
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Application of resource allocation optimisation to provide profitable options for dairy production systems

W.J. ANDERSON[1]* and B.J. RIDLER[2]

[1]Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private Bag 11-222, Palmerston North 4442, New Zealand
[2]142 Ballantyne Road, Poraiti, RD 2, Napier 4182, New Zealand
*Corresponding author: w.j.anderson@massey.ac.nz

ABSTRACT

A linear program (LP) model analysed resource use on a 100 ha dairy farm. A single optimum-profit combination was established for resources which were either optimised or constrained. It was found that, with a fixed herd of 320 milking cows, when production increased from 305 kg milksolids per cow (kg MS/cow) to 415 kg MS/cow, cash profit increased by 65%. This required additional supplements. If, however, feed demand and supply were optimised at 415 kg MS/cow, the LP reduced milking cow number rather than buy in feed to meet the increased feed demand from higher production per cow. At all production levels chosen between 305 and 415 kgMS/cow, it was most economic to dry off and cull cows early in dry summers to optimise feed demand *vs.* feed grown; use nitrogen (N) fertiliser to avoid a feed deficit only when response rates of better than 10 kgDM to 1 kg N could be expected; not use N for growing supplements to harvest. Pasture cover, within defined constraint levels, provided a buffer for feed demand and supply fluctuations. The study highlights the importance of assessing production, income and cost in an integrated framework to identify the point at which individual resources become limiting.

Keywords: dairy farm systems; computer model; simulation; optimise; resource allocation.

INTRODUCTION

The use of computerised modelling is common in New Zealand agriculture. Examples include, Grazing Systems (GSL, Ridler *et al*., 2001), Farmax, UDDER (Larcombe, 1988) and Dexcel Whole Farm Model (Wastney *et al.,* 2002), with the developed models having varying levels of impact on farmer behaviour (Woodward *et al.,* 2008). Linear programming (LP) has been used mainly to simulate particular aspects of farm production systems (Stott, 2008) with few used to simulate farm systems (McCall & Clark, 1999), especially where the emphasis is on the marginal productivity of the system being investigated (Santarossa *et al.,* 2004).

Models are flexible and respond rapidly to input changes. These features enable users to examine in detail situations ranging from the individual animal to the whole-farm, depending on the model structure and parameters. This paper reports on the results of a linear programming model (GSL LP) which integrates the physical and financial environments in which farmers operate. It includes receipts for products and costs of operating a farm.

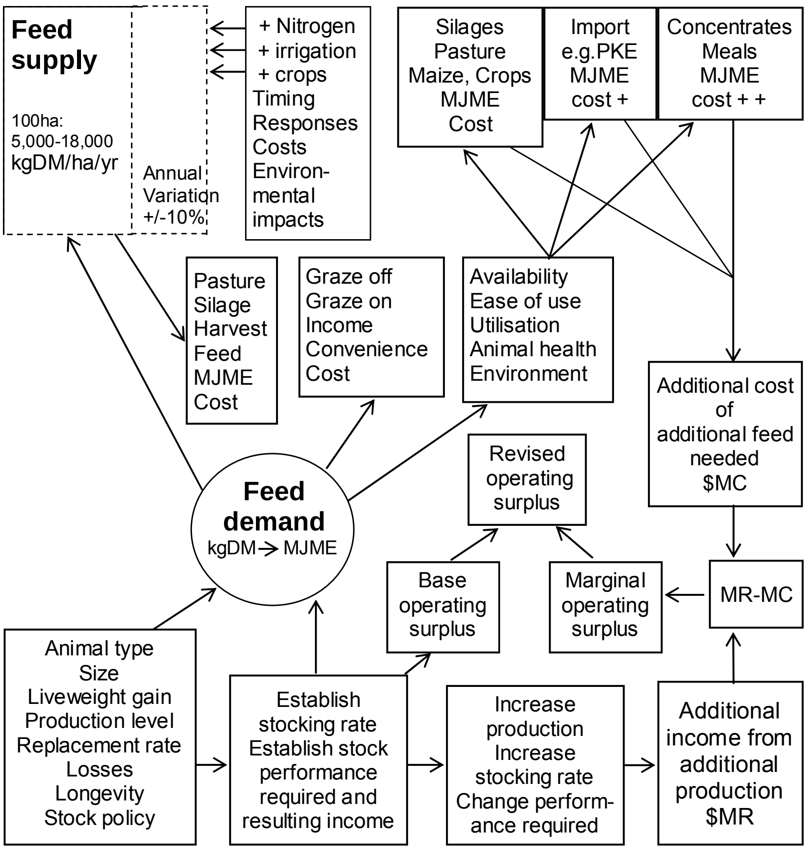
This LP model allocates resources according to energy relationships derived from controlled experiments. The user defines inputs which then apply to a unique situation that the LP model is analysing. For example, the average pasture growth rate and availability, quantity and quality of all forages expressed as Megajoules of metabolisable energy (MJME) per kg of dry feed, herd age structure and production, addition of nitrogen, crops or irrigation and all other resources are initially specified but can then be varied as required for each two-week period of a year. The resources in the LP model used in this investigation were for predominantly pasture-fed dairy cows reflecting New Zealand's main production system. "In principle, efficient milk production on grassland involves, as a prerequisite, the best possible fit between the varying curve of pasture production and the much more stable curve of cow and herd requirements" (McMeekan, 1960).

As the LP model has the ability to add, replace or modify in quantity and output the resources being used in a controlled stepwise manner (Figure 1), these functions allow incremental addition of resources after initially constraining selected resources.

The stepwise application of constraints by the LP model provides the means to investigate change, then to modify or optimise each resource in order to understand the response of the system to a specific change. Although the change is ultimately driven by its financial outcome, it depends primarily on feed-energy relationships and the cost of the energy. Interpretation of solutions in this context is not complex and is aided by reporting of forage status, animal production and cash flows in two-weekly intervals.

Roche and Newman (2008) advised against investigating total extra product from total extra input, defined as "Margin over Feed", but did not

FIGURE 1: a model representing the relationship between feed supply, feed demand and production economics in a grazed livestock production system. MJME = Megajoules of metabolisable energy; MC = Marginal cost; MR = Marginal revenue; DM = Dry matter; PKE = Palm kernel expellar.



explain how a marginal analysis should be conducted to investigate the effects of individual increments of inputs on the incremental output and subsequent extra revenue. The law of diminishing marginal returns (DMR) (Kay *et al.,* 2008) states that as additional units of a variable input are used in combination with one or more fixed inputs, marginal extra physical product will eventually decline. Examples of fixed inputs are land and buildings. "DMR is based on the biological processes found in agricultural production and results from the inability of plants and animals to provide the same response indefinitely to successive increases in nutrients or some other input" (Kay *et al.,* 2008).

If a program does not simultaneously account for financial factors, DMR and physical constraints on resources, it lacks the accuracy and efficiency required for modern dairy production systems (Ferris & Malcolm, 1999). Models that consider financial resources after the physical calculations are complete usually fail to fully account for DMR because the process must include the ability to select the most economic mix based on marginal return to each possible resource within a dynamic system. The LP methodology of continual analysis of multiple resource use based on productive and economic combinations ensures this occurs.

Some analysts use averaging procedures such as a gross margin of total revenue *minus* variable costs; a partial budget where only the part of the business deemed to be affected by a change is analysed; a benchmarking system where properties and businesses with similar characteristics are compared to identify differences in production, farm performance and profitability; or feed budgeting. These techniques do not generally allow one to comprehensively assess the effect of integration of farm resources on the production system or on farm profitability (Makeham & Malcolm, 1993).

Figure 1 illustrates how feed demand may be established and adjusted for any combination of resources. When this has been established, feed-back loops which include the economics of each aspect of production can be constructed to more accurately allocate resources profitably. If a LP optimisation routine is used to calculate total feed supply and the pattern of feed supply, feed demand from specific animals can be exactly matched. If this feed demand can be met from existing pasture production alone, this sets a base from which other options can be compared.

Manipulation of animal number and performance, and pasture type and supplement availability can be used to provide a wide variety of management options with varying financial outcomes, management constraints and risk profiles.

METHOD

The LP model objective in this study was ultimately the best economic return. The LP model allowed selected resources to be constrained, primarily cow number and production per cow, but it allowed the addition of other resources such as supplementary feeds, nitrogen and grazing off. The model depended primarily on relationships involving feed energy and its cost. Interpretation of solutions was aided by reporting of forage, animal production and cash flows in two-weekly intervals.

Costs and prices for 2010 were applied, for example \$6.15/kg milksolids (MS). Expenses included only variable costs such as farm-working

TABLE 1: Expected production, profit and the resource requirements of a pasture-based, spring-calving, seasonal-supply, 100-ha New Zealand dairy farm at specified numbers of cows and/or per-cow production levels. MS = Milksolids.

Run name	Number cows (# = fixed)	Average production (kg MS/cow)	N Fertilizer		Silage made (t DM)	Supplement purchased (t DM)	Concentrate required in Sept/Oct (t)	Dry-off date	Number cows culled	Total production (kg MS)	Income less costs ($)
			Applied 13/7 (kg)	Applied 10/8 (kg)							
Base fix	320#	305	50	25	14	152	0			97,653	166,091
Base optimise	286	305	40	25	57	0	0			87,172	187,254
Base early dry/cull	320#	298	50	25	14	98	0	19/4	59	95,372	198,108
332 kg MS	320#	332	25	50	0	225	0			106,257	196,120
332 optimise	274	332	40	25	54	0	0			90,829	223,562
366 kg MS	320#	366	25	50	0	327	0			117,286	228,645
366 optimise	262	366	50	25	56	0	0			96,149	265,871
415 kg MS	320#	415	25	50	0	452	8.5			132,773	273,443
415 optimise	243	415	40	25	50	0	6.5			100,823	316,924
415 early dry/cull	320#	402	25	50	0	379	8.5	19/4	59	128,801	300,653

TABLE 2: The effect of different herd sizes at one per-cow milk-production level on the resources required, expected production and profit of a pasture-based, spring-calving, seasonal-supply, 100 ha New Zealand dairy farm. MS = Milksolids.

Run name	Number of cows	Average production (kg MS/cow)	N Fertilizer		Silage made (t DM)	Supplement purchased (t DM)	Concentrate required	Replacement heifers grazed on-farm	Total production (kg MS)	Income less costs ($)
			Applied 13/7 (kg)	Applied 10/8 (kg)						
Fix	320	305	50	25	14	152	0		97,653	166,091
Fix	310	305	50	25	25	103	0		94,602	173,949
Fix	300	305	50	25	36	53	0		91,550	181,695
Fix	290	305	50	25	43	4	0		88,498	186,300
Optimise	286	305	40	25	57	0	0		87,172	187,254
Fix	280	305	46	25	58	0	0	4 Rising 2 yr	85,450	187,000
Fix	270	305	50	25	64	0	0	30 Rising 2 yr	82,395	185,733
Fix	260	305	50	25	71	0	0	60 Rising 2 yr	79,343	183,978
Fix	250	305	50	25	99	0	0	All Rising 2 yr + 10 Rising 1 yr	76,292	181,562

expenses and excluded fixed costs and capital expenditure.

In Table 1 are shown successive runs of the LP model. A base performance was established for the model farm of 100 ha effective growing 12,026 kg pasture dry matter (DM). In the first row of the table, herd size was set at 320 cows of mixed ages, including first-calving two-year-old heifers. Production was set at 305 kg MS per cow based on a herd profile of 25% replacement rate; live-weight gain in replacements; a maximum of six years in the herd; live-weight variation between seasons as cows lost and regained condition; and intake and production of younger cows proportionate to mature cows. The nitrogen (N) fertiliser available to the model was constrained to set dates of application, and the amounts available were also discrete, not continuously variable, in line with typical on-farm practice. The amounts showing in Table 1 were those indicated by the model to supply the required feed at least cost for the specified conditions.

Other factors determined by the model were the amount of silage made and supplements purchased; concentrates required (Table 1) and pasture covers carried forward, subject to upper and lower constraint levels for each period; and financial performance. The model had user-defined or default values for two-weekly feed quality and also feed quality/cow-intake constraints.

In the second row of the table, a base level of 305 kg MS per cow was set and the farm system was then allowed to optimise itself ("Base optimise"). The third run, on Row 3, had fixed herd size, but the model was allowed to dry-off cows early and cull some of the herd. In Rows 4 to 10, average production per cow was set and where indicated, numbers of cows were also set.

To establish the relationship between stocking rate, production and profitability for the conditions on this farm the number of cows was set in all but one of the LP model runs, as was per-cow production. In that one run, the model was allowed to determine the optimum cow number. Per-cow production was held constant. Outputs from these scenarios are given in Table 2.

RESULTS

The effects of setting stocking rate and per-cow milksolids production, or allowing the LP model to optimise within one of these constraints are shown in Table 1. In general it was found that a high-producing herd was more profitable than a lower-producing herd, notwithstanding the need for extra feed for the former. The LP model showed that, with a fixed herd of 320 milking cows grazing the 100ha, profit increased 65% from $166,091 to $273,443 when production was increased from 305 kg MS per cow to 415 kg MS per cow. This required additional supplements of 152 t DM if the cows averaged 305 kg MS per cow or 452 t DM plus some concentrate, if the cows averaged 415 kg MS per cow.

If feed demand and feed supply were optimised through resource allocation, the LP model reduced milking cow number and fed them with an all pasture diet, rather than buying in feed to compensate for the increased feed demand from the higher producing cows (286 cows producing 305 kg MS per cow returning $187,254 *versus* 243 cows producing 415 kg MS per cow returning $316,924).

At the four production levels chosen of 305; 332; 366; and 415 kg MS per cow, it was most economic to dry off and cull cows in dry summers to optimise feed demand *versus* feed grown (Table 1). The model used nitrogen (N) fertilizer to avoid a feed deficit only when response rates of better than 10 kg DM to 1 kg N could be expected. It did not use N for growing supplements to harvest. Pasture cover rose or fell, within defined constraint levels, to provide a buffer for periods of low or high feed demand.

The analysis of the effect of progressively reducing the number of cows producing 305 kg MS per cow determined that the optimum profit was generated with 286 cows grazing the 100 ha. It should be noted that there were marked differences between each run of the model in the amounts of resources used. It was found that, as cow stocking rate declined, it became more profitable to graze some, or all, of the replacement heifers on the model farm than to pay fees to graze them elsewhere.

Increasing the cow number from 286 to 305 by the addition of 34 cows reduced "profit" from $187,254 to $166,091, a drop of $21,163.

Reducing cow number by 36 below the “optimal” of 286 to 250, reduced the profit by $5,692. As each additional cow above optimal was added, there was an increasingly large drop in profit, emphasising the importance of a “marginal analysis”, comparing marginal revenue and marginal costs (Kay *et al*., 2008).

The LP model indicated that there was less financial risk, with reduced profit, associated with being slightly under-stocked than with being highly stocked, provided that the control of feed enabled the maintenance of pasture growth rate and quality. When moving from the LP run with the highest number of cows towards that with the lowest number, the model was able to eliminate all the bought-in feed and began to allocate resource use from cheaper feed options such as N fertilizer and grazed-off stock. It then eliminated the next most expensive feed source which, in this case was grazing one- to two-year-old replacement heifers off the model farm, then the 4-month to 1 year-old stock before any reduction of N fertilizer at a >10:1 response rate, calculated as kg DM:kg N, or grazing mature cows on the farm over winter.

Table 2 presents but one set of scenarios. New scenarios could be generated by changing the level of per cow production, cost structure, product price or feed supply curve.

DISCUSSION

It is generally accepted that supplementation of dairy cows is most profitable when used to fill a short-term deficit in pasture so as to ensure continuation of lactation. However, if an accurate pasture-demand profile can be established and adjustments to this demand can be made at critical times, this will prove to be more profitable than supplementation within established farm systems.

Resource allocation can determine the most profitable option when supplementary feeds are being evaluated. Rather than debating the differences between kinds of supplements, or the response and substitution rate of each supplement when being fed, it should first be established whether supplementation is merited. This study found it was most profitable to have fewer, high-producing cows, fully-fed on pasture. Macdonald *et al.* (2008) reported over 415 kg MS per cow can be achieved from all-pasture feeding. Pasture production, quality and utilisation can be manipulated by altering grazing interval for individual paddocks and by adjusting daily stocking rate through herd size and area grazed (Ridler & Hurley, 1984).

If the farm experiences regular poor spring growth and frequent dry summers, it was found that it is usually better to dry off and cull cows in dry summers.

On the model farm, N fertilizer was of limited benefit unless response rates of better than 10:1 were achieved at the time of the feed deficit. Ironically, the time when extra pasture is most needed, the response rates to applied N fertilizer are poorest such as during a cold spring, or a dry summer/autumn period.

If the same deficits occur regularly, feed demand can be altered economically through running fewer stock (with potentially better production per cow), altering calving date or more aggressive drying off and/or culling cows.

This study has shown the importance of integrated resource allocation optimisation when changing resource use to optimise profit on a seasonal supply dairy farm. With this objective, the LP model gave a practical management approach suitable for a commercial dairy farm offering the user an ability to innovate by evaluating multiple outcomes from changing the resources of an established base.

Management is characterized by the daily decisions needed to modify plans promulgated using the best knowledge at a time of imperfect knowledge. Too often, plans concentrate on production and financial targets without due regard to the quantity and quality of resources available. Such plans should not act as rigid frameworks within which management is constrained, particularly when the plans are based on single-factor or straight-line analyses such as gross margins, benchmarks, partial budgets, or response functions to supplementary feeds. These do not truly reflect the multitude of options and possible combinations from the continually changing mix of resources present on any farm. Due to the facility of the LP model to add single or multiple increases in available resources, a profile of likely options and their individual effect on profit within the framework of an existing farm with its unique resources was established.

This study showed that, for the model farm, profit was optimised where cows were fully-fed on good-quality pasture at a stocking rate that enabled high production in the region of 415 kg MS per cow. Supplementary feeding led to higher total profit if it led to increased per-cow production, not increased farm stocking rate. Early drying off/culling was the best option for the farm under summer-dry conditions. The effect of the pattern of feeding supplements to pasture-fed cows, supplement characteristics such as quality (MJME/kg) or cost, and the relationships between supplements, herd characteristics, and basic farm-management practices on the model farm warrant a further report.

REFERENCES

Ferris, A.; Malcolm, W. 1999: Sense and nonsense in dairy farm management economic analysis; Agribusiness perspectives papers, Paper 31 Australasian Business Papers On-line http://www.agrifood.inf/perspectives/1999/Ferris.html.

Kay, R.D.; Edwards, W.M.; Duffy, P.A. 2008: Farm Management, Sixth edition. McGraw-Hill, New York, USA. 468 pp.

Larcombe, M.T. 1988: DAIRYMAN: A simulation model to predict the production of dairy herds fed pasture. *Proceedings of the Australian Society of Animal Production* **17**: 372. Abstract.

Makeham, J.P.; Malcolm, L.R. 1993: The Farming Game Now. Cambridge University Press, Cambridge. UK. 399 pp.

Macdonald, K.A.; Penno, J.W.; Lancaster, J.A.S.; Roche, J.R. 2008: Effect of stocking rate on pasture production, milk production, and reproduction of dairy cows in pasture-based systems. *Journal of Dairy Science* **91**: 2151-2163.

McCall, D.G.; Clark, D.A. 1999: Optimised dairy grazing systems in the Northeast United States and New Zealand. *Journal of Dairy Science* **82**: 1808-1816.

McMeekan, C.P. 1960. Grass to Milk: A New Zealand Philosophy. New Zealand Dairy Exporter, Wellington, New Zealand. 193 pp.

Ridler, B.J.; Hurley, E.M. 1984: The management policy for Massey University's large herd. *Proceedings of the Ruakura Farmers Conference 1984*. p. 15-19.

Ridler, B.J.; Rendel, J.M.; Baker, A. 2001: Driving innovation: Application of linear programming to improving farm systems. *Proceedings of New Zealand Grasslands Association* **63**: 295-298.

Roche, J.; Newman, M. 2008: Profitable low input systems – separating the myth from the magic. *Proceedings of the South Island Dairy Event 2008*. p. 1-10.

Santarossa, J.M.; Stott, A.W.; Woolliams, J.A.; Brotherstone, S.; Wall, E.; Coffey, M.P. 2004: An economic evaluation of long term sustainability in the dairy sector. *Animal Science* **79**: 315-325.

Stott, A.W. 2008: The economic advantage of longevity in the dairy cow. *Journal of Agricultural Economics* **45**:113-122.

Wastney, M.E.; Palliser, C.C.; Lile, K.A.; Macdonald, K.A.; Penno, J.W.; Bright, K.P. 2002: A whole-farm model applied to a dairy system. *Proceedings of the New Zealand Society of Animal Production* **62**: 120-123.

Woodward, S.J.R.; Romera, A.J.; Beskow, W.B.; Lovatt, S.J. 2008: Better simulation modelling to support farming systems innovation: review and synthesis. *New Zealand Journal of Agricultural Research* **51**:235-252.