These data are summarised in Table 7 below.

Table 11 Farm 4 Impact on optimised output functions as Nx output is constrained

Nx Limit (kgNx)	$surplus	Herd number	Bulls	Supplement made kgDM	Pasture discard kgDM	**N leach ha kgN/ha**	**Total N leached farm**
51,000	$344,820	288	120	25,000	48,000	**20**	[redacted]
50,000	$341,700	278	120	0	91,000	**20**	[redacted]
48,000	$327,290	264	120	0	231,000	**19**	[redacted]
45,000	$304,500	244	120	0	276,000	**18**	[redacted]
44,000	$296,000	238	120	0	322,000	**18**	[redacted]
43,000	$288,000	231	120	0	357,000	**18**	[redacted]
42,000	$281,000	224	120	0	395,000	**18**	[redacted]
41,000	$254,000	217	120	0	440,000	**18**	[redacted]
40,000	$237,000	210	120	0	488,000	**18**	[redacted]

A nitrogen leaching abatement cost "curve" can be calculated for this farm using the above data and Overseer®.

Some may find it "counterintuitive" or more bluntly "wrong" that the model can waste so much feed (up to 400,000 kgDM) and be able to halve the milking herd before the new $surplus falls below the current farm. What must be understood is that many of the Base farm inputs are actually *losing* money and this has been explained previously with regard to MC vs. MR of inputs vs outputs. With MS price at $4.50 and the cheapest current input costing 28 cents/ kg of wet weight - which by the time they are stored, transported, fed out, utilised and adjusted to MJME equivalent pasture are costing about 45 cents/kg utilised DM for the current cheapest cost and highest MJME option (Refer Appendix 3 for full explanation of calculation.)

However, all this does not alter the Overseer® N leach readings as shown in the above Table where only a 2 kg N leach/ha reduction has been achieved despite a herd and production reduction. This is an example of how any soil will reach a "basement level" of N leach and even with less feed being grown, the cost of reducing N leach will increase at an increasing rate. **In this case -$107,000 reduction in $surplus for only 2 kg N leach / ha. This illustrates the problem of imposing low N leaching caps without identifying what the marginal impact on a specific farm will be.**

A series of supplementary runs were completed to look at sensitivity of use of BIF with regard to price vs MS price and also integrating the 41 ha runoff block into the overall dairy and dairy-beef scenario to better understand the balance required and the sensitivity to MS vs bull beef prices.

If the runoff is used with bull beef and herd and replacements to be as close to self-contained as possible:

- 300 cows + replacements all "grazed on" both blocks.
- 120 bulls reared and grown to slaughter on total area.
- 130 tonne grass silage made.
- About 5,900 kgDM/ha consumed from runoff block in total.

- MS at $4.50/kgMS and beef at $4/kgCW returns $343,000 and Nx of 56,600kgNx.

If bull beef falls to $3.60 /kgCW (currently at $5+/kgCW but weakness appearing in USA market and competition growing from Brazil) model still chooses same ratio of herd to bulls but $surplus drops to $323,000.

If MS increases to $5, model increases herd to 325 and drops bulls to 90 bulls

At $4/kg MS and $3.30/kg CW for bull beef drops to 290 cows but 120 bulls fixed.
If allowed to optimise at same product prices as above, drops herd to 270 and increases bulls to 140. This number is probably above self-replacing bull beef numbers for this herd size but if some beef bulls can be used over the herd, beef x heifers can be used for “local trade” and beef x heifers run with reduced herd replacement number.

If both MS and CW product prices reduce as above, $surplus decreases to $265,000. This is similar to current farm being run inefficiently with higher BiF inputs than profitable with the associated increase in herd numbers and costs.

In examining the sensitivity to product price changes and use of BiF (11MJME) a series of runs were completed.

- At $4 the model will not use any BIF until the cost drops to 16 cents/kgDM. This BiF fills in some feed gaps. The cost needs to drop another 1-2 cents/kgDM to get full use but at very little $surplus benefit in total.
- At $4.50 the model uses some BiF at 19 cents but more at 18 cents.
- At $5/kgMS the model begins to use some BiF at 22 cents/kgDM and more at 21 cents.

This shows that feeding BiF to poorer producing cows may retain herd number but is uneconomic at current input/output prices. Reducing herd number and feeding a higher proportion of pasture per cow and reducing BiF per cow will improve profit. Reducing herd number, feeding only supplementary feed (fill short infrequent feed deficits) and increasing per cow production will return the maximum benefit.

The bull beef dairy combination will provide a varied demand profile and allow more control of pastures with grazing animals. It also fits the feed grown profile better as lowered winter requirements from bulls sold and reduced early spring with reduced herd numbers but increasing early summer demand as yearling plus 14 month bulls feed demands increase.

This system would be self-contained using the figures from the model as above, yet be spread over two quite different markets and add value to both with a reduction in risk, labour and variable costs. It would require an altered perspective on pasture management, ensuring mob control suited the timing and quality of feeds required.

Table 12 Farm 4 Maximum price of BIF cents per 11.0 MJME DM and amount used for this farm (MC=MR)

	22 cents/ kgDM	21 cents/ kgDM	20 cents/ kgDM	19 cents/ kgDM	18 cents/ kgDM	17 cents	16 cents	15 cents
$4.00/kgMS	0	0	0	0	0	0	65,000	100,000
$4.50/kgMS	0	0	0	33,000	100,000			
$5.00/kgMS	9,000	100,000						

➢ *Farm 5*

Size: [redacted]

Table 13 Farm 5 Economic and N leach outcomes as N leach is reduced

Description	Base	Vary cow 370-395	Vary cow 350-395	Vary cow 330-395	Optimise Herd	Limit Nx 46,000 kg	Limit Nx 42,000kg	Limit Nx 39,000kg
Run no.	1. Base	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
No Cows	395	370	350	330	302	290	261	247
kgMS/cow	402	402	402	402	402	402	402	383
KgN/hatotal	118	82	70	56	56	45	25	0
Supplmade	12,000	2,000	57,000	65,000	86,000	120,000	188,000	0
Total BIF	460,000	333,000	277,000	246,750	250,300	126,550	188,000	61,000
MSprodn	158,730	148,680	140,645	132,610	121,555	116,550	105,030	94,640
$Income	785,090	735,400	695,650	655,900	601,235	576,458	519,510	470,240
$costs	581,750	506,302	457,650	410,540	353,930	345,485	306,590	290,245
$Surplus	**203,750**	**229,100**	**238,000**	**245,354**	**247,300**	**230,970**	**212,920**	**179,990**
CO2 tonne	1,471	1,413	1,354	1,320	1,310	1,210	1,120	1,050
N excreted	55,150	51,140	50,045	48,740	48,000	46,000	42,000	39,000
Crop area ha	10 turnip	12 turnip	12 turnip	10 turnip	10 turnip	10 turnip	5 turnip	0
Total T DM use	1,864	1,730	1,622	1,572	1,554	1,491	1,352	1,255
N leached KG/HA	**62**	**57**	**54**	**50**	**45**	**44**	**34**	**34**

Discussion of Farm 5 Table 9

- Run 1 uses the original farm data to establish the Base farm for use as a comparison for subsequent resource allocation changes.
- Run 2 allows herd size to vary from 370 minimum to 395 maximum.
- The ability to vary N use dates and rates within constrained periods and response rates.
- The bought in feed is offered at price and weights of the original Base maximum.
- Run 3 allows herd size to vary from 350 minimum to 395 maximum.
- Same Nitrogen dates and rates allowed and same BIF.
- Run 4 allows herd size to vary from 330 minimum to 395 maximum.
- Same Nitrogen dates and rates allowed and same BIF.
- Run 5 allows model to optimise for herd number, nitrogen use, crop area, grazing off and BIF.
- Runs 6 and 7 (plus Run 8 not included) limit amount of N leach in a stepwise process by constraining Nx within the output function of the GSL model.

- These runs are therefore sub optimal as Run 5 established the most economic allocation of resources available.

Conclusions

The Opening Summary lists the important points.

- Sensitivity analysis indicates that the “optimal” resource use and $surplus provided by these farms at current $4.50/kgMS and input prices will prevail until a price of over $7 /kg MS is paid.
- This depends on the production of milk-solids per cow achieved. Higher per cow production and efficient management in terms of cost structures allows better profits and may allow use of BIF at about $7.
- The marginal benefit from BIF even at this price will be small and may not warrant the extra risk and management expertise.
- Emphasis must go back to profitable farming. This will involve efficient resource use which will reduce inputs and in turn reduce detrimental environmental legacies.
- Farmers need reassurance that pasture farming is not difficult but also may not always appear “perfect” in terms of perception of what pastures should look like at all times.

For any “message” to be understood well enough to be implemented requires farmers to participate in, not just “perceive” what is being put forward. The same applies to those who are making rules. Those rules need to be carefully thought through after all avenues of knowledge have been investigated. This may seem to make the conclusions that can then be taken from such work, a simple exercise.

The problem with this however is that often maligned quote offered by Donald Rumsfeld: “There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don't know. But there are also unknown unknowns. These are things we don't know we don't know”. Donald Rumsfeld.

This report has conducted analyses, some simple and some very complex, in order to expand the knowledge on what the outcomes may be from making resource allocation changes to complex systems. However the final analysis relies on Overseer which is a computer model that deals more with 'known knowns' but is used to make decisions on what are still at best known unknowns, but that also include unknown unknowns. The data used within Overseer® is merely an averaged snapshot of what a particular farm system may have resembled at one point in time. The subsequent calculations then rely upon ratios and extrapolations to provide a guide to future outcomes.

The GSL model provides the opportunity to delve deeper into what, how and why each resource contributes to a farm system and to provide a range of outcomes. These outcomes are dependent upon the relationships and resource constraints that may apply. The GSL model itself may choose pathways and resources that simpler input/output model (I/O models) are incapable of detecting. I/O provides a single option whose parameters require to be changed each time a new solution is sought. Even the “optimisation” routine in such models is limited.

The iterations undertaken as the final step Linear Programming by the GSL model ensures the best resource allocation will emerge from the large range of options offered from the initial data functions. Both specified input and output constraints can be used to ensure logical progression of outcomes towards a specified goal. In this project's case, this was to find the best economic solutions to decreasing N leach.

The GSL model is therefore capable of pushing past perception and providing deeper understanding of what may be possible. This is getting to know what the unknowns may look and perform like. But this still leaves the unknown of how best to firstly present such new concepts and ideas and secondly how to manage our way through that change.

The good news is that New Zealand farming was very close to managing the changes required in the years from 1958 (McMeekan: From Grass to Milk) to about 1986 when the "more production through intensification" wave began.

The past four to five years, management at the Lincoln University Dairy Farm combined with the work by Chris Glassey of DairyNZ should be reviving this simplification; but that work does not yet include the production economics backing to clinch the argument (despite GSL being used to initiate the 2011 changes at LUDF).

Useful references include:

- Pellow, R; Lee, S; Metherell, A; McCallum, R; Moir, J; Roberts, A; Wheeler, D. 2015: Assessing the impact of input choices within Overseer ® (V6) on the modelled N losses to water for Lincoln University Dairy Farm (LUDF) *Occasional Report No. 26.* Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.
- Glassey, C.B; Roach, C.G.; Lee, J.M; Clark, D.A. 2013: The impact of farming without nitrogen fertiliser for ten years on pasture yield and composition, milksolids production and profitability; a research farmlet comparison. *Proceedings of the New Zealand Grasslands Association* **75**: 71-78.
- Glassey, C.B.; Pinxterhuis, I. 2015: Nutrient Management. Stocking rate: more is not always better. Presentation by DairyNZ., Hamilton, NZ. *Pers comm.*

This report attempts to tie this (economics, implementation, environment) together with an emphasis on reducing N leach at least cost while providing a number of "asides" to examine and explain why many of the current perceptions about production, efficiency and economics are not fallacious. An additional message is that by presuming some of the 'known unknowns', regulations should not be enforcing rules that condemn efficient farmers to relinquish farming while inefficient farmers continue to waste resources.

Appendices

Three graphs to illustrate intensification of pasture systems:

Figure 1 All pasture self contained

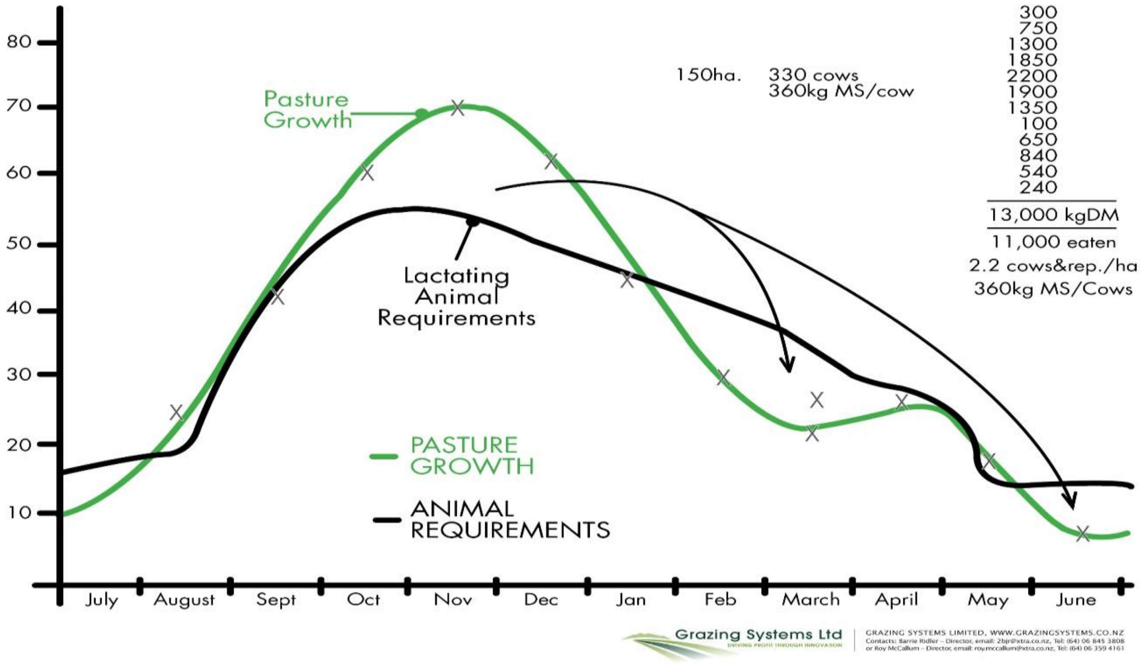


Figure 2 Increased intensification. Now more feed required (blue line) than basic farm pasture growth (green line) can produce so buy in feeds for much of year.

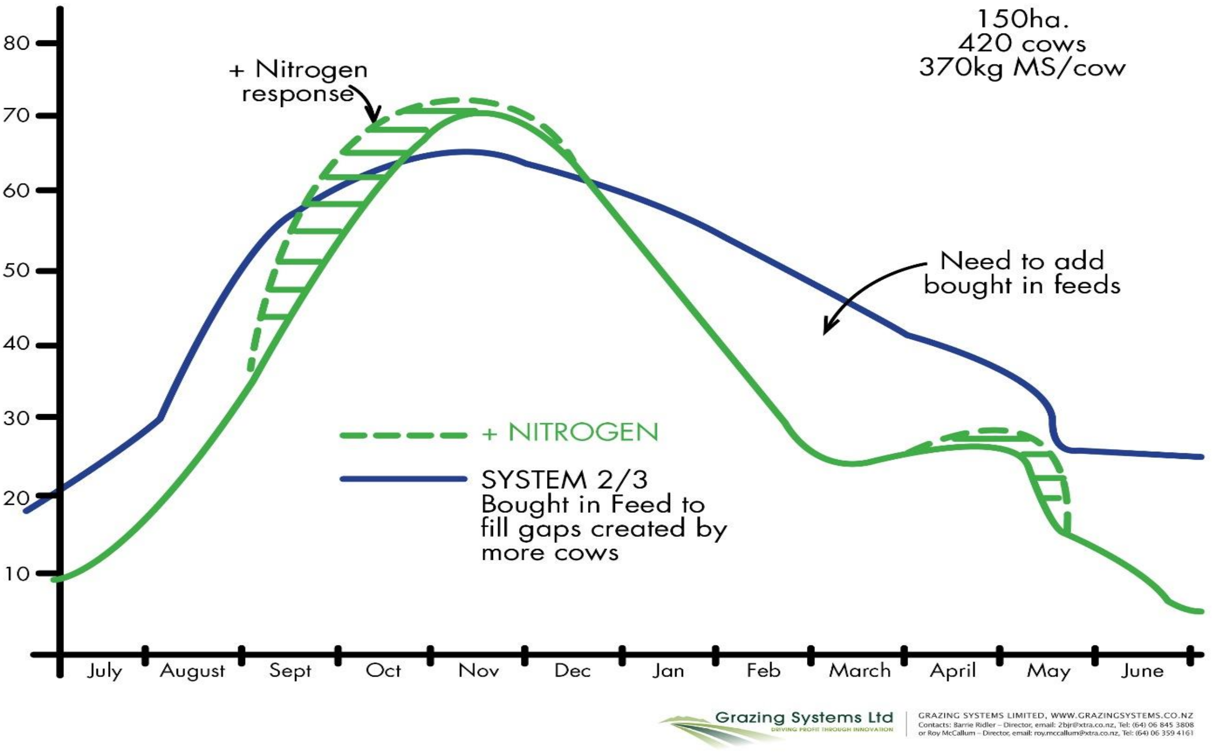
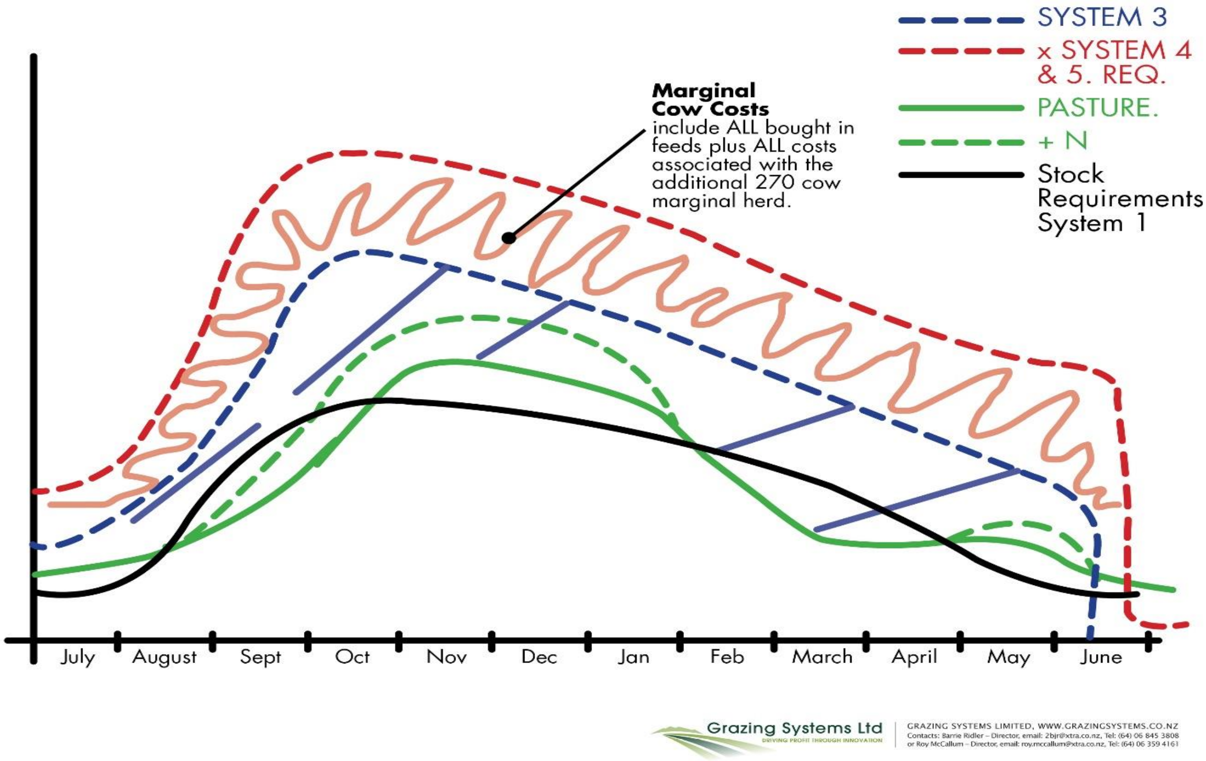


Figure 3 Now intensified and 600 cows at higher MS per cow require bought in feeds (BIF) throughout the full year.



Real costs of BIF (Bought In Feed)

Simple mathematical calculation of true cost of bought-in feed vs pasture.
The important point is to be able to identify when **supplementary feed** (to fill in genuine feed gaps when feed demand is balanced with production required) becomes **bought-in feed** (when additional animals are supported solely from bought-in feed or **BiF**).

1 kg of bought-in feed example:

Most farmers (and many advisors) use the actual purchase price of **BiF** to perform a simple margin over feed cost (MOFC) comparison. This is incorrect. Buy-in cost 28 cents per kg off truck but may be 90% DM (PKE type products and many concentrates), but:

- To feed 1 kg of say 11MJME feed means a cost of 3– 8 cents /kg wet weight depending on where fed (labour, machinery costs), which implies 31-36 cents /kg 'wet weight'.
- Utilised at 85% (higher if barn/feed pad but feed out costs higher as costs of silos, in-shed feeding infrastructure)
- This brings the consumed cost to 36.5 cents/kg wet weight fed.
- At 90% DM, this brings cost per kgDM consumed to **40.5** cents

- BIF substituting for pasture at 11.5 MJME/kgDM requires 6.5% more BIF than pasture.
- This adds another 3 cents to the comparative costs of bought in feed vs. pasture eaten.
- Total cost of about **43 cents/kg pasture equivalent** being substituted.

If this is a true supplement that fills in genuine feed gaps only and meets required production targets, this 43 cents /kgDM cost should now be used for calculations.

However, if there are more cows being run than pasture growth allows, the **additional cows** can be viewed as consuming a complete feed intake of **all BiF** (NB: an optimisation model such as GSL identifies the tipping point where supplements become **BiF**).

If this is the case, the simple calculation takes on another dimension as ALL costs associated with the additional cows must now be attributed to those cows.

- A 400 kgMS cow (quite efficient by NZ standards) with a replacement rate of 25% requires about 6000kg of 11.5 MJME DM to sustain its full herd contribution (Milk + part replacement) each year.
- Simplistically, if all bought in feed is used the feed cost is 6000 x $0.43 = $2,580.
- It may be simple to think that $2,580/400kgMS = $6.45/kgMS price covers this, but this is wrong.
- There are also all the additional costs that are incurred by that additional animal.
- These include not only the feed costs but the costs of rearing a replacement (8 weeks), animal health, AI, proportion of animal management costs (shed, labour) interest costs on actual cow and shares but also added infrastructural costs if enough extra cows are milked to require them.
- These add at least a minimum $500 of additional costs (more with infrastructure) which now requires a $3080/400 kgMS
- Break-even product price is now $7.70 /kgMS but also brings extra risks, stress and requires better management ability.

The tipping point (where marginal costs exceed marginal return) is critical when assessing where to attribute costs. Averages, benchmarks and ratios used in Input/Output (I/O) models cannot identify this tipping point as no marginal analysis is possible because substitution of resources that show negative diminishing marginal values are unable to be identified within the I/O model format.

Such costs are averaged equally across all production income in the account structured databases and the costs associated with specific actions are also hidden within all-encompassing accounting “categories” (such as Fuels and Oil; Repairs and Maintenance – Machinery; Dairy Shed, Supplementary Feeds...). This makes any reliance on averages, benchmarks and ratios fraught with misinterpretation and erroneous “causal relationships”.

This calculation allows the marginal cost of additional cows to be established. However, this calculation also depends on the kg milk solids per cow. As per cow performance increases, so the efficiency of feed improves (as less maintenance “fixed cost” feed relative to that used for milk solids (“variable feed”.)

In the following diagram, choose the level of per cow production that seems possible for a farm and this will indicate the kgDM required. If ALL this feed is for an additional cow compared to what pasture can supply, use the BiF cost of feed calculation to find the cost of feed to compare with MS produced. If the cow is additional to what the pasture can supply, add per cow costs to this figure to find a milksolid price that must be achieved to breakeven.

REQUIREMENTS FOR

450kg LW COW (No replacement added.)

If 25% replacements add about + 1080kgDM / cow

Maintenance 2,500kg 11MJME D.M.	250kgMS +1500 kgDM	300kgMS	350kgMS	400kgMS	450kgMS

250kgMS

requires 4,000kgDM
16kgDM / kgMS

300kgMS

4,300kgDM
14.3kgDM / kgMS

350kgMS

4,600kgDM
13.2kgDM / kgMS

400kgMS

4,900kgDM
12.3kgDM / kgMS

450kgMS

5,200kgDM