TECHNICAL FOREWORD

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E2M: Technical Foreword

Explanation of E2M

E2M is a unique farm-planning tool that can identify how to achieve a particular outcome on a farm within the many constraints that farm operates within—whether it be maximising economic performance or minimising external inputs, nutrient losses, or emissions. It is a full farm systems model, summarising farm operations in fortnightly increments including pasture growth, grazing, fertiliser use, economics, nutrient outputs, and greenhouse gas emissions[1].

E2M works differently to other farm systems models available in Aotearoa New Zealand (and the world)—and this makes it much more efficient and effective than those models. However, without an understanding of the concepts behind E2M some of its suggestions can seem counterintuitive, if not 'just plain wrong'. This foreword aims to provide that understanding.

Most farms systems models available in Aotearoa New Zealand are effectively 'calculators'. Information about a farm management scenario is 'punched in' and the model provides an 'answer' stating the predicted outcomes of that scenario: the profits, costs, nutrient outputs, and/or emissions, among other things. These models are ok (within constraints) for assessing the outcomes of a current or past farm management scenario—i.e. what a farm is doing now or did last year—but are limited when it comes to determining the best options for future management or system change.

If a farmer wants to investigate how to achieve a different outcome on their farm using one of these models (perhaps they want to intensify a part of their farm; remove synthetic fertiliser or Intensive Winter Grazing from their system; reduce nutrient leaching or emissions to meet an environmental regulation or standard; or increase their profitability), the operator of the model must make educated guesses about what changes could be made to farm management to achieve that outcome, 'punch' those changes into the model, and run the model again. They then have to check whether the 'input scenario' achieved the outcome or not and, if not, tweak the input before running the model over and over again until they find a way to achieve the desired outcome (or something close to it) or rule it out as an impossibility within the constraints of that farm. Needless to say it can be a time-intensive, inefficient, and costly process, and can mean potential management scenarios are 'missed'.

As an example, a farmer might need to reduce their nutrient leaching by 20% to meet an environmental regulation. The model operator would know from experience that reducing fertiliser inputs, reducing irrigation, or lowering stocking rates (among other options) could all help achieve this outcome. They would have to 'guess' at what combination of changes

[1] E2M has been assessed as a tool for quantifying emissions under the government's 'He Waka Eke Noa' program (approval pending).

to the system would most efficiently reach the desired outcome without an unnecessary impact on profitability, run the model over and over with minor changes each time, and then report back to the farmer when they think they had reached an 'optimum' management scenario to reach the outcome.

E2M essentially runs in reverse to these other models. When a 'base run' has been established in E2M using the existing farm management scenario, the outputs of that scenario are provided in an 'outcome report' window. If a farmer wants to investigate how to achieve a different outcome on their farm, the operator does not have to adjust the *input* scenario like in other models, but instead can make changes to the *output* scenario and define constraints for the model to work within. For example, as above, a farmer might want to determine how they can decrease their nutrient output by 20% without adversely effecting profitability. Rather than running the model over and over with different input scenarios in an attempt to achieve this outcome, the operator of E2M would simply set the output for nutrients at a value 20% lower than that of the 'base run' and indicate to the model that it should attempt to maximise profit within this constraint. When the model is run it effectively tests endless combinations of inputs with the aim of achieving the 20% reduction in nutrient outputs while maximising profitability, and reports back with the most efficient way of achieving that outcome. In this case, it would report the management scenario that reduces nutrient outputs by 20% *and is most profitable*. All of this can be achieved in seconds and effectively takes the 'educated guesswork' out of the modelling[2].

If a farmer wants to test a different input scenario or achieve a different outcome then adjustments can be made to either end of the model—inputs or outcomes—in a few moments with the farmer sitting next to the operator, and the model can be run again to produce an output summary in seconds. This massive increase in efficiency means that, after a 'base run' has been set up, an E2M operator's time can be spent co-constructing management solutions with a farmer (often on-farm), rather than spent away in an office somewhere adjusting input scenarios only to report back on potential options days or weeks later.

E2M has been used across Aotearoa New Zealand to investigate increased efficiency through farm systems change[3] and is the basis for several peer-reviewed journal articles[4] on efficient farm systems. Increases in efficiency and reductions in environmental impact resulting from the use of E2M are most evident in the results of the Lincoln University Dairy Farm[5], which,

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[2] This was summarised well in the Environment Court proceedings for the Proposed Hurunui and Waiau River Regional Plan in the evidence of Dr.David Graeme McCall for Fonterra and Dairy NZ, who stated "*The [E2M] model was chosen over Farmax... because [it] is more efficient at finding optimal resource use allocations due to it being an optimising, rather than a simulation model. With simulation models (such as Farmax) the definition of optimal resource use requires the user to iterate their way to an optimum solution. This iteration is time consuming, not always full-proof and optima may be missed.*"

[3] On individual farms, as well as by regional councils – e.g. Horizons RC (http://www.horizons.govt.nz/HRC/media/Media/One%20Plan%20Documents/GSL-Final-Report-July-27-2016-with-minor-redactions-20180312.pdf?ext=.pdf) and Hawke's Bay RC (Appendix 19: https://www.hbrc.govt.nz/assets/Document-Library/RWSS-Reports/Appendices-to-RWSS-report.pdf)

[4] e.g. https://www.publish.csiro.au/AN/AN16457

[5] Lincoln University Dairy Farm Focus Day, 2012, http://www.siddc.org.nz/assets/LUDF-Focus-Days/10-May-2012-.pdf

through a reduction in external inputs and the size of its herd (from 630 to 560 cows), increased its production (from 400kgMS to over 500kgMS per cow) and profitability, while decreasing its nitrogen leaching (by 30%)[6]. This (approximately) 11% reduction in herd size would have resulted in a significant reduction in CO_2 and methane emissions in line with the target reductions currently being discussed by the Climate Commission—all achieved without any adverse impact on farm operations or profitability, and all without expensive mitigation technology.

Marginal Analysis and Profit Maximisation

E2M achieves its efficiency by employing a relatively simple (but under-utilised) economic technique called 'marginal analysis'. It is built on the Jade OO programming platform[7] and uses Linear Programming[8] as a means to solve various equations as required as part of the suite of functionality that the JADE program provides. E2M is not an "LP Model" and avoids the restrictions that linear programming exhibits when integrating multiple complex systems. These techniques are not used in other farm systems models available in Aotearoa New Zealand. In fact, E2M differs from farm systems models worldwide.

Marginal analysis is an economic technique used to identify the 'tipping point' at which an increase in production comes at a cost, rather than a benefit, to a producer. If readers aren't well-versed in economics they might have some idea of the concept through the idea of the 'point of diminishing returns'. As an example, buying in fertiliser will increase grass growth on a farm, but there's only so much fertiliser a farmer can apply before throwing more on starts to have minimal impact on grass growth and is just an unnecessary cost to the farm (and the environment), eating into potential profits. Marginal analysis underpins E2M and is referred to extensively in this report, so it is vital the reader has a working understanding of the concept—otherwise large sections of the report might seem, as above, counterintuitive or wrong.

A useful starting point is to consider a simple 'accounting' view of profit (п), 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 as:

п = TR - TC

Profit = Total Revenue – Total Cost

(Essentially: profit equals what you earned minus what you spent to earn it).

Production Economics goes a step further than this and distinguishes between a company that 'makes a profit' (where profit is a positive number) and one that is 'profit maximising'

6 https://www.stuff.co.nz/business/farming/97071476/demonstration-dairy-farm-cuts-nitrate-leaching-30-per-cent-and-stays-profitable
7 https://en.wikipedia.org/wiki/JADE_(programming_language)
8 Linear programming is defined as a mathematical technique used in computer modelling (simulation) to find the best possible solution in allocating limited resources. https://en.wikipedia.org/wiki/Linear_programming

(where profit is as high as possible within constraints). Marginal analysis is 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' (a widget being some type of good or service), and 'marginal revenue' (MR) is the revenue generated from selling one more widget[9].

Widgets are made by 'companies'—and a dairy farm is analogous to a company if the widget in question is milk (the same can apply to a farm producing beef, lamb, wool, venison, etc).

The standard assumption in economics is that firms will try to maximise profits. This occurs when marginal costs equal marginal revenue (MC=MR) 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**, because it is offset by the cost of producing that widget—implying no further gains can be made.

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

- if marginal cost is less than marginal revenue (MC<MR) 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 (MC>MR) then it is profitable to decrease production to restore profitability (as the last dollar spent is more than the last dollar earned).

This framework of marginal analysis is especially useful when making decisions to increase or decrease production, which is something farmers do all the time. On a dairy farm, this would mean only producing a quantity of milk (the number of widgets) up to the point where producing any extra milk starts to erode profitability. So if marginal cost is currently less than marginal revenue (MC<MR) on a farm, it would be profitable to increase production (i.e. 'add cows'), **however**, if marginal cost is currently greater than marginal return (MC>MR), it is profitable to decrease production (i.e. 'reduce cows'). E2M can identify this 'tipping point'.

An Example

A practical example neatly illustrates the theory, with the results summarised in the table below. Let's assume a hypothetical dairy farm is currently producing 950 kgMS/ha (highlighted in grey). This is a little under the national average. Therefore the farmer is considering increasing production; and is targeting 1100 kgMS/ha production over the same land area through intensification (highlighted in yellow). As planning figures, let's assume:

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

- Farm gate milk price is $5 /kgMS
- Fixed costs (FC) are $4 /kgMS
- Variable costs (VC) range from $0.20 to $2.50 /kgMS depending on intensity
- Current farm working expenses (FWE) are $4.50 /kgMS
- Whilst the farm is currently producing 950 kgMS/ha, the possible range is 700 kgMS/ha - 1,200 kgMS/ha.

Table A: *Hypothetical farm profitability analysis. Milk price is $5 /kgMS. Refer to Table B for an explanation of the terms and colour-coding.*

kgMS /ha	FC $	VC $	FWE $	TC/ha $	MC $	TR/ha $	MR $	п/ha $	Mп $
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	257.50	4500	250	630.00	-7.50
950	4.00	0.50	4.50	4275.00	405.00	4750	250	475.00	-155.00
1000	4.00	1.00	5.00	5000.00	725.00	5000	250	0.00	-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	-312.50
1150	4.00	2.25	6.25	7187.50	587.50	5750	250	-1437.50	-337.50
1200	4.00	2.50	6.50	7800.00	612.50	6000	250	-1800.00	-362.50

Table B: *Explanation of terms and colour-coding used in Table A.*

kgMS/ha	kilograms of milk solids produced per ha
FC	fixed costs (e.g. infrastructure maintenance)
VC	variable costs (e.g. staff, bought-in feed, vet bills, fertiliser)
FWE	farm working expenses (FC + VC)
TC/ha	total costs per hectare (kgMS/ha x FWE)
MC	marginal cost (the cost of moving from one level of production to the next—i.e. the cost of increasing production by 50 kgMS/ha, as determined by the difference between rows in the TC/ha column)
TR/ha	total revenue per hectare (milk price x kgMS/ha)
MR	marginal revenue (the additional revenue made by moving up one level of production—i.e. increasing production by 50 kgMS/ha, as determined by the difference between rows in the TR column)
п/ha	profit per hectare (TR/ha – TC/ha)
Mп	marginal profit (the change in profit when moving from one level of production to the next—i.e. increasing production by 50 kgMS/ha, as determined by the difference between rows in the п/ha column)
Grey	Current production
Yellow	Targeted production
Green	Profit-maximising output
Red	Loss-making production

Table A illustrates the following:

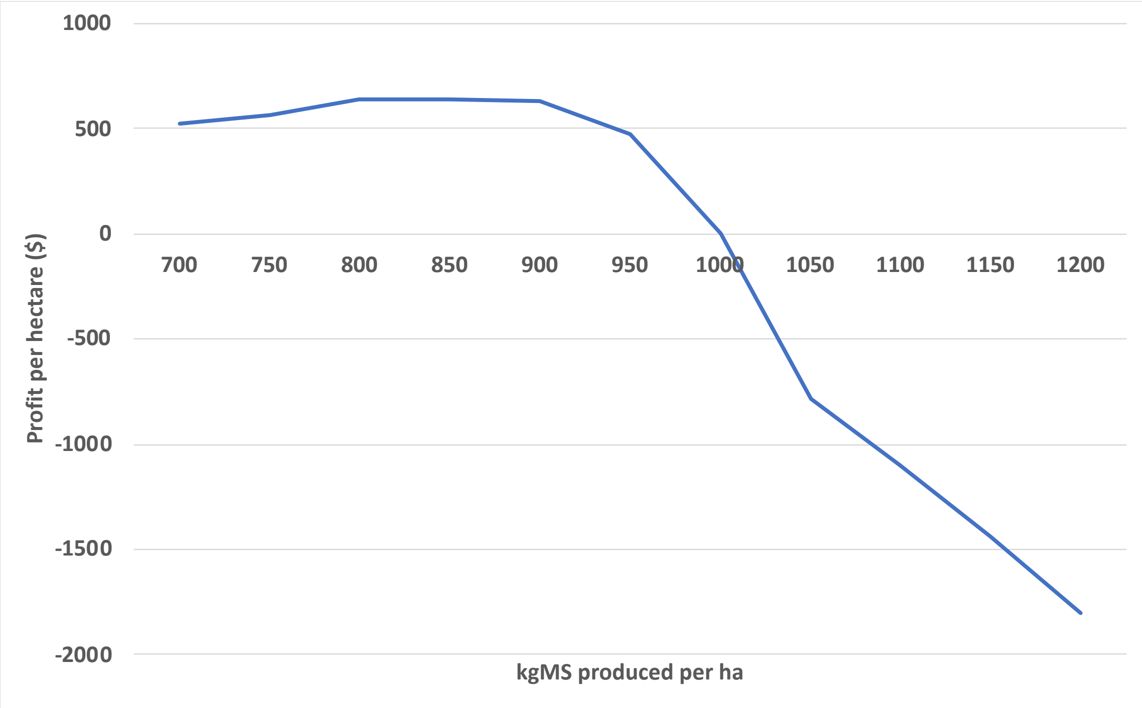
- At an expected milk price of $5 /kgMS, any level of production above 1000 kgMS/ha will be unprofitable. This is evident in the 'profit per ha' (п/ha) column, which peaks (at $640 /ha) at a production level of around 800 kgMS/ha and decreases to $0 /ha at 1000 kgMS/ha.
- Because of the above, the targeted expansion should be abandoned. It would result in losses of $1100 /ha.
- Current production of 950 kgMS/ha, whilst profitable (п/ha = $475), is not optimal. This is because the MC ($405) is greater than the MR ($250) at this point. Farm profitability would benefit from reducing production (the environment might also benefit if emissions and leaching drop too).
- Profit-maximising production occurs between 800-850 kgMS/ha (at almost exactly 850). This is the point where marginal profit (Mп) = $0 (this is the 'tipping point' where any increase in production actually starts to erode profitability, and can be seen in the п/ha column). In this case a 21% drop in production would lead to a 34% increase in profitability.
- The column denoting profit per ha (п/ha) achieves a maximum before reaching a 'tipping point' (at $640) and then declining; whereas the marginal profit approaches zero at the maximum and is negative thereafter.
- There is a difference between being 'profitable' and 'profit-maximising'. While the current farm makes a profit of $475 /ha at 950 kgMS/ha, it would make around $640 /ha if it lowered production to 800-850 kgMS/ha.
- E2M can identify this profit-maximising point.

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. As a result, many farms essentially have 'two herds': the first is the profit-maximising herd, which makes money; and the second is a 'parasitic' herd, which generates net costs and thereby reduces the profitability of the entire farm.

In the example above, the extra cows required to produce the marginal 100 kgMS/ha are the 'parasitic' herd.[10] Profitability per ha (п/ha) at different MS production levels in the example is represented in figure 1 (below). You can see how this 'parasitic' herd reduces the farm's profit as soon as it passes production of 850 kgMS/ha.

[10] the 100 kgMS/ha is the difference between the profit-maximising 850 kgMS/ha and the farm's 'current' production of 950 kgMS/ha.

Figure 1: *Profit per hectare (п/ha) at different levels of production, reflecting Table A data.*



Changes in the Milk Price

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 C shows, this is flawed thinking. In table C the milk price assumption is increased significantly to $8.00 /kgMS (above the forecast 2021 price) but the cost structure remains unchanged.

Table C: *Revised hypothetical farm profitability analysis. Milk price is $8 /kgMS. Refer to Table B for an explanation of the terms and colour-coding.*

kgMS /ha	**FC $**	**VC $**	**AC $**	**TC/ha $**	**MC $**	**TR/ha $**	**MR $**	**п/ha $**	**Mп $**
700	4.00	0.25	4.25	2975.00	-	5600	-	2625.00	-
750	4.00	0.25	4.25	3187.50	212.50	6000	400	2812.50	187.50
800	4.00	0.20	4.20	3360.00	172.50	6400	400	3040.00	227.50
850	4.00	0.25	4.25	3612.50	252.50	6800	400	3187.50	147.50
900	4.00	0.30	4.30	3870.00	257.50	7200	400	3330.00	142.50
950	4.00	0.50	4.50	4275.00	405.00	7600	400	3325.00	-5.00
1000	4.00	1.00	5.00	5000.00	725.00	8000	400	3000.00	-325.00
1050	4.00	1.75	5.75	6037.50	1037.50	8400	400	2362.50	-637.50
1100	4.00	2.00	6.00	6600.00	562.50	8800	400	2200.00	-162.50
1150	4.00	2.25	6.25	7187.50	587.50	9200	400	2012.50	-187.50
1200	4.00	2.50	6.50	7800.00	612.50	9600	400	1800.00	-212.50

As can be seen:

- The 1100 kgMS production target (in yellow) is now at a profit-making point (compared to a $1100 /ha loss before) but is still nowhere near optimal.
- The current 950 kgMS/ha level of production has improved and is now very close to optimal (though there still appears to be a very small 'parasitic herd').
- Maintaining the current, or even moving to a lower, level of production still results in a higher profit per hectare (π/ha) than would be achieved at 1100 kgMS/ha.
- A 60% increase in the milk price only resulted in only an (approximately) 11-12% increase in the optimum production level (and it still suggests a slight reduction from the farm's current production).

Note: In reality, it is not possible with a biological system like a farm to obtain the level of precision outlined in the tables above—but a model, such as E2M, can closely approximate them.

Other Farm Systems Models

Unfortunately, very few farmers actually employ any type of profit-maximising analysis. This is in part because other models (and the plethora of industry benchmarks) are incapable of profit-maximising. They base their analysis on 'average profits', rather than 'marginal profits', so can only identify whether a farm is making a profit 'on average' or 'overall'. These models average profits across an entire farm, so cannot identify which parts of the farm are 'profit-making' (e.g. the profit-maximising herd) and which parts are 'loss-making' (e.g. the 'parasitic herd'). As demonstrated above, a farm can be making money 'on average' across the farm, but could be very far from the optimum economic position. Averaging profits is a substantial limitation of these models[11].

An example of the limitations of averaging can be found in any of the values provided in the benchmarking for the dairy industry[12]. As illustrated by the example above, attempting to meet or exceed any of these averages as 'KPIs' (e.g. the kgMS/ha, as in our example above, or the cows/ha) is fraught, because it does not take into account the very different circumstances of the individual farm and could lead to a lower-than-optimal (or even detrimental) outcome for farm profitability, as well as an increased environmental impact.

One of the reasons profit-maximising analysis is almost never employed is an assumption that higher production must equate to higher profitability[13]. The result is a form of 'output maximisation' ('productionism') rather than profit-maximisation. This 'productionist' assumption of 'more production means more profit' only occurs if there are economies of

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[11] For a good explanation of average costs and marginal costs, and how these can help determine how much of something to produce, check out this 'Khan Academy' video: https://www.khanacademy.org/economics-finance-domain/ap-microeconomics/production-cost-and-the-perfect-competition-model-temporary/short-run-production-costs/v/marginal-revenue-and-marginal-cost

[12] https://www.dairynz.co.nz/business/dairybase/benchmarking/latest-dairybase-benchmarks/

[13] This was promoted in part by the 2008-2017 National Government's 'export double' vision: https://www.beehive.govt.nz/release/minister-outlines-'export-double'-vision-primary-sector

scale (EoS) where a farm is struggling to achieve the minimum efficient scale. In such a case average costs (i.e. FWEs) need to be decreasing as production increases, so all a farmer needs to do is keep expanding until average costs stabilise. (e.g. milking 10 cows mightn't be profitable because FWEs offset profits, but milking 100 cows might be).

However, all systems are ultimately bound by diminishing marginal returns when one input is fixed. That is, the return (profits) on inputs (efforts to produce) will eventually become zero. For example, on a farm the number of cows, the amount of fertiliser applied, and volumes of bought-in feed (BiF) can all be increased; but if size of the farm is fixed then that becomes the constraint of the system. Trying to push these systems further is futile and only decreases marginal returns. It is marginal costs—rather than average costs—that are critical to knowing when to stop.

Summary

E2M is an economic model built on the Jade OO programming platform that uses linear programming (LP) techniques to undertake marginal analysis. (though, as above, it is not just an 'LP' model). It can ascertain both where a farm 'is' (i.e. it's current 'base' scenario) but also where a farm could 'be' (i.e. the point of profit maximisation, within constraints). Other models cannot do this because they are based on average, rather than marginal, costs and revenues.

As suggested earlier, a real strength of E2M (and JADE enhanced linear programming) is its ability to find a solution within constraints: for example, to profit-maximise subject to a nutrient output constraint by 'crunching' alternative management combinations. E2M can analyse a range of substitutes to meet the energy demands of a farm, such as the application N fertiliser, the purchase of bought-in feed, or a reduction in stocking rate, as well as their significantly different cost structures, and find the most profitable option to meet that demand. Essentially, once a constraint is identified, E2M can calculate the least-cost method of addressing that constraint subject to an overall objective of profit-maximisation. In doing so it also 'de-clutters' the analysis by seamlessly eliminating a myriad of inferior outcomes.

The analytical power of E2M becomes apparent when one considers the use of benchmarks within the dairy industry. The rationale for industry benchmarks is simple: given an inability to maximise numerous variables (all subject to constraints) across numerous farms, the simplifying assumption is made that farms are, on average, the same (so are akin to standardised multi-site processes such as a fast-food restaurant). This assumption is critical as it permits the application of simple benchmarks (e.g. comparative analysis such as milk production targets (kgMS/ha), per cow production targets (kgMS/cow), intensity targets (cows/ha), etc.) that are irrelevant and often incomparable between farms. In reality, these benchmarks do not provide the information farmers require to make informed decisions, and can be misleading or erroneous (as the averaging processes masks useful farm-specific information). Unfortunately, many farm systems models are also based on these sorts of 'average' assumptions.

In comparison, E2M can analyse a farm 'as is' and provide a ‘base’ case from which alternative futures—based on optimum outcomes—can be considered.

These ‘futures’ can be adjusted and tested in a few moments with a farmer sitting next to an E2M operator, and the model can be run again to produce an output summary in seconds. This massive increase in efficiency means that, after a ‘base run’ has been set up, an E2M operator’s time can be spent co-constructing management solutions with a farmer (often on-farm), rather than spent away in an office somewhere adjusting input scenarios only to report back on potential options days or weeks later. The learning opportunities of this, for both parties, cannot be understated.

The report that follows provides this ‘base’ run, with alternative runs (or ‘futures’) stemming from it based on the different outcomes sought or constraints imposed. We hope it is insightful and presents options for an alternative vision for your farm, both in terms of economic performance and reduced environmental impact. Or, if you’re already running a near-optimum scenario, we hope it presents you something you hadn’t thought of before.

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