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

Farming within limits – can system fundamentals be the key?

PC Beukes[a]*, AJ Romera[a] and DA Clark[b]

[a]DairyNZ, Private Bag 3221, Hamilton 3240, New Zealand; [b]2 Callard Place, Hamilton 3216, New Zealand
**Corresponding author. Email: pierre.beukes@dairynz.co.nz*

Abstract

The design of dairy systems with increased production and profit, but reduced environmental footprint, presents a problem with objectives that are seemingly at odds. We argue that this is why we have to go back to the ecological principles that underpin farm systems and use these to develop new systems that will achieve the above objectives. Healthy topsoil is a living nutrient trap. It requires long term thinking and action to achieve and maintain healthy topsoil. The rumen is a very complex ecosystem with the microbes as a key component. Farm systems aimed at optimal performance per cow, with lowest possible methane and urinary nitrogen waste products consistent with this performance, need to ensure effective rumen function. Maintenance dilution and cow longevity are important principles for sustainable and profitable farming. Pastoral livestock systems need ecological and financial buffers to remain resilient in uncertain times. We present a plan consisting of five strategies, based on some of these fundamentals, that we believe is a step towards farming profitably and within limits.

Keywords: ecosystem principles; maintenance dilution; rumen microbes; soil health; uncertainty buffers

Introduction

Farming within limits is the road to farming sustainably. Sustainability is defined here as an agricultural system that sustains the people, ensures animal welfare and preserves the land. Dairy farming in New Zealand could be more sustainable than it is currently. This could be achieved by either imposing regulations, or what would be preferable, by adopting a change in thinking and acting from within the industry. Pastoral dairying is a complex system where farmer, soil, pasture, crop, animal, capital, energy and nutrients are interconnected. These connections are often non-linear and have feedback loops that result in unexpected consequences when management changes. The ideal outcomes of a sustainable system would achieve the objectives of lifestyle and profitability for the farmer, welfare for the cow, product for the dairy processor, responsibility towards the environment, contribution to the community and goodwill from the public. These ideal outcomes are sometimes at odds, for example it will not be possible to produce the absolute maximum milk that New Zealand could produce without compromising other outcomes, but it may be possible to increase milk production and achieve the other objectives. We argue that this is why we have to go back to the ecological principles that underpin farm systems and use these to develop new systems that will achieve the best compromise for the above objectives.

In this paper we focus on using the fundamentals of a New Zealand dairy farm to develop more sustainable systems. We explore how these system fundamentals are related to farming within limits and how they can be manipulated or managed to achieve a balanced outcome for seemingly conflicting objectives. Finally, we summarise how some of these principles form the basis of a five-strategy plan designed to address the objectives of increased production and profitability, with lower environmental footprint from dairy farms.

The topsoil: a living nutrient trap

Soil health is broadly defined as the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran 2002). A healthy soil has good structure, active soil biology, active cycling of organic matter, and improved storage and use of nutrients. Thinking of the soil as a productive ecosystem may require some management changes, but the returns in the end are worthwhile. It will require a re-visit of our thinking regarding the use of artificial fertilisers, especially nitrogen (N).

A healthy plant-soil complex can fix much of its own N through biological fixation. Indeed, until 20 years ago New Zealand agriculture relied almost completely on this form of N input. If and when it is necessary to use N fertilisers, think about precision application in terms of rate, timing and space. Other considerations will be to minimise cultivation of permanent pastures and, thereby, prevent undesired decomposition of organic matter (Saggar et al. 2001). Accumulating organic matter results in increased carbon storage in the soil. This carbon also stores N in the ratio of C:N of about 10:1. Furthermore, reducing pugging and compaction damage by animals and machinery stimulates aeration and soil life, making plants grow better and take-up more nutrients. This in turn reduces nitrate leaching as well as the formation of the greenhouse gas nitrous oxide (Bos et al. 2009). A recent study has shown that New Zealand farms that use balanced mineral inputs combined with processed residual organic matter, not only had lower nitrate concentrations in the leachate (Magesan & McFadden 2012), but farmers also reported other positive changes to soil such as increased clover abundance and root mass, higher earthworm populations, and less soil compaction.

The leakiest part of a pastoral dairy system is the urinary N that is deposited as urine patches onto pasture and forage crops during grazing. The urine patch is a major source of nitrate leaching, because the amount of N deposited in the patch usually far exceeds the capacity of plants in the patch to take-up and use the N for new growth. Nitrogen leaching from this source can be reduced by focussing on the N that is excreted in urine – reduce it, capture it, treat it (Beukes et al. 2013). For reducing urinary N, management strategies have to focus on the cow and the amount of N in her diet. For capturing urinary N, stand-off or housing facilities could be alternatives. For treating deposited urinary N, the focus is on soil processes. Since 'treat it' refers to the use of nitrification inhibitors to slow the conversion from slow-leaching ammonium to readily leachable nitrate, and nitrification inhibitors are currently withdrawn from the market, we may have to change this to 'trap it'. This is where a healthy topsoil with plenty of organic matter and biota will immobilise more of the inorganic N thereby 'trapping it', and slowly releasing it over time. Modelling has shown that selecting deeper-rooted, winter-active pastures and crops, combined with management that promotes a healthy topsoil, can increase soil nutrient use by 50%. This would improve total efficiency of use of farm N, N output in product per unit N through the farm gate, by up to 59% and reduce N losses by up to 41%, depending on the predominant N sources used on the farm (Kohn et al. 1997).

The cow's rumen: a fine-tuned fermentation vat

Rumen fermentation is a fundamental process in the system because it converts cellulose of no nutritional value to humans into volatile fatty acids that drive milk production. This process also generates by-products that affect the environment and are subject to regulatory control. Methane from microbial fermentation is expired and contributes to greenhouse gases. Generally, vegetative ryegrass-clover pasture contains more crude protein than is necessary to meet the nutritional requirements of a grazing cow (Moller et al. 1993). This crude protein fraction contains approximately 16% N. Surplus N not required by the cow, is converted into ammonia, absorbed into the blood stream, converted to urea in the liver and excreted in the urine. It is this urinary N, which ends up in the urine patch and has about a 20% chance of leaching below the root zone and into the water ways (Romera et al. 2012). The challenge is to design feeding strategies for dairy cows that decrease the production of ammonia within the rumen, increase N utilisation for milk production and lower total urinary N excretion. Lower N fertilisation rates of say 100 kg N/ha versus 300 kg N/ha, high-sugar ryegrass, afternoon allocation of pasture, defoliation at the four-leaf stage of ryegrass versus defoliation at the two- and three-leaf stage, and maize silage supplementation, all have the potential to reduce total urinary N excreted through lowering N intake (Gregorini et al. 2010). Kohn et al. (1997) showed that improvements in animal diet and management that increase the conversion of feed N to animal product by 50% would increase the efficiency of use of farm N, N output in product per unit N through the farm gate, by 48% and reduce N losses per product by 36 to 40%. High intakes of balanced, quality feed will result in a highly functional rumen microbial community, with a consequent rapid breakdown of the ingested feed and a faster passage of the digesta through the rumen, thereby resulting in a lower methane yield per unit of dry matter intake (Blaxter & Clapperton 1965).

A fundamental principle of cow metabolism is that energy is required for maintenance before any is used for production. Total maintenance energy per unit area of land is related to total animal biomass expressed as stocking rate and cow live weight. High stocking rates require a higher proportion of the available energy for maintenance, with less energy available for production. This results in sub-optimal production per animal. However, such a system can still result in high production per hectare, because a large proportion of total pasture is eaten, with a lower production per cow. It is likely that to farm within stringent limits of nutrient emissions, lower stocking rates combined with higher production per cow, will be required, to maintain operating profit per ha. This is based on the principle of dilution of maintenance whereby lower stocked, high genetic merit, well-fed cows can produce the same per hectare as higher stocked, average genetic merit cows on a restricted diet. Feed conversion efficiency will be higher and working expenses lower in the former. Creating the conditions for each animal to thrive will mean special attention to animal welfare and other factors that affect maintenance requirements.

A final principle regarding the cow is that increased cow longevity with the cow remaining in the herd for an additional season or two, not only makes economic sense but also makes environmental sense. The economic benefit is derived from having lower culling and replacement rates, more lactations per cow and the need for fewer replacement animals. Rearing replacement animals is expensive, with each replacement animal producing methane and urinary N. Each of these factors has a potential environmental impact, with the replacement animal not producing any product for at least the first two years of their lives. For instance, a heifer at the end of her first lactation of 240 days has spent 78% of her life producing methane and urinary N without producing any milk. These economic and environmental benefits can be reaped, starting with well-fed cows at calving with a body condition score of five or more (Roche et al. 2009) and a well-executed breeding programme, with special attention to the heifers. Non-pregnant rates should be low resulting in low involuntary culling, leaving room for discretionary culling up to a recommended rate of 18%, below the industry average of 22% (Simmonds 1998).

Resilience: buffers against uncertainty

"Systems need to be managed not only for productivity or stability, they also need to be managed for resilience - the ability to recover from perturbation, the ability to restore or repair themselves" (Meadows 2008). This is exactly what will be required to an increasing degree from future dairy systems. Management for resilience will not only be driven by climate change and a predicted increase in weather variability, including more frequent and severe extreme events, but also by milk price volatility. Other uncertainties include input costs, interest rates, capital appreciation, milk quality and environmental regulations. It is clear that a farm striving for sustainability will have to ride through 'the highs' and 'the lows', and still remain profitable.

Any man-managed biological system pushed to its limits will at some stage topple over into a more degraded system that requires more intensive management to keep it going. We need to accept the limits of the biological system we are dealing with and step down a notch in the pressure we put on it. This applies to the effects of our inputs, mainly stock numbers, and also to the degree of harvesting of the natural resources. The need for some form of buffer is fundamental to the sustainability of any grazing ecosystem. In our dairy systems we need buffers in the form of adequate pasture cover carried-over from year to year, adequate cow condition going into the new season, and adequate amounts of silage in the feed store. Regarding the storage of preserved feed for the lean years; maybe it is time to re-evaluate the practices from the 'good old days' when surplus pasture was stored as silage in a leak-proof bunker, well compacted and covered, where it could last for up to 10 years as perfectly good 'emergency rations'. Compare this to the present day plastic-covered baleage that barely lasts two years.

The best way to build financial resilience into your system is to keep the average cost of production as low as possible. This will allow for some room to move with extra expenditures during tough times. Costs of capital and labour can be kept down by doing due diligence, including net present value calculations, before major investments in infrastructure, and by reducing the time required for cow management by improving cow health and welfare.

Fundamentals of the five-point farm

Recent modelling studies (Beukes et al. 2011; Beukes et al. 2012; Vogeler et al. 2013), followed by farmlet experiments aimed at devising dairy systems that are productive, profitable and environmentally sustainable, have taught us valuable lessons. Firstly, there is no silver bullet for farmers to satisfy all the potential environmental limits and still stay in business. A combination of strategies where every little bit helps is the way to go. Secondly, greenhouse gases and N leaching are closely linked. In most cases a reduction in one leads to a reduction in the other. The challenge is to put strategies together that fit synergistically into the farm system, are practical and do not over-complicate management, and are readily available and adoptable right now.

A combination of five on-farm mitigation strategies, based on some of the fundamentals mentioned above, can substantially reduce greenhouse gases and N leaching, whilst still delivering production and profit comparable to top performing farms. Our modelling has shown that the combination of the first three strategies listed below can reduce urinary N load onto pastures by approximately 20%, with consequent reductions in N leaching.

The five on-farm mitigation strategies are:

Strategy 1: Lower N inputs in the form of fertiliser and low crude protein supplements will reduce the flow of N through the cows. Lower use of N fertiliser will result in lower pasture yield. However, improved clover vigour and soil health resulting in improved natural N fixation will compensate to some extent.

Strategy2: A lower pasture yield will be acceptable because of a lower stocking rate with higher genetic merit cows generating a lower total feed demand. This point is based on the maintenance dilution and efficiency principles and has the aim of getting the best out of each cow in terms of kg of milksolids per kg of live weight.

Strategy 3: Based on the increased longevity principle the aim is to reduce the replacement rate, resulting in lower environmental impact from non-producing animals.

Strategy 4: Standing lactating cows on a stand-off pad for part of the day for say 8 hours per day in late-summer and autumn, and the dry cows for say 15 hours per day in winter. The aim of this practice is to capture some of the effluent nutrients and recycle it onto pastures when it can be used by the plants. A further aim is to reduce pugging and compaction damage of wet soils, and thereby improve the general soil health of the farm. This can be a costly strategy and requires careful planning and consideration of several of the above mentioned fundamentals like cow health and welfare, and the need to keep capital costs and working expenses as low as possible.

Strategy 5: Before the withdrawal of nitrification inhibitors, such as dicyandiamide (DCD), from the market, the use of DCD was recommended with the aim of treating urinary N once it has been deposited onto the paddock. Modelling has shown that a combination of standing the cows off pasture and DCD could reduce N leaching by approximately 20%. The two strategies complement each other and reduce N leaching at a cost of approximately $25/ha for every 1% reduction in N leaching. If DCD remains off-limits, we may have to look for a replacement strategy. A strategy that 'traps' some N in the root zone before it is flushed out of the soil, such as adding ground bark or other organic manures to the soil, will improve soil biology by increasing microbial biomass and activity, resulting in a decrease in total mineral N (Stark et al. 2007).

Conclusions

System fundamentals are key principles underpinning the functioning of pastoral livestock enterprises. As we move into an era where the demands on these enterprises become more varied and seemingly at odds with each other, it requires a re-think of system design that often demands a break with traditional ways; a thinking outside the box. We argue that it will serve us well to re-visit some of these fundamentals that may have been neglected over the past decades when the single-minded objective was to grow, graze, and produce as much as possible per hectare. Fundamentals like soil health, providing the best for each cow, and farming with adequate buffers, should be in the forefront of our minds when designing sustainable dairy systems.

References

Farming within limits – Combined reference list

Abell J, Stephens T, Hamilton D, Scarsbrook M, McBride C 2012. Analysis of Lake Rotorua water quality trends: 2001-2012. Collaborative report prepared by Waikato University Environmental Research Institute and DairyNZ in response to an Environment Court mediation on the Bay of Plenty Regional Policy Statement of 21 November 2012. 22p. http://www.waikato.ac.nz/eri/research/publications [accessed 20 June 2013].

AgFirst 2009. Upper Waikato nutrient efficiency study. http://www.waikatoregion.govt.nz/Community/Your-community/For-Farmers/Healthy-Farms-Healthy-Rivers/Upper-Waikato-nutrient-efficiency-study/ [Accessed 20 June 2013].

Beukes PC, Gregorini P, Romera AJ 2011. Estimating greenhouse gas emissions from New Zealand dairy systems using a mechanistic whole farm model and inventory methodology. Animal Feed Science and Technology 166–167: 708–720.

Beukes PC, Romera AJ, Gregorini P, Khaembah E 2013. Strategies to reduce nitrogen leaching. What have we learned from modelling so far? DairyNZ, Hamilton, New Zealand. Technical Series, February 2013. Pg. 12–16. http://www.dairynz.co.nz/page/pageid/2145878009/Technical_Series#773. [accessed 18 June 2013].

Beukes PC, Scarsbrook MR, Gregorini P, Romera AJ, Clark DA, Catto W 2012. The relationship between milk production and farm-gate nitrogen surplus for the Waikato region, New Zealand. Journal of Environmental Management 93: 44–51.

Blaxter KL, Clapperton L 1965. Prediction of the amount of methane produced by ruminants. British Journal of Nutrition 19: 511–522.

Bos AP, Cornelissen JMR, Groot Koerkamp PWG 2009. Designs for system innovation. Cow Power. Stepping stones towards sustainable livestock husbandry. Animal Sciences Group, Wageningen University and Research Centre, Lelystad, The Netherlands. 27 p. edepot.wur.nl/12251 [accessed 18 June 2013].

Doran JW 2002. Soil health and global sustainability: translating science into practice. Agriculture, Ecosystems and Environment 88: 119–127.

Gregorini P, Beukes PC, Bryant RH, Romera AJ 2010. A brief overview and simulation of the effects of some feeding strategies on nitrogen excretion and enteric methane emissions from grazing dairy cows. In: Edwards GR and Bryant RH. eds. Meeting the challenges for pasture-based dairying. Proceedings of the 4th Australasian Dairy Science Symposium, 31 August–2

September 2010, Lincoln University, Christchurch, New Zealand. Pg. 29–43.

Hoogendoorn CJ, Betteridge K, Ledgard SF, Costall DA, Park ZA, Theobald PW 2011. Nitrogen leaching from sheep-, cattle- and deer-grazed pastures in the Lake Taupo catchment in New Zealand. Animal Production Science 51: 416–425.

Hungerford 2009. Evaluation of the integrated catchment management pilot project - final report June 2009. Number TR 2009/17. Waikato Regional Council, Hamilton, New Zealand. http://www.waikatoregion.govt.nz/Services/Publications/Technical-Reports/TR200917/ [accessed 20 June 2013].

Kingi T, Park S, Scarsbrook M 2012. Solutions for a sustainable Lake Rotorua: The farmers' perspective. In: Currie LD and Christensen CL. eds. Advanced nutrient management: Gains from the past – Goals for the future. Occasional Report No. 25. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. 11 p. http://flrc.massey.ac.nz//workshops/12/Manuscripts/Kingi_2012.pdf. [accessed 17 June 2013].

Kohn RA, Dou Z, Ferguson JD, Boston RC 1997. A sensitivity analysis of nitrogen losses from dairy farms. Journal of Environmental Management 50: 417–428.

Ledgard SF, Welten B, Menneer JC, Betteridge K, Crush JR, Barton MD 2007. New nitrogen mitigation technologies for evaluation in the Lake Taupo catchment. Proceedings of the New Zealand Grassland Association 69: 117–121.

Magesan GN, McFadden G 2012. Nutrient leaching under conventional and biological dairy farming systems. In: Currie LD and Christensen CL. eds. Advanced nutrient management: Gains from the past – Goals for the future. Occasional Report No. 25. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. 11 p. http://flrc.massey.ac.nz//workshops/12/Manuscripts/Magesan_2012.pdf [accessed 17 June 2013].

McLeod M 2011. Large scale in situ lysimeter array near Lake Taupo. Discovery, Issue 35: 4–5. www.landcareresearch.co.nz/_data/assets/pdf_file/0019/36316/DiscoveryIssue35.pdf [accessed 20 June 2013].

Meadows DH 2008. Thinking in systems: A primer. White River Junction, Vermont, USA: Chelsea Green Publishing Company. 218 p.

Ministry for the Environment 2011. National Policy Statement for Freshwater Management 2011: Implementation Guide. Wellington, New Zealand: Ministry for the Environment. www.mfe.govt.nz/publications/rma/nps-freshwater-guide-2011/nps-freshwater-management-guide.pdf [accessed 19 June 2013].

Ministry for the Environment 2013. Freshwater reform 2013 and beyond. Wellington, New Zealand: Ministry for the Environment. 58p. www.mfe.govt.nz/publications/water/freshwater-reform-2013/freshwater-reform-2013.pdf [accessed 19 June 2013].

Ministry for Primary Industries 2013. The dairying and clean streams accord: snapshot of progress 2011/2012. Wellington, Ministry for Primary Industries. 12p. http://www.mpi.govt.nz/news-resources/publications.aspx?title=Dairying%20and%20Clean%20Streams%20Accord. [accessed 20 June 2013].

Moller S, Matthew C, Wilson GF 1993. Pasture protein and soluble carbohydrate levels in spring dairy pasture and associations with cow performance. Proceedings of the New Zealand Society of Animal Production 53: 83–86.

Parliamentary Commissioner for the Environment 2012. Water quality in New Zealand: Understanding the science. Wellington, Parliamentary Commissioner for the Environment. www.parliament.nz/en-NZ/PB/SC/Documents/Reports/8/0/e/50DBSCH_SCR5845_1-Report-from-the-Parliamentary-Commisioner-for-the.html [accessed 19 June 2013].

Parsons O 2012. Community Governance: An Alternative Approach to Regulation and Market Mechanisms for Management of Nitrogen Loss. Proceedings of the 2012 New Zealand Agricultural and Resource Economics Society Conference. 30–31 August 2012. Tahuna Conference Centre, Nelson, New Zealand. 20p. http://ageconsearch.umn.edu/bitstream/136053/2/Parsons%202012%20complete.pdf [accessed 20 June 2013].

Resource Management Act 2009. A gateway to information about the Resource Management Act 1991. www.mfe.govt.nz/rma/index.html [accessed 19 June 2013].

Roche JR, Friggens NC, Kay JK, Fisher MW, Stafford KJ, Berry DP 2009. Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. Journal of Dairy Science 92: 5769–5801.

Romera AJ, Levy G, Beukes PC, Clark DA, Glassey CB 2012. A urine patch framework to simulate nitrogen leaching on New Zealand dairy farms. Nutrient Cycling in Agroecosystems 92: 329–346.

Saggar S, Yeates GW, Shepherd TG 2001. Cultivation effects on soil biological properties, microfauna and organic matter dynamics in Eutric Gleysol and Gleyic Luvisol soils in New Zealand. Soil and Tillage Research 58: 55–68.

Simmonds J 1998. What is a profitable, sustainable replacement rate? Proceedings of the Ruakura Farmers' Conference Pg. 66–69.

Stark C, Condron LM, Stewart A, Di HJ, O'Callaghan M 2007. Influence of organic and mineral amendments on Microbial soil properties and processes. Applied Soil Ecology 35: 79–93.

Vant B, Husar B 2000. Effects of intensifying catchment land use on the water quality of Lake Taupo. Proceedings of the New Zealand Society of Animal Production 60: 261–264.

Vogeler I, Beukes P, Burggraaf V 2013. Evaluation of mitigation strategies for nitrate leaching on pasture-based dairy systems. Agricultural Systems 115: 21–28.

Waikato Regional Council Regional Plan 2011. Variation No. 5 – Lake Taupo catchment. Waikato Regional Council, Hamilton, New Zealand. http://www.waikatoregion.govt.nz/Council/Policy-and-plans/Rules-and-regulation/Protecting-Lake-Taupo/ [accessed 20 June 2013].

Wheeler DM, Ledgard SF, de Klein CAM, Monaghan RM, Carey PL, McDowell RW, Johns KL 2003. Overseer® nutrient budgets - moving towards on-farm resource accounting. Proceedings of the New Zealand Grasslands Association 65: 191–194.