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Milk, money, muck and metrics: inefficient resource allocation by New Zealand dairy farmers.

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SUMMARY

Dairy producers have focused on increasing production and ignored the implications this may have on resource allocation efficiency. Averaged comparative figures are used to justify the production message but these cannot distinguish the point at which diminishing profitability from additional inputs will occur. Resource allocation using Linear Programming allows the effects of a simultaneous variation in resources to be revealed. Dairy production profitability is optimised where technical and biological efficiency combine to provide the best economic and coincidentally, environmental outcomes.

INTRODUCTION

New Zealand dairy production has increased in volume and value for many years (DairyNZ 2009; Riden 2009). There appear to be two major drivers, both of which are classified in this paper as "productionist":

- intensive growth: more cows on existing dairy farms (but with little increase in average production per cow).
- extensive growth: an increasing area in dairy production, converted from other livestock enterprises and cash cropping.

This paper primarily examines aspects of increasing dairy production. The conversion of marginal land to dairying, with its declining resource allocation efficiency and its contingent implications for economic and environmental sustainability, is a separate study and is not pursued further here.

There has been little quantitative analysis of the impact of increasing dairy production on efficient resource allocation and on farm profitability, yet the relationship between these practices and declining environmental outcomes is both well studied and accepted (PCE; 2004). In addition to being environmentally questionable, productionist techniques are also commercially irrational as they continue to deploy resources well after diminishing marginal returns (DMR) have set in. DMR occurs where additional or marginal revenue (MR) from progressively greater amounts of the resource or input will eventually start to decline until it is equal to or less than the marginal cost (MC) of a unit of the resource or input. Not only is an excessive resource allocation commercially irrational, it is also environmentally unsustainable. Moving, however, from inefficient to efficient allocation will not only improve the financial bottom line, it will also improve the environmental impact. This arises because the starting point is typically inefficient, which implies there is no need to trade off or sacrifice environmental and efficiency outcomes.

Animal and pasture researchers have long known how to efficiently enhance production (Hutton, 1972). Rather than trying to optimise their systems, however, many farmers used heuristics, where they set a stocking rate and then provided the feed needed, made easier by abundant supplements. This was further buttressed by increasing amounts of nitrogen fertiliser, principally urea. Under such regimes, total production per hectare increased as cow number increased, but production per cow stayed largely the same.

The economic inefficiency of this approach has been shown (Anderson, 2010) and modelling can also show that technical inefficiency must also be occurring. It is difficult, however, to identify from either heuristic approaches to farming, or from existing farm system models where this inefficiency occurs and how it can be improved.

Data from surveyed farms are often used to produce averages or ratios which are quick and simple to calculate. They are used to compare different farms and assess a farm's physical and economic status and apparent opportunity for improvement. Candler and Sargent (1962) explained the flaws inherent in using such averages and ratios for comparative analyses. An important tenet of this paper is that if a resource or input is added to any farm's production system, it will exhibit diminishing marginal returns.

It is also assumed that except in unusual circumstances, no rational manager would continue to use the input or resource at a level beyond the point where MR = MC, the profit-maximising point. Critically, this is also the point of optimal or efficient resource allocation. Calculation of a ratio such as the average revenue or a Gross Margin does not indicate when that profit-maximising 'tipping point' has been reached.

Furthermore, ratios involving data e.g. kg plant dry matter (DM) per hectare (ha), are very unlikely to identify the point of optimum application of multiple resources and inputs (Rae 1977, Kay et al 2008, Makeham and Malcolm 1993). Linear programming (LP) provides an efficient and effective method of achieving optimisation. This paper reports on the application of an established resource allocation LP to a dairy farm to ascertain the optimal cash surplus (profit) and carbon dioxide (CO_2) emission.

Every farm system has specific constraints to further improvement. Unless they are clearly identified and the resources needed to overcome them quantified, adding more resources will be economically inefficient as any response will be sub-optimal. Two types of farm on either side of the "traditional" pasture-based farm system described by McMeekan, (1960) can therefore be identified:

- Type 1 farmers: low efficiency; increase cow number with supplementary feed purchases; fail to lift per cow production,
- Type 2 farmers: buying in more supplements and concentrates to improve per cow production towards a biological maximum.

METHOD

An integrated resource allocation linear programming (LP) model (Ridler 2001; Anderson and Ridler 2010) was used to assess the effects of simultaneous variation in a number of resources within a specified 100-ha Waikato dairy-farm system.

The model allows any unconstrained resource to be varied during each run and requires that all resources and inputs be integrated into the analysis. Stock number, supplements, use of nitrogen fertiliser, farm silage made, average pasture covers and grazing off figures can all differ between runs.

The LP model established feed demand for stock requirements based on AFRC (1995) energy equations applied for each specific situation. The amount of feed on offer then determined the number of stock carried in the model. If the costs of supplements and prices of milk and meat justified it, additional feed could be purchased to produce additional product for sale up to the point where the additional input costs did not exceed the additional returns gained. In this exercise all stock, including replacements, were grazed **on** the farm.

The run for Table A, 1a increased production by adding supplements to feed more cows whilst production per cow remained the same.
For Table A, 1b, supplements were fed in increasing quantities to increase production per cow in a fixed-size herd.
For Table A, 1c stock numbers were allowed to optimise with increasing per cow production.

It should be noted that in these examples:
There could be variation in costs per cow between systems. Only additional feeds, nitrogen and their cost were included. There could be large variations in animal health, in-calf rates and longevity if cows were stressed at either the high input/low production or high input/high production potentials. Usually, these vary according to the expertise of the management involved. Any decline in these factors will have cumulative negative effects on overall farm system efficiency. There was minimal increase in cow live weight between each option. High-producing cows were heavier and had a slightly higher maintenance requirement.

These points can be addressed in more detail when specific farm data are used.
In this example the base resources remained constant with extra feed energy purchased at cost. Principal results of interest were, cash surplus and amount of CO_2 produced.

RESULTS

The model showed that feeding progressively more supplements to a pasture-fed herd to increase cow number with no increase in milksolids per cow led to progressively less profit (Table A and Figure 1).

Table A: The effects of setting (fix) milk production per cow, and/or setting or optimizing herd size, on the amount and cost of supplementary feed (bought or made on farm) and concentrates required: milk production; CO_2 production; and cash surplus.

No. Cows	MS/cow kg	Suppl. buy t	Conc buy t	Silage made t	MS kg	Surplus $	CO_2 t	Suppl cost $
1a								
Fix 225	300	0	0	112	67,675	175,208	1,025	0
Fix 250	300	127.5	0	66	75,035	158,280	1,109	47,175
Fix 275	300	294	0	27	82,538	132,657	1,187	108,780
Fix 300	300	462	0	0	90,042	103,566	1,266	170,940
1b								
Fix 225	326	11	0	99	73,341	203,203	1,054	4,070
Fix 225	350	54	0	79	78,692	225,137	1,074	19,980
Fix 225	375	101	0	58	84,557	248,868	1,096	37,370
Fix 225	400	144	0.3	45	89,799	268,836	1,115	53,445
1c								0
Opt.221	326	0	0	109	72,008	204,525	1,033	0
Opt.217	350	0	0	98	75,960	229,975	1,049	0
Opt.211	375	0	0	93	79,229	256,580	1,048	0
Opt.205	400	0	0.25	89	81,992	278,961	1,048	137.5

Feed energy: Megajoules of metabolisable energy / kg dry matter: MJME/kg DM
Pasture Silage made: 10.4 MJME/kg DM; Maize silage bought: 10.4 MJME/kg DM
Conc = barley at 13 MJME/kg DM. Pasture: 11.8 MJME/kg DM.
Milksolids price \$6.15/KgMS. Cull cow price \$2.20/Kg carcass weight. Surplus calves \$45/head.

Feeding supplements to increase cow number without any increase in production per cow led to diminishing cash surplus, indicating increasingly large cash losses from feeding supplement (Marginal Cost $_{\text{Supplements}}$> Marginal Revenue $_{\text{Supplements}}$). This illustrates both technical and economic inefficiency and poses greatest risk of financial failure.

Feeding supplements to improve production per cow within a fixed herd improved economic return (MR>MC) but was heavily dependent on input and output prices to remain profitable. This option illustrated slight improvement in technical and economic efficiency and posed some risk of financial failure.

The most profitable, least risky regimen was matching feed demand (herd number) with feed supply to improve production per cow through efficient use of pasture (Opt 205). It showed improving technical and economic efficiency.

There was no significant effect on CO_2 production of reducing the number of cows at any given level of feeding (Table A; 1c) as more feed was consumed per cow. This example illustrates a reduction in ratios of kgDM / kgMS and kgCO2 / kg MS produced. (Figure 1)

Table A shows how optimising resource allocation highlights the large improvements that can be made to net profit from:

- running the same number of cows but increasing per cow production from the additional feed (Table A; 1b)
- reducing cow numbers and increasing production per cow (Table A; 1c)

Table B: The effect of setting ('fix') high levels of milk production per cow and of setting ('fix') or optimising herd size on the amount and cost of supplementary feed (bought or made on farm) and concentrates required; milk production; CO_2 production; and cash surplus.

No. Cows	MS/cow kg	Suppl. buy t	Conc buy t	Silage made t	MS kg	Surplus $	CO_2 t	Suppl cost $
Fix 225	425	82	64	60	95,555	287,607	1,117	65,540
Fix 225	450	75	106	85	101,310	296,004	1,132	86,050
Fix 225	475	52	158	120	106,582	299,394	1,145	106,140
Fix 225	500	6	228	170	111,934	298,146	1,154	127,620
Fix 225	550	0	382	280	123,879	277,198	1,150	213,920
Opt.206	425	0	25	99	87,507	296,139	1,058	13,750
Opt.205	450	0	63	110	92,225	304,403	1,067	34,650
Opt.208	475	0	112	138	98,466	306,316	1,089	61,600
Opt.214	500	0	180	173	98,466	303,000	1,120	99,000
Opt 214	550	0	360	290	117,823	267,813	1090	198000

Pasture Silage made: 10.4 MJME/kg DM 15cents to make + 6 cents feed; Maize silage bought: 10.4 MJME/kg DM 30 cents to buy 6 cents to feed.
Conc = barley at 13 MJME/kg DM. 45cents buy and 6 cents feed. Pasture: 11.2-11.8 MJME/kg DM. Utilisations vary from 80-95%

- Above 400kgMS average per cow (herd) some concentrate feed was required.
- As production increased above 425kgMS/cow increasing levels of concentrate were required at increasing cost.
- Due to the need to feed concentrates to ensure high production, surplus pasture was made into silage as quality was not high enough to sustain these high levels of production past a defined proportion of the diet.
- Above 450kgMS/cow for this herd, there was little economic advantage.
- At 550kgMS/cow optimal resource allocation reached a flat response of $282-283,500 cash surplus by altering cow number and feed purchases.
- Above this level of per-cow production alternative combinations of feeds were needed to prevent animal health failure which increased the marginal cost of feed and cash surplus began to curve downwards again.

The combinations represented in Table B were based on production per cow beyond the level that the pasture (11.2-11.8MJME/kg DM) could sustain without it being displaced with more concentrated and expensive feed. It is an example of high technical efficiency, increasing biological efficiency but of variable economic efficiency, depending on the system employed, cost of inputs, price of outputs and the manager's attitude to risk. Higher risk occurs as dependence on purchased feeds increases.

DISCUSSION

Confusion as to what constitutes an "efficient system" may be hampering improvements in technical and economic efficiencies on farms. When data are averaged a single simple "take home message" is produced for all farmers. This modeling has re-affirmed the evidence of Candler and Sargent (1962) that quality multi-element decisions cannot be consolidated into a simple average expressed as an objective.

The associations derived from such figures often assume the status of causal relationships. Such associations are more likely due to undetected constraints within the system. A common example is the benefits attributed to supplements and nitrogen.
If the Table A 1a Fix300 farm system is optimised for stocking rate, calving date and a more flexible dry-off and cull policy, the perceived advantage of supplements and nitrogen diminishes or vanishes. The relationship was due solely to the fixed manner in which the underlying resources were used rather than some insight into the systems response to inputs or change. This emphasises the need for systems modelling using a resource allocation LP framework.

The large improvements in net profit represented in Table A were not seen in Table B; the effect was far less pronounced when feeding more to cows to produce very high production per cow. Large improvements (Table A) can be obtained through increasing production per cow and decreasing cow number (along with replacement number). The amount of feed used within the system for growth, pregnancy and maintenance decreases and the feed thus made available is substituted from maintenance to principally milksolids production. Increasing production per cow provides increasing economic surpluses up to a point, and then it plateaus. This point varies, depending on the resources and inputs available and their cost compared to the value of product being received.

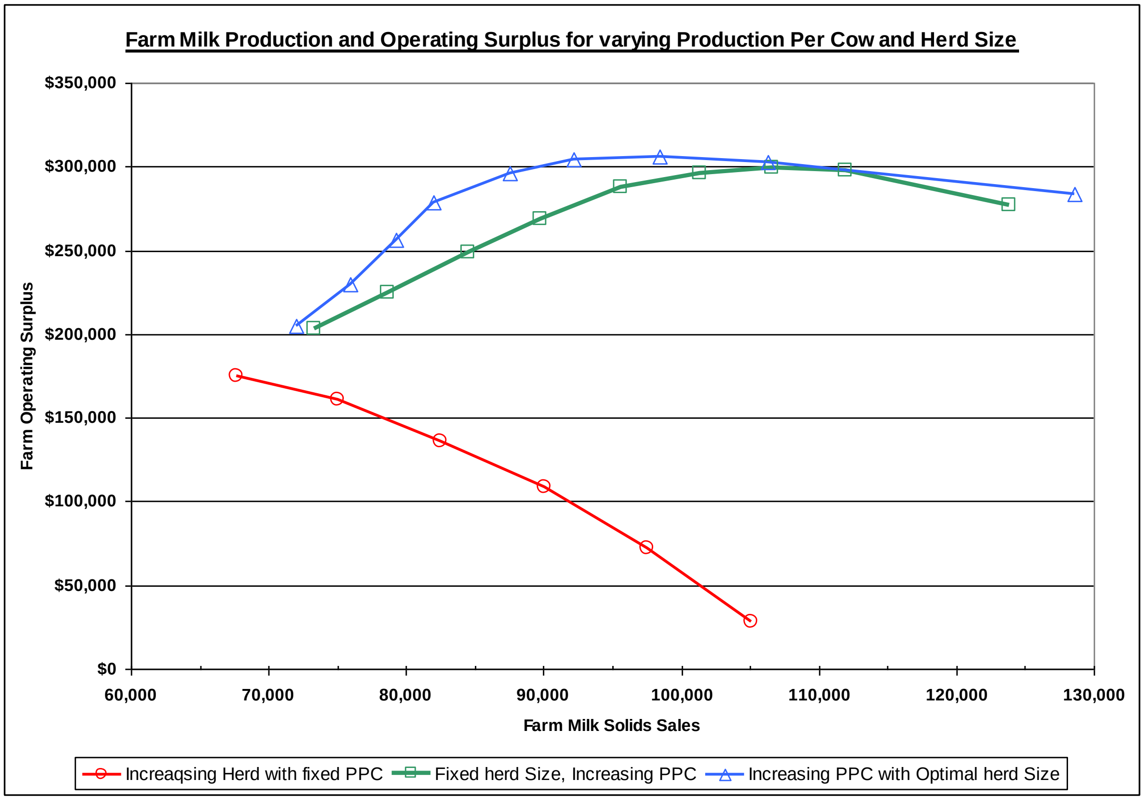
Adding more cows and feeding to maintain the current average per cow production rapidly increases maintenance overheads both for the increasing cow herd and the extra replacements required. As cow numbers increase, the day to day costs of running the additional cows must be added to the additional feed costs and the cost of more replacement stock (grazing, veterinary care/health and breeding).

At higher levels of production per cow, more expensive supplements (higher energy content to overcome physical intake constraints) must be used. The use of each additional unit of concentrate displaces some pasture from the diet (intake constraint). Initially this can be seen to be profitable but as more and more pasture is displaced, the tipping point is reached and MC>MR dictates the point of maximum supplementation. Even at the low concentrate prices that sometimes occur, when concentrates displace so much pasture that production and some maintenance are from concentrates, the marginal return (MR-MC) from more concentrate is increasingly negative. At higher production levels per cow the overhead of maintenance for the cow and its part replacement decreases in comparison with lower producing cows. But this reverses if fertility and longevity are compromised by the demands of high production.

An optimal combination of cows, production and GHG emissions can be calculated for any resource mix. This "optimal" mix can vary quite widely yet still provide similar economic outcomes. The "optimal" system will vary with resources available. At the optimal point of each production function, technical and economic efficiency must be high. Many New Zealand dairy farmers are either producing at well below this optimum or considering systems which will take them well beyond this point. Those well below optimal are contributing more GHG emissions per kg product than those near optimal. A carbon charge per unit of product does not recognize this fact and disadvantages those who choose to produce at optimal efficiency.

Figure 1 shows the different options graphically.

Figure 1. Comparison of ways to increase total production and their effect on profit.
300 per cow: Increase supplements and cows but fix production per cow at 300 kg MS
225 fix: Static herd size. Increase production per cow by increasing supplements.
Opt cows: Increase production per cow and allow optimal resource allocation.



Figures 2 and 3 show that as farms become more efficient (fewer animals, higher production) a flat emissions charge per kg product becomes increasingly punitive on the efficient vs. the inefficient producers on the basis of resource use and allocation.
To use a single ratio from selected average figures to construct a picture of what is presumed to have occurred within a system and then apply this across systems, ignores all the interrelated changes that will occur.

Figure2: Emissions per kg MS as production per cow increases (PPC)
Base 350kgMS/cow

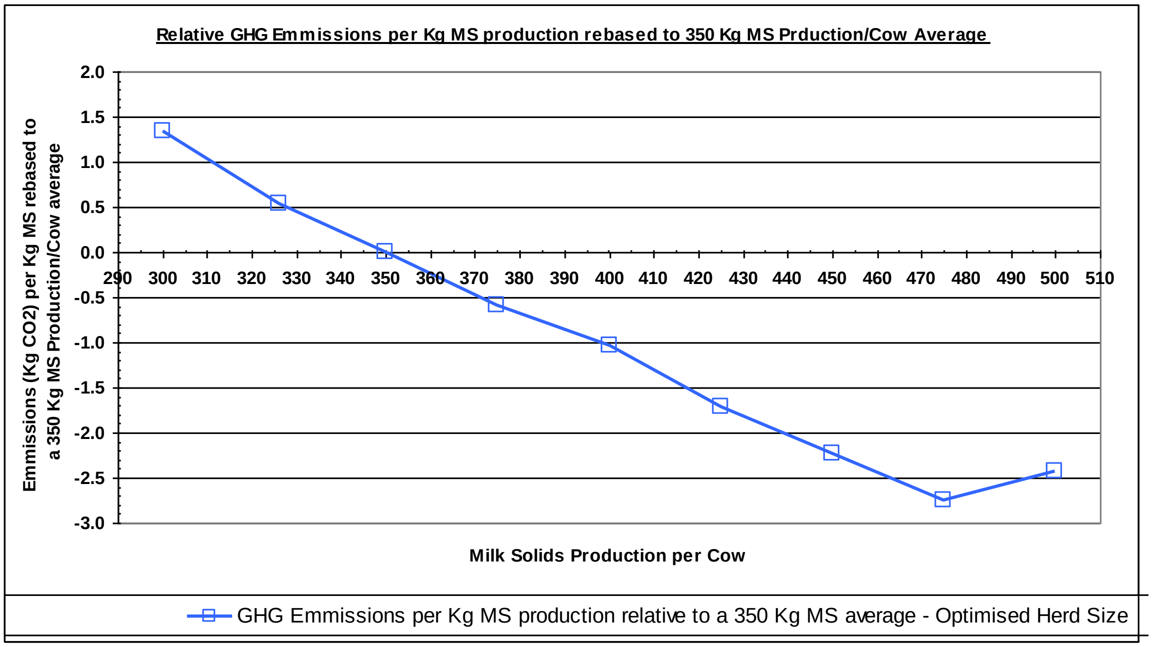
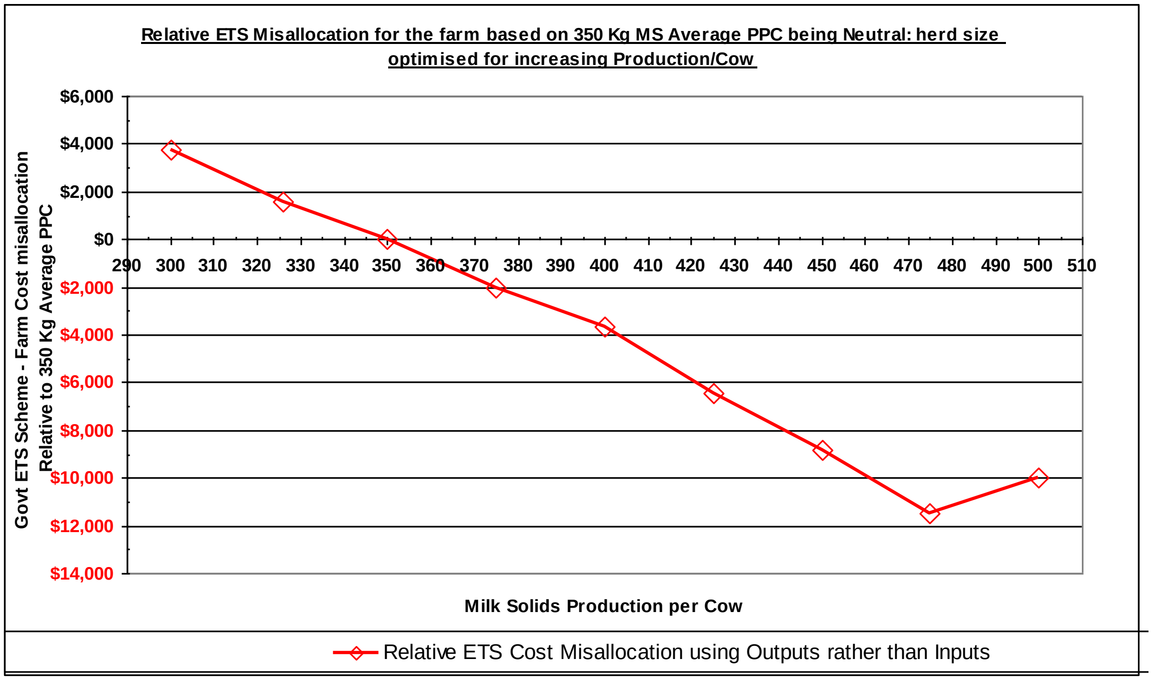


Figure 3: Emissions cost misallocation as Output cost charge.
Base 350 kg MS/cow



Where inefficient resource allocation applies, there is the possibility to improve the allocation so that commercial and environmental outcomes can both be improved rather than one traded off against the other. Technically and economically inefficient farmers are also contributing more total GHG and effluent than those near optimal which has an environmental impact beyond the farm boundary.

Other data currently being presented do not include the specific farm detail necessary to assess constraints within, or the technical efficiency of systems. This detail may be no more expensive to present than the averaged figures already offered.

It is obvious that recommendations for resource or input allocation for the system illustrated in TableA 1a can be quite different to those for the system in 1c or those in TableB. This will apply to such economic inputs as supplements, crops, nitrogen and investment in new technologies. Indeed the paradox is that those farms most likely to benefit from such investment cannot afford to make that investment unless they alter their farm system.

Even when the farm has improved to reach level TableA 1c, many of these investments are still not worth implementing but all farms will benefit from improving animal health, fertility and longevity.

Currently, there are three methods of analysis of farm systems for comparative purposes which Candler and Sargent (1962) and other agricultural economists (Mauldon and Schapper,1970; Ferris,1999; Malcolm, 2001) warned have little if any relevance to the best allocation of resources:

Firstly, some analysts are using feed-based budgets or mathematical models for farm planning to obtain physical allocation of resources and then they subsequently assess financial performance of that plan. Feed-based budgets seldom simultaneously incorporate financial assumptions and do not respond to changes in relative costs of the feeds used, the timing of production and/or the prices of the system products. They can help decide what enterprise to run, but they do not reliably help decide how best to run the enterprise. It is assumed by farmers and some of their advisers that there is no diminishing marginal utility from more cows, but in reality the economics and biology of the systems still have diminishing marginal returns.

Secondly, some data are recorded for tax purposes (farm accounts). The presentation of farm accounts makes them inherently unreliable for making future production decisions (Kirton *et al*., 1994). Moreover, some analysts would then use such data bases to compare between farm systems or between years on the same farm to try to develop future actions based on such tenuous comparisons. Many ratios can be produced from data bases but these ratios cannot indicate the point of optimum profit from selected inputs. They cannot be used to identify the input or resource that is constraining the next most-economic improvement in any given system. The answer to this requires an analysis that can accurately determine profit maximization using marginal analysis. This then identifies the "tipping point" for the whole system but in the process identifies the constraints that are causing this. From there the process of improving economic efficiency becomes relatively easy and flows on to identify the most important technical improvements that must be made to improve system performance.
This process is efficient and it can replace trial and error on farms and much of the farmlet-study work undertaken on research stations.

When an averaging process is used to produce estimates of responses to inputs, which are then used to compare between systems, the detail that makes the marginal productivity unique to each mix of resources and vital for efficient resource allocation, is lost. Caution is required when such estimates are discussed as it is likely they are artefacts created by the averaging process and confounded by additional factors such as changing production per cow.

Thirdly, some "productionists," in dairy farming have allowed "lumpy" inputs such as expensive machinery, services and irrigation to be added to a farm system, but the additional capital (if costed at all) and operating costs are averaged across the entire enterprise. Their corollary is often a two-way sensitivity table (e.g. input and output) to assess risk. These figures cannot identify the flow-on effects of resource use if a single change to a farm system is made, yet they are regarded as precise.

Within a systems context, however, any metrics are quite transitory in their influence due to the effect that the most constraining input has on full-system performance. What is vital within a system today may become only of minor relevance when the constraint has been overcome. An example of this would be the effect of cobalt on farms in the central North Island.

A number of major considerations are being ignored in the comparative process

1) the importance of efficient resource allocation
2) the marginal value of any change.
3) The level of technical efficiency input to the system
4) The economic efficiency that can be determined from assessing points 1-3 on any farm.

The decisions and marginal responses likely to occur within one system are unlikely to be the same as those that will occur within another as the data that may help define the technical efficiency of a farm such as feed grown to eaten, feed supplied and animal performance, replacement and loss rates and longevity in the herd, will differ.

CONCLUSION

If a model such as the one used for this paper were used more widely in New Zealand, it would provide the benefits of more efficient resource allocation, improvement in economic efficiency, encourage improvements in technical efficiency, GHG emissions, investment decisions and a wider understanding of the flow-on affects of change within farm systems.

Summary Table:

Series	Herd size	kgMS /cow	kgMS sold	Farm silage made Tonne	Suppl buy Tonne DM	Conc buy Tonne DM	Econmic surplus	CO2 Tonne
Increase herd size 300MS/cow	225	300	67,675	0.0	0.0	0.0	$175,208	1025
	250	300	75,035	0.0	127.5	0.0	$160,700	1109
	275	300	82,538	27.0	294.0	0.0	$136,400	1187
	300	300	90,042	0.0	462.0	0.0	$108,500	1266
	325	300	97,545	0.0	637.5	0.0	$71,900	1346
	350	300	105,048	0.0	705.0	90.5	$27,800	1400
Fix herd increase MS/cow	225	326	73,341	99.0	11.0	0.0	$203,203	1054
	225	350	78,692	79.0	54.0	0.0	$225,137	1074
	225	375	84,557	58.0	101.0	0.0	$248,868	1096
	225	400	89,799	45.0	144.0	0.3	$268,836	1115
	225	425	95,555	60.0	82.0	64.0	$287,607	1117
	225	450	101,310	85.0	75.0	106.0	$296,004	1132
	225	475	106,582	120.0	52.0	158.0	$299,394	1145
	225	500	111,934	170.0	6.0	228.0	$298,146	1154
	225	550	123,879	280.0	0.0	382.0	$277,198	1150
OptimalHerd increaseMS/cow	225	300	67,675	0.0	0.0	0.0	$175,208	1025
	221	326	72,008	109.0	0.0	0.0	$204,525	1033
	217	350	75,960	98.0	0.0	0.0	$229,975	1049
	211	375	79,229	93.0	0.0	0.0	$256,580	1048
	205	400	81,992	89.0	0.0	0.3	$278,961	1048
	206	425	87,507	99.0	0.0	25.0	$296,139	1058
	205	450	92,225	110.0	0.0	63.0	$304,403	1067
	208	475	98,466	138.0	0.0	112.0	$306,316	1089
	214	500	106,333	173.0	0.0	180.0	$303,000	1120
	234	550	128,611	290.0	0.0	360.0	$283,548	1202

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- Knowledge gained from this work was used to develop an entirely new LP model (2002/2003) that overcame deficiencies in previous model format and function. More efficient routines and a much improved interface for data entry and reporting.
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Descriptor
Peter is a self described policy wonk whose experiences span both social and regulatory policy, with a strong applied microeconomic foundation spanning the two
Between February 2007 and February 2010 Peter was a principal advisor within MAF Policy with responsibility for dairy issues relating to Fonterra's capital structure and sector competition policy (including regulated milk).
Peter is currently working on different projects in the agricultural and social policy spaces.
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