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The changing nature of farm systems research

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Abstract

A personal review of the contribution of farm systems research to New Zealand pastoral agriculture. Case studies have been selected from the author's experience in sheep, dairy beef and dairy cow research over the past 40 years. These are used to emphasise the importance of progress in agricultural science and of wider societal concerns. The change in emphasis over time for farm systems research, from animal production *per se*, to production and profit, and now to production, profit and environmental protection is highlighted. Examples are also given of the value of thinking in a systems context in order to maximise the value of investment in basic and applied agricultural research.

Keywords: sheep; dairy beef; dairy cows; once-daily milking; environment

Introduction

Although my career has changed course on a number of occasions, there has been a common theme that has been evident. This is one of developing and improving farming systems in terms of production, profitability and sustainability. At different times the emphasis on these three strands has changed dramatically. Early in my career the focus was on agricultural output per hectare, this was then balanced by an increasing concern for profit and then, over the past 20 years, a greater emphasis on how to mitigate some of the effects of intensive ruminant production from grazed pastures. Although this change reflects to some extent changes in personal philosophy, it reflects to a much greater extent the demands of industry and Government who fund agricultural research.

The outstanding success of reductionist science over the past century has had major spill-overs into agricultural science. Consumers and farmers have both been major beneficiaries of this process. Benefits will continue to flow for many years yet. However, there has always existed, and there will always exist, the challenge of how to best incorporate knowledge derived from reductionist science into productive, profitable and sustainable farming systems. The design of these systems is perhaps more an engineering problem than a scientific one, but I contend that the intellectual challenges are no less in the former. For a review of the contribution that farmlet research has made to dairy farming in Australia and New Zealand see Clark (2010).

This paper will use six examples of farm system experimentation that have I been involved with over the past 40 years. It will discuss these in relation to the political, social and economic contexts in which they occurred, the important background science knowledge they incorporate, some of the opportunities that exist and, in some cases, the challenges that remain. Knowledge gained from these and other examples will be used to suggest ways in

which farm system experimentation can be used more effectively to evaluate new technologies and management in the future.

Dairy beef

Context

Farm system experimentation is always expensive. Consequently, farmlets are rarely set up on the whim of a single researcher. In the case of work on dairy beef there was a strong demand from a group of Manawatu-Horowhenua farmers, many with dairy farms, for information on how best to operate beef systems using surplus Holstein-Friesian bulls from dairy herds. The wider context was that there was an increasing demand for lean beef to supply the North American hamburger trade and returns from milk production were relatively low. This was leading to milk being used to rear surplus bull Holstein-Friesian calves. There were animals that had previously been slaughtered at four days of age. In turn this was leading to a change in breed from the predominantly Jersey cow in the New Zealand dairy herd to either Jersey x Holstein- Friesian or Holstein-Friesian.

In the early 1970s Dr. Ray Brougham, Grassland Division, DSIR, Palmerston North, set up a farm system experiment at Aorangi Research Station on alluvial plains near Palmerston North to measure the production of beef from Friesian bulls grazing perennial ryegrass–white clover pasture. I joined Ray's team in 1973 with the task of measuring the grazing intake of bulls throughout the year.

Science knowledge

The hypothesis and rules for grazing management decisions were based strongly on the pasture treading work done with sheep by Don Edmond, Grassland Division and the intensity and frequency of grazing research done by Ray Brougham using small plots (Edmond 1963; Brougham 1959).

Farmlet experiment

The importance of stocking rate as the key driver of converting pasture to animal product was well known by the 1970s and so the farmlets were stocked at 7.5 rising yearling bulls/ha over winter, with these bulls still being present when replacement calves were added in October each year. Initially, six small farmlets, containing 12 bulls each, were used with three farmlets allocated to a Control treatment and three to some management intervention or input. In later years twelve farmlets were used. Some examples are given in Table 1 with treatment explanation in the footnotes and some key results of each intervention. In the initial experiments, intensive rotational grazing was used to ration pasture, but since no bought-in supplements or nitrogen (N) fertiliser were allowed for the Control treatment, pasture allocation could only really be controlled by grazing frequency with the result that individual pasture dry matter (DM) intakes were low (Clark & Brougham 1979). The hypothesis was that using a stand-off or loafing pad on the Kairanga silt loam soils at the site during periods of high soil moisture would protect pastures from damage and result in greater pasture and meat production per ha compared to a system where no stand-off facility was available.

Dr Gerald Cosgrove continued Ray's work at Aorangi and tested hypotheses about the effect of new cultivars, and N fertiliser and irrigation, both as single factors and when combined, on system productivity. In a return to Aorangi in the late 1980s I examined the use of both rotational grazing and set stocking at widely differing stocking rates (Clark 1992).

The main findings were (Table 1; Cosgrove et al. 2003):

- 1,000 kg hot carcass meat/ha could be produced from grazed pasture alone, if 16 to 20 month bulls were slaughtered at low (180 to 210 kg) carcass weights (Brougham et al. 1975),
- Initiation of extended grazing frequencies of 80 to 100 days in rotation length after autumn rains was crucial to providing sufficient pasture for maintenance from June to August inclusive,
- There was little benefit in terms of total carcass yield/ha from using a stand-off pad intensively over winter, because higher winter-spring ryegrass DM yields on stand-off farmlets were counteracted by lower white clover DM yields in autumn,
- Summer over-grazing only marginally reduced live weight gain/ha because the reduction in summer performance was compensated by extra gains in the following spring,
- Pasture renewal with 'modern' cultivars led to a 12% increase in liveweight gain/ha at 7.5 bulls/ha,
- The stocking rate to achieve maximum profit/ha of 3.75 bulls/ha was much lower than that to achieve maximum carcass yield/ha of 7.5 bulls/ha.

Table 1 Mean annual liveweight gain for four experimental dairy beef comparisons conducted over 3 to 4 years. In each case the Control and Treatment farmlets were stocked at 7.5 bulls/ha with 'best practice' management except for the stocking rate treatments where two decreasing stocking rate treatments were used (from Cosgrove et al. 2003).

Treatment	Control group (kg/ha)	Treatment group (kg/ha)	Difference (%)
Stand-off pads ¹	1,997	2,037	+2
Overgrazing ²	1,858	1,838	-1
New pasture ³	1,761	1,965	+12
Stocking rate ⁴	1,805	1,740 & 1,116	-4 & -38

¹ Bulls stood-off pasture over winter after daily pasture allocation consumed.

² Bulls kept past optimum slaughter date to deliberately overgraze pastures from January to March.

³ Old pastures cultivated and resown with 'modern' cultivars of perennial ryegrass and white clover.

⁴ Two stocking rates of 5 bulls/ha and 2.5 bulls/ha respectively.

Outcomes

This experiment gave confidence to bull beef farmers throughout New Zealand to invest in bull beef enterprises. By so doing this provided many dairy farmers with extra income either indirectly through sale of high priced surplus bulls, or directly by allocating part of their operation to a bull beef enterprise. Longer term it contributed to the demise of pure bred Jersey herds and their replacement, especially by crossbred cows. It also encouraged the development and use of new technologies such as bloat capsules and the TechnograzingTM system (Charlton & Wier 2001).

The results from Aorangi meant that farmers did not have to invest in stand-off facilities even on fragile soils.

The failure of the Aorangi experiments, at least in the first 15 years, to consider profit, meant that other researchers working on the Massey University, Tuapaka Farm, developed lower yielding, but more profitable systems that addressed farmers concerns about what stocking rate and management to use when carcass schedules and production costs changed (McRae & Morris 1984).

Finally, this long term farmlet experiment, reviewed by Cosgrove et al. (2003) demonstrated quite clearly that management principles derived from small plot experiments will not necessarily survive a test in a whole farm system where all important interactions have an opportunity to operate. Agricultural scientists, and those who fund their research, might benefit from paying closer attention to this conundrum.

Table 2 Annual mean phosphorus (P) fertiliser inputs applied to the Ballantrae farmlet trials between 1973 and 1980, and associated changes in stocking rate, pasture dry matter (DM) yield, lamb weaning weight and total wool weight between 1975 and 1980 for the fertiliser and grazing management treatments. The set stocked results are the mean of three replicate farmlets. Significance is indicated as *** P <0.001, ** P<0.01, * P <0.05, NS >0.05. (Stocking rate and pasture data from Lambert et al. 1983; Lambing and wool data from Clark et al. 1986).

Measurement	Year	Low P fertilizer		High P fertilizer		Significance	
		Set stock	Rotational grazing	Set stock	Rotational grazing	Fertilizer effect	Management effect
Fertilizer (kg P/ha)		14	14	48	48	-	-
Stocking rate (ewes/ha)	1975	6.5	6.5	8.8	8.8	-	-
	1980	12.0	12.0	16.1	16.1	-	-
Pasture yield (kg DM/ha)	1975	7,540	8,450	6,870	7,200	NS	NS
	1980	9,130	10,270	12,560	13,210	***	NS
Lamb weaning weight (kg/ha)	1975	167	128	217	179	***	*
	1980	295	297	434	390	*	NS
Total wool weight (kg/ha)	1975	40	38	47	49	**	NS
	1980	67	69	97	95	***	NS

Hill country sheep and beef

Context

In the 1970s there was a realisation by hill country farmers, rural professionals and Government agencies that untapped potential existed in the hill country of both islands (Hight 1979). Hill country development was given further impetus by Government subsidies such as the Livestock Incentive Scheme (1976) and the Land Development Encouragement Loan Scheme (1978). However, the costs of subdivision, capital stock, fertiliser application and the increased management skill required, were acknowledged as considerable impediments to investment. Demonstration at sufficient scale to convince farmers to invest, was considered a critical factor in realising this potential (National Research Advisory Council 1977).

In 1971, Ray Brougham convened a working group to design an experiment at the recently purchased DSIR, Ballantrae hill country farm near Woodville. The implementation of a large scale grazing experiment was handled by Grassland Division scientists David Grant and Dr Greg Lambert. After David Grant left I took up a position at Ballantrae to assist Greg with the management of this experiment.

Science knowledge

The hypotheses were built on a great deal of soil science and pasture research in the previous decades, especially the ecological approach to N cycling in pastures by Dr Peter Sears and others (Sears 1960). The importance of stocking rate and grazing management had already been studied at Te Awa, in the Northern Manawatu by Eddie Suckling in the 1950s and 1960s (Suckling 1975).

Farmlet experiment

The experiment was on 99 ha of steep hill country which had received no fertiliser since 1950. The pastures were dominated by 'low fertility tolerant' grasses, particularly Browntop (*Agrostis capillaris*), with <2% legume content. The area was divided into farmlets balanced for slope and aspect. Five farmlets received low inputs of phosphate fertiliser with three of these grazed by set stocking Romney ewes, one rotationally grazed by Romney ewes and one rotationally grazed by Angus beef cows. A further five farmlets received high annual inputs of phosphate fertiliser with the same grazing management treatments as for the low input farmlets (Lambert et al. 1983). The important principles of hill country subdivision by electric fencing, combined with high stocking rates of sheep and/or cattle over summer to control Browntop, were applied from the start of the Ballantrae experiment in 1973. The aerial oversowing of white clover and other legumes in June 1974 was combined with capital dressings of superphosphate, lime and molybdenum. There were no direct applications of N fertiliser because of cost and its likely deleterious effect on legume content and hence the nutritive value of summer-autumn pasture. The grazing management treatments started in late winter 1975.

Several hypotheses were tested:

- That large capital dressings of superphosphate fertiliser and oversowing with white, red and subterranean clover, and *Lotus pedunculatus* would quickly lead to increased N input with a subsequent shift from Browntop to Perennial ryegrass dominance,
- That rotationally grazed sheep versus rotationally grazed cattle would lead to different rates of pasture composition change,

- That rotational versus set stocking with sheep would lead to different rates of pasture composition change,
- That rotational versus set stocking with sheep would lead to different outcomes in terms of wool and lamb production.

Some key pasture and animal production results for the sheep farmlets are presented in Table 2.

Main findings from the data presented in Table 2 were:

- There was little difference in either wool or lamb production when sheep were either set stocked or rotational grazed throughout the year (Clark et al. 1986),
- The soil nutrient status, especially phosphorus (P) and N, was the key driver of pasture production and composition (Lambert et al. 1983), and hence animal output from hill country farming systems,
- Low and high P fertiliser inputs allowed stocking rate to be increased by 85% and 248% respectively from the low fertility stocking rate in 1975 when animal treatments were imposed,
- Low and high P fertiliser inputs increased lambing weaning weight by 100% and 208% respectively over the low fertility stocking rate in 1975,
- A balance existed between defoliation frequency and severity, tiller size and density, such that the amount of leaf removed was similar for both management systems, and as a consequence major differences in either pasture or animal production could not be expected (Clark et al. 1984),
- Cattle were effective at reducing Browntop dominance quickly with the sward damage imparted by the cattle's hooves leading to gaps for legumes and perennial ryegrass to colonise the sward. These gaps were also ideal sites for ragwort and gorse infestation with serious consequences to the sward in the longer term.

Outcomes

This experiment, together with other research by Ministry of Agriculture and Fisheries (MAF) staff in both the North and South Islands, gave farmers the confidence to invest in significant development of hill country. This was given further impetus by Government subsidies, such as the Livestock Incentive Scheme (1976) and the Land Development Encouragement Loan Scheme (1978). The removal of subsidies from farming in the mid- 1980s caused widespread financial stress as many farmers had taken-out loans to finance development work to achieve this end. With hindsight, the encouragement of high stocking rates and the clearing of steep hill country was not a sensible decision from either an economic or environmental perspective. However, the knowledge around grazing management and the importance of high pasture nutritive value for ewe milk production and lamb growth formed an

important foundation for profitable systems when lambing rates improved and farmers were rewarded for the production of higher weight carcasses.

Some of the Ballantrae experimental farmlets have been maintained to this day. They have provided an excellent time series of the development of hill country soil nutrient status under different fertiliser inputs. Their maintenance speaks of the importance of firstly implementing well designed farmlet experiments and, secondly, having the foresight to support them through decades of change in science funding priorities, management enthusiasm and science personnel.

1,750 kg milksolids per hectare

Context

Improved dairy prices, and decreased cost of N fertiliser, meant that from 1990 N could be used at levels above the recommended application rate of 20 to 50 kg N/ha in late winter to overcome a short term pasture deficit. The technical challenges of achieving consistently high yields of maize for silage in the North Island to use as a supplement to extend lactation and to increase base stocking rate encouraged widespread usage of N fertilizer on dairy farms. Improved genetic merit of cows, the use of North American Holstein semen and the continuing problem of maintaining a 365 day calving cycle, all contributed to a desire by some farmers to use more supplementary feed. The New Zealand Dairy Board believed that gains in dairy genetic improvement had not been matched by gains in ryegrass and white clover yield.

In 1992 I joined the Dairying Research Corporation (DRC) at Ruakura. This entity, which was established in 1991, was jointly funded by the technical arm of the Ministry of Agriculture and Fisheries (MAFTech), which later became AgResearch in 1992, and the New Zealand Dairy Board. Ken Jury and Dr Arnold Bryant recruited a team of recent graduates to kick start a new era of dairy research with key research priorities of feed supply, dairy cow reproduction and dairy nutrition. There were great expectations. This pressure induced me, at my first seminar, to identify a goal of producing 1,000 kg milk fat/ha from grazed perennial ryegrass- white clover pasture. Current maximum production at Ruakura was around 800 kg milk fat/ha. This casually formulated goal was seized upon by senior management and the DRC Board as a flagship for the new entity.

Science knowledge

There was a substantial body of knowledge about the seasonal and annual responses of ryegrass-white clover pastures to different rates of N fertiliser. There was also knowledge of the effects of supplementing cows grazing pasture with maize grain or maize silage. Much of this knowledge had been incorporated into a simulation model of a grazed

Table 3 Experimental details for seven farmlets at Dairy Research Corporation (DRC) Number. 2 Dairy, with annual nitrogen fertilizer input, herbage accumulation, milksolids yield/ha and economic farm surplus/ha (Mean of 2 years) (From Penno et al. 1996). DM = Dry matter; N = Nitrogen.

Measurement	Farmlet						
	1	2	3	4	5	6	7
Stocking rate (cows/ha)	3.24	3.24	3.24	3.24	4.48	4.48	4.48
Nitrogen fertilizer (kg N/ha)	0	0	216	381	0	209	377
Herbage accumulation (t DM/ha)	15.9	15.4	18.7	21.0	16.4	20.0	20.3
Net supplements fed (t DM/ha)	0	1.8	0.3	0	7.8	5.7	5.2
Milksolids production (kg/ha)	1,122	1,298	1,328	1,355	1,717	1,807	1,818
Economic farm surplus (\$/ha)	2,487	2,200	2,553	2,484	968	1,940	1,877

dairy farm, developed by Dr Michael Larcombe and named “UDDER” (Larcombe 1990).

Farmlet experiment

Some preliminary modelling, in conjunction with Dr David McCall (AgResearch) and Neil McLean (Agricultural Business Associates), soon identified the futility of this exercise if feed supply was to come solely from ryegrass-white clover. However, having set the goal we had to reach it, and so the necessary feed was supplied in the form of N-boosted pasture, maize grain and maize silage.

Seven farmlets were established at DRC Number 2 Dairy in June 1993 and stocked with high genetic merit Holstein-Friesian cows. Details are given in Penno et al. 1996 and in Table 3. Briefly, Farmlet 1 acted as a Control. It was stocked at 3.24 cows/ha, the optimum for milksolids (MS) yield/ha from grazed pasture only, with no N fertiliser applied or bought-in supplements fed. Farmlets 2, 3 and 4 nominally received 0, 200 and 400 kg N/ha/yr, respectively, with bought-in supplements fed to the cows. Farmlets 5, 6 and 7 nominally received 0, 200 and 400 kg N/ha/yr, respectively, with greater amounts of bought-in supplements fed to the cows to support the higher stocking rate of 4.48 cows/ha. Ruakura dairy research since 1950 had built up a set of ‘decision rules’ for the management of dairy farm systems based on small plot agronomy, indoor cow nutrition experiments and self-contained, entire lactation farmlets (Macdonald & Penno 1998). These rules were used in managing each system. A long-standing research collaboration with AgResearch soil scientists involving measurement of nitrogen losses from different farmlet systems was started.

Several hypotheses were tested:

- That the absolute quantity of feed supplied, rather than the composition of that feed was the critical factor in achieving the goal,
- That the goal could be achieved using the traditional spring calving regime,
- That the use of large amounts of N fertiliser would lead to reduction in white clover DM yield and N fixation,

- That the nitrate leached from grazed pasture would be proportional to the amount of N input.

The main findings summarised in Table 3 and by Penno et al. (1996) were:

- That the goal of 1,750 kg MS/ha could be achieved by a combination of N fertiliser and maize silage or maize grain, if a high enough stocking rate was used,
- The goal could be achieved within a seasonal calving pattern and by using the standard decision rules for grazing management, pasture conservation and drying off,
- Use of N fertiliser reduced the white clover content of pasture (Harris & Clark 1996) and increased N leaching (Ledgard et al. 1999), with the most marked effect in moving from 200 to 400 kg N/ha,
- That high MS/ha was no guarantee of high profitability/ha unless it coincided with a high MS payment: input cost ratio.

Outcomes

The outcome of this and other experiments in New Zealand studying N fertiliser and supplementation, led to a rapid increase in N fertiliser usage in dairying and the use of either home-grown or bought-in supplements. Coincident upon these changes there was a 5%/annum increase in the production of processed milksolids between 1992 and 2012 (DairyNZ 2011). Although much of this can be attributed to dairy conversions from sheep/beef or forestry to dairying, the new conversions especially in the South Island were enthusiastic users of both N fertiliser and supplements. In the drive to produce more milk, some producers lost sight of the fundamental economic tenet of not producing more product to the extent that marginal costs exceeded marginal returns. The increased inputs into dairying also led to concerns about an effect on water quality and greenhouse gas emissions which continue today. It is important to note that such concerns have also been expressed by sectors of the dairy industry and not just by urban pressure groups.

Table 4 Predicted milksolids yield, milk composition, somatic cell count, post calving body condition score, and reproductive parameters for Holstein-Friesian and Jersey cows milked once a day (OAD) or twice a day (TAD) for four years (from Clark et al. 2006). Bold text indicates significance at $P < 0.05$. Italic text indicates significance between $P = 0.05$ and $P = 0.10$. CIDR = Controlled internal drug releaser.

Measurement	Breed				Pooled standard error of difference	P value		
	Holstein-Friesian		Jersey			Breed	Frequency	Interaction
	OAD	TAD	OAD	TAD				
Milking frequency								
Stocking rate (cows/ha)	3.5	3.0	4.2	3.6				
Milksolids production (kg/cow)	237	336	222	278	8	<0.001	<0.001	0.04
Milksolids production (kg/ha)	880	1,051	979	1,045	20	0.009	<0.001	0.005
Milk fat (%)	4.5	4.4	5.8	5.7	0.01	0.009	0.10	0.45
Milk protein (%)	3.6	3.5	4.2	4.1	0.05	<0.001	<0.001	0.54
Milk lactose (%)	4.70	4.84	4.81	4.94	0.03	<0.001	<0.001	0.68
Log ₁₀ Somatic cell count	2.21	1.87	2.19	1.92	0.06	0.82	<0.001	0.68
Post-calving body condition score	5.0	4.6	4.9	4.7	0.1	0.49	0.003	.017
Use of CIDR (%)	5	24	6	9	3	0.02	0.001	0.01
Three week pregnancy rate (%)	42	37	50	39	5	0.17	<i>0.06</i>	0.37
Six week pregnancy rate (%)	70	67	75	68	4	0.38	0.13	0.44

Once daily milking

Context

The past two decades have seen a major expansion in dairying in New Zealand. This has led to complex issues around the availability and capability of labour to operate farms that have become much more diverse. The milking operation can take up to 50% of the farm labour requirement. Farmers have therefore sought ways to reduce labour input, such as by once daily (OAD) milking or using automatic milking systems. A joint AgResearch/DairyNZ survey, however, showed that the reasons for farmers considering switching to OAD milking fell into six categories: herd expansion, time needed to build capital, decreasing labour, increasing labour flexibility, feed shortfalls and herd health (Bewsell et al. 2008). Milk processing companies expressed concern about the effect on both milk supply and the quality of that milk. There was however little evidence that either of these possibilities would become major problems, even if the practice became more widespread. This alternative practice strikes at the heart of dairy industry tradition in New Zealand. As such it had not received the level of research support that it needed to progress.

In 1997 I convened a workshop on the issue of human resources in the dairy industry (Clark 1998). The outcome of this workshop was a decision by the NZDB to fund two projects, the Greenfield automatic milking project and a whole farm system OAD milking project.

Science knowledge

There was extensive literature on the effects of OAD milking from both New Zealand and overseas researchers of the effect on the cow, dating back to

1950. Much of this research was for periods less than a full lactation, but some key principles had emerged. Milk yield and lactose content were decreased and milk protein and sometimes fat content were increased by OAD milking compared with twice daily (TAD) milking. There were obviously large differences in the ability of individual cows to tolerate OAD milking and the Jersey breed seemed to be better adapted to the practice than Holstein-Friesians. There was evidence that cows milked OAD consumed less pasture and both Prof. Colin Holmes (Holmes et al. 1992) and Dr. Steve Davis (Davis et al. 1999) had suggested that a decrease in MS yield/ha on OAD might be avoided by increasing stocking rate for OAD herds.

Farmlet experiment

Four experimental (10 hectare) farmlets were established at Normanby in Taranaki (Year 1) and then transferred to the Westpac Trust Agricultural Research Station at Hawera (Years 2 to 4). Two mixed age Jersey herds were milked either OAD or TAD from calving. Similar treatments were also imposed on two mixed age Holstein-Friesian herds. Production results are shown in Table 4. Weekly herd tests measured milk yield, milk composition and somatic cell counts (SCC). Comprehensive results on subclinical and clinical mastitis, and on reproductive performance, were obtained.

Several hypotheses were tested:

- That there would be differences in tolerance to full lactation OAD milking between Jersey and Holstein-Friesian cows,
- That the known decrease in MS yield/cow from OAD versus twice a day (TAD) milking could be attenuated on a per hectare basis by carrying a higher stocking rate for the former,

Table 5 Resource efficient dairying (RED) trial design. Farmlet stocking rate, nitrogen fertiliser rates and planned feed inputs (from Jensen et al. 2004); milksolids yield and nitrogen leached (mean of four years). Nitrogen leaching data from Control, Stand-off and Low Input farmlets are actual measurements. Values for other farmlets are estimated from the Overseer model (Ledgard et al. 2006). DM = Dry matter; N = Nitrogen.

Measurement	Farmlet					
	Control	Stand-off	Low input	Supplement		
				Low	Medium	High
Stocking rate (cows/ha)	3.0	3.0	2.3 ²	3.8	5.2	7.0
Nitrogen fertilizer (kg N/ha)	200	200	0	200	200	200
Pasture production (t DM/ha)	17.5	17.5	15.0	17.5	20.5 ³	20.5 ³
Supplement fed (t DM/ha) ¹	0	0	0	5.0	10.0	20.0
Milksolids (kg/ha)	1,151	1,111	945	1,493	2,122	2,839
Nitrogen leached (kg N/ha)	42	31	21	48	67	113

¹Purchased maize silage costing \$0.25/kg DM fed from troughs in paddock. Soybean meal was used for High supplement group when total ration below the recommended crude protein level for lactating cows.

²Plus 0.44 heifers/ha as replacements.

³Irrigated as required to compensate for water deficit.

- That OAD milking for several consecutive lactations would not compromise MS yield,
- That udder health would not be compromised by OAD milking,
- That product quality from OAD milk would not be compromised.

The main findings as shown in Table 4 and reported by Clark et al. (2006) were:

- Higher stocking rates for Jerseys milked OAD were able to largely offset the loss of MS yield/cow compared with TAD, but this was not the case for Holstein-Friesians,
- However, it was possible to produce >1,000 kg MS/ha from either Jersey or Holstein-Friesian herds from OAD milking throughout lactation, if late lactation pasture allowances were high,
- The overall MS yield loss was about 20% from OAD milking for Jersey cows and heifers and mature Holstein-Friesian cows but >30% for Holstein-Friesian heifers,
- Somatic cell counts were always higher for cows milked OAD but there was no increase in the incidence of mastitis (Lacy-Hulbert et al. 2005),
- There were no obvious long-term consequences on cow health or production from milking OAD for up to four years,
- Some reproductive parameters were improved when cows were milked OAD from calving.

Outcomes

It appears that only about 5% of New Zealand dairy farms milk OAD all year. However, many more use the practice for sections of the year, such as at calving to reduce labour input at the busiest time of the year, prior to and during mating to improve conception rate, during summer to increase leisure time and almost universally towards the end of lactation to aid drying-off and to improve body

condition score (BCS). The demonstration of OAD milking at a farmlet scale with different breeds over several lactations persuaded most farmers that it is a management option that they can have confidence in, even if they do not use it at present.

The fact that OAD milking can be so successful using cows bred to be milked TAD begs the question of what could be achieved with a concerted effort to breed a special purpose OAD cow. The success has encouraged dairy genetic companies to examine the feasibility of breeding for tolerance to OAD milking and, in some cases, to produce a OAD index for bulls. It also led us to a further analysis of the OAD challenge data from the Boviquet crossbreeding trial in Taranaki which has led to the patenting of a gene, thrombospondin. Variants of this gene are associated with different levels of tolerance to OAD milking (Littlejohn et al. 2010).

There are now two OAD discussion groups operating, one in the Southern North Island and one in the Waikato. These allow existing OAD farmers and those contemplating the change to access research and, very importantly, to learn from each other.

Resource efficient dairying (RED)

Context

The past decade has seen an on-going debate around the 'best' system to use to profitably produce MS. High prices for MS in some seasons have led to the most efficient operators where more than 20% of their feed is 'bought-in', making large operating profits. However, DairyBase data (M Newman, Personal communication) have shown that many such operators make no higher profits than efficient farmers where less than 14% of their feed is 'bought-in' with most of that being fed to non-lactating cows and heifers (Hedley et al. 2006). Several factors have acted in concert to encourage greater supplement and

N fertiliser use. These include the improved milk production potential of modern cows, the difficulty of regaining BCS before the next calving, the availability of Palm kernel expeller (PKE) and maize silage at low cost, and the additive response from irrigation and high N fertiliser inputs.

In the late 90s important questions were being asked about the profitability of different systems of milk production, with some farms buying 50% of total feed from off-farm, while others used no supplements at all. There were continuing concerns about the impact of dairy intensification on the environment, especially water quality and greenhouse gas emissions.

Science knowledge

This research built on the same knowledge as used for the 1,750 kg MS/ha experiment, but with added knowledge about how to supplement grazing cows effectively to ensure a balanced ration was delivered.

Farmlet experiment

Six experimental farmlets, varying in area from three to seven hectares, were established at the Dexcel, Scott Farm, near Hamilton on 1 June 2001 and continued for four to 12 years. Stocking rates varied to match expected feed supply such that each farmlet aimed for the same comparative stocking rate of 85 kg live weight/t DM. Table 5 gives details of the experimental farmlets and the key inputs. As for the 1,750 kg MS/ha experiment, well-established decision rules were used to ensure that defensible management decisions were made for the widely

differing systems. AgResearch again collaborated by monitoring nutrient leaching, nutrient losses from a stand-off pad and nitrous oxide emissions.

Several hypotheses were tested:

- That inputs such as N fertiliser, irrigation and maize silage would have additive effects on both MS yield and environmental impact,
- That stand-off use would increase production and reduce environmental impact,
- That financial and environmental risk profiles would change with changes in milk payment and input prices.

The main findings as shown in Table 5 and Figure 1 were:

- Standard decision rules allowed each system to produce about 400 kg MS/cow, with a range of 945 to 2,839 kg MS/ha reflecting feed input and stocking rate,
- Stand-off pad use reduced N leaching but led to slightly less rather than more MS yield/ha,
- Nitrate leaching was closely aligned to N inputs from whatever source – N fixation, N fertiliser or N in purchased feed (Ledgard et al. 2006),
- Low input systems had much lower financial risk and risk of environmental damage than high input systems,
- In years with high milk pay out: feed price, high input systems had much greater operating returns/ha than low input systems.

Outcomes

A perhaps naïve outcome desired for the RED trial was that the definition of a trade-off matrix between economic returns and environmental impacts would facilitate constructive debate between the dairy industry and the public. The trial certainly demonstrated the resilience of soils and pasture to stocking rates up to seven cows/ha. It also showed that in the absence of mitigating factors, it would be very difficult to meet annual targets of <30 kg N leached/ha unless no, or very low rates of, N fertiliser were used.

Pastoral 21 - Stage 2

Context

The Pastoral 21 - Stage 2 research programme involves Government, Fonterra, Dairy Companies Association of New Zealand, Beef + Lamb New Zealand, DairyNZ and the Ministry for Business, Innovation and Employment as investors. The importance of the on-going Pastoral 21 - Stage 2 farmlet experiments in the Otago, Canterbury, Manawatu and Waikato lies in the fact that they address critical current concerns for dairying. These are: the

Figure 1 Annual operating profit (\$/ha) for six Resource Efficient dairy farmlets with increasing levels of intensification at four milk payment prices (\$4.50, \$5.50, \$6.50, \$7.50/kg MS). Mean of four years.

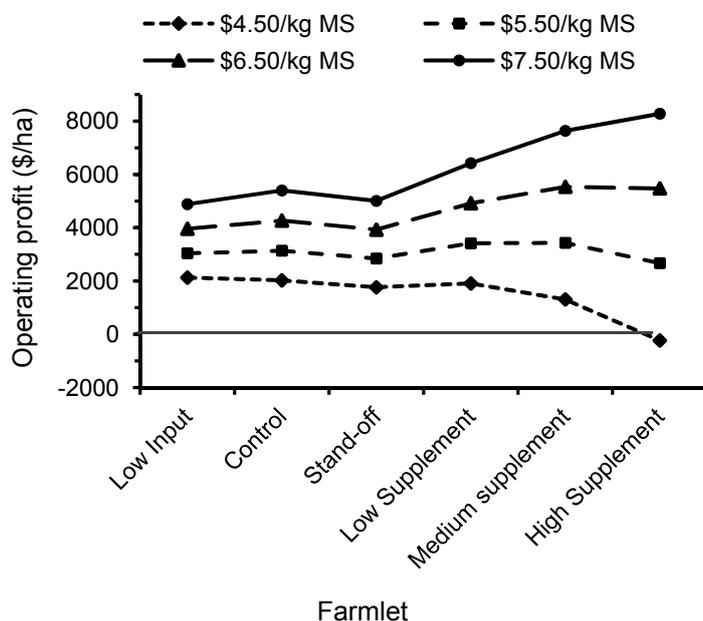


Table 6 Treatment details and results for year 1 (2011-2012) for Current and Efficient Pastoral 21 Stage 2 farmlets in the Waikato (based on Chapman et al. 2012). DM = Dry matter; N = Nitrogen.

Measurements	Farmlet	
	Current	Efficient
Stocking rate (cows/ha)	3.2	2.6
Cow genetic merit (breeding worth)	99	183
Replacement heifer (%)	21	18
Nitrogen fertilizer input (kg N/ha)	142	51
Use of stand-off pad	No	Yes
Use of nitrogen inhibitor	No	Yes
Total feed intake (t DM/cow)	5.00	5.66
Milksolids production (kg/cow)	372	461
Milksolids production (kg/ha)	1,202	1,207
Operating profit (\$/ha)	3,109	3,004
Nitrogen leached (kg N/ha) ¹	56	28

¹Model prediction including support land for replacements and maize grain, if used.

demand by processors for more milk, the demand by farmers for profitable milk production systems and the demand by farmers, the public, and local and international consumers, for dairy systems that demonstrably protect the environment. The recent voluntary withdrawal of nitrification inhibitors from the market has placed even greater emphasis on the use of efficient farming practices to themselves achieve the combined goals mentioned above. The recent legal decisions delivered for the Horizon region concerning levels of allowable N leaching on different land classes has also increased the urgency to find solutions based around efficient farming systems.

In 2009 I was fortunate to be awarded the Ray Brougham Award from the New Zealand Grasslands Trust. The invitation from the Trust to present a series of seminars on a topic of my choice meant that I was able to further examine the matrix of dairy production, profit and environmental impact. I was extremely fortunate to have the assistance of the DairyNZ farm systems modelling team to assist me with this task. We set ourselves the modelling goal (Beukes et al. 2010, 2012) of coming up with an 'Efficient' unirrigated dairy system that would increase MS yield by 200 kg/ha, increase profit by \$500/ha and decrease annual N leaching from between 45 and 50 kg N/ha to between 25 and 30 kg N/ha, compared to current Waikato dairy farms where less than 14% of the feed is 'bought-in' and used for non-lactating cows.

Science knowledge

The experimental plan and decision rules benefitted greatly from recent advances in science knowledge. The efficacy of dicyandiamide (DCD) in reducing N leaching and nitrous oxide emissions from urine patches had been demonstrated by Di & Cameron (2005). The value of autumn stand-off pads

as a means of reducing winter N leaching had been predicted from modelling (Shepherd et al. 2011). In addition the importance of lowering replacement rates from the industry standard of >20% to 16% had shown through our modelling as well as that by Lopez-Villalobos and Holmes (2010) that this reduction would have little long term effect on the improvement of herd genetic merit. The Strain trial (Macdonald et al. 2008) had also shown the difficulty of reaching BCS targets in high genetic merit cows at the start of calving.

Farmlet experiment

When Pastoral 21 Stage 2 was commissioned in 2011 the modelling results were used as a framework to generate hypotheses about 'Efficient' dairy farming at the four regional sites and to test these hypotheses using farmlet scale experimentation.

The hypotheses being tested at the DairyNZ Scott Farm are:

- That very high genetic merit (Breeding worth (BW))/production worth (PW) cows would have higher intake than cows of lesser BW/PW so the former could be stocked at a lower rate,
- That N input is the key driver of N leaching so that more efficient systems must apply less N fertiliser,
- That the use of autumn-winter stand-off pads and autumn nitrification inhibitor (DCD) applications would have an additive effect on N leaching,
- Small amounts of low N supplements would improve system performance without compromising N leaching targets.

Table 6 gives details of the experimental farmlets, key inputs and results. The key findings from Year 1 of the trial were (Chapman et al. 2012):

- The production target of 1,200 kg MS/ha was reached on both the Current and Efficient farmlets in a season with good summer-autumn pasture growth,
- Profitability/ha for both systems was very similar,
- Support for the hypothesis that the Efficient system substantially decreased N leaching, but this needs to be confirmed over a number of contrasting seasons,
- That the predicted problems with pasture and conservation management on the lower stocked Efficient system did not occur because of strict application of effective decision rules.

Outcomes

It is too soon to evaluate the degree of success that can be achieved by integrating all our knowledge into more efficient farming systems. Early signs are promising and the fact that some farmers are actively following this path can only increase the probability of success and encourage early adoption of any

successful strategies. It is important to accept that while the adoption of more efficient systems may require investment of time and money by farmers, it will not preclude them using single factor mitigating agents for reductions of N losses or greenhouse gas emissions should these become available.

Conclusions

Farm systems research is often the last, stringent hurdle a new technology must face before it is widely promulgated to the farming community. Often the technology is being marketed ahead of completion, or indeed initiation, of such research. To avoid costly failures, the above case studies suggest the following steps:

- Any new technology, or proposed advance in an existing one, be 'imagined' in a real farm system/supply chain,
- Modelling, cerebral and/or computer simulation, be used to incorporate the many interactions that exist in a 'real' system, but are necessarily largely neglected in component experimentation,
- Use sceptical farmers and contrarians to envisage the use of the proposed technology on actual farms and to evaluate future public and market reactions to the technology.

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