DAIRY COWS – ECONOMIC PRODUCTION AND ENVIRONMENTAL PROTECTION

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ABSTRACT: New Zealand's history of settlement and economic development has been tied to dairy production. Over the last two decades, a tipping point of public understanding has been reached, and increasing research has been directed towards understanding the economic impact of the dairy industry, both in terms of the export economy and the environment. This chapter outlines the development of the dairy industry, its current state, and New Zealand's economic dependency on dairy exports. Environmental impact is discussed and the cost and implications of attempting to regulate water quality emphasised.

Key words: carbon, dairy, production, food safety, nitrogen, water quality.

INTRODUCTION

Cows have been milked in New Zealand since 1814 when New South Wales Governor Lachlan Macquarie gave animals from the Crown Herd to missionary Samuel Marsden. They were shorthorns – useful draught animals, with what was then considered to be 'good milk and excellent meat' and the ideal multi-purpose animal for missionary stations. In addition, butter, which was less perishable than milk and cream, could be traded. Butter was the first dairy product with off-farm value.

The century of settlement and developing agriculture was characterised by assumptions about land, now termed the Waste Lands Doctrine (McAloon 2002): 'Waste is an unreasonable or improper use of land by an individual in rightful possession of the land. A party with an interest in a parcel of land may file a civil action based on waste committed by an individual who also has an interest in the land'. In the 1800s the settlers considered that New Zealand was being 'wasted' by the Māori. Breaking in the land to produce food was deemed by the settlers to be doing God's work; by importing grass and legume species from Europe they were ameliorating the environmental conditions of their new home, and ensuring that production could meet expectation (Holland et al. 2002).

Making a profit from the land was uppermost in the mind of the settler, and was also the goal of the government. The New Zealand year books (available on line at www.statistics.govt.nz) track stock numbers, profitability of different activities, and prices. In 1893, milking-cattle commanded £5 to £8 per head and top herds were doing 40% better in terms of milk yields than average herds. The 1893 year book also described land development in the west coast of the North Island: 'this will be the great dairying district of the colony, the humidity of its climate rendering it better adapted to this industry than any other. The luxuriance of the pastures has to be seen to be appreciated. Large tracks of bush-lands are being thrown open for small settlements, and are eagerly taken up, for the most part by thrifty hard-working men'.

The growth of dairy herds from 1882 was related to the availability of refrigeration for the export of butter. By 1884 twenty dairy factories had been built; the most successful made both butter and cheese, enabling adaptation to changing supply and demand. The Anchor brand, now famous across the world, was created in 1886.

In 1900, the dairy industry was being touted as capable of much greater expansion without even increasing the number of what were then called 'milch cattle', but by improvement in breeding. New Zealand dairymen were urged to raise dairy cattle that would yield milk of the best quality; 'in fact, nothing but intense farming will pay in the future applied to every branch', (New Zealand Year Book 1900). The message of intensification (as it was understood then) was taken on board. In 1890, dairy products formed 7% of total exports, the bulk going to Britain and Australia. By 1920, the proportion was 22% of total exports, increasing to 42% by 1930. The milking herd had reached 1.3 million cows.

Fast forward to 1970 and the national herd had increased to over 2 million cows in milk. The North Island had more than twelve times as many dairy cows as the South Island and the Shorthorn had been replaced by the Jersey as the predominant breed of dairy cattle, reflecting the fact that butterfat was the main component required.

Over the next 20 years the size of the national herd fluctuated between 2.2 and 2.5 million cows, but a change in breed to Holstein-Friesian, increased milk yields. The Holstein-Friesian had been in the country since 1884, but the early emphasis on milk fat for butter and cheese exports meant that they were not favoured. Markets for milk powder put an emphasis on protein and lactose, and the Holstein-Friesian came into its own, but with complications. Holstein are larger than Jersey cows. A mature Holstein cow typically weighs 580 kg, and stands 147 cm tall at the shoulder, whereas a Jersey cow is 350–425 kg and stand 115–120 cm at the shoulder. This difference in weight has implications for soil and soil fauna.

As Holstein-Friesian cows formed an increasingly large proportion of the national herd, fertility problems became apparent. Large cows need considerable feed, and selection for milk production appeared to be at the expense of conception rates. Anoestrus rates increased from 7 to 20% between the mid-70s and mid-2000s. Confounding problems included a rapid expansion in the dairy herd – from 2.4 million to approximately 4 million between 1990 and 2005 (Burke and Fowler 2007), indicating a lower cull rate than usual. At the same time, herd size increased (from approximately 115 cows to over 320) and staffing structures changed.

Although the breed was not the sole reason for the anoestrus problem, the kiwi-cross was developed, combining the best attributes of both the Holstein-Friesian and the Jersey cow – medium-sized, fertile, easy-calving, long-lived and free of leg and foot problems (at least in theory). In 2005 the farmer cooperative LIC launched KiwiCross™, making New Zealand the first country in the world to offer a team of crossbred bulls, and a third of replacement cows entering the herd were kiwi crosses.

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Holstein-Friesian cows

Jersey cows

In 2007 New Zealand had more than 4.2 million dairy cows producing over 15 billion litres of milk. The national dairy herd was made up of Holstein-Friesian (47%, although declining), Jersey (15%), Ayrshire (2%), and an increasing number of kiwi-cross cows.

By 2012, the national herd of milking cows numbered over 5 million, and the grumblings about the effect the cows were having on the environment had reached epic proportions. Milking cows now outnumber humans in New Zealand, and although dairy herds are considered to be everywhere, the total effective area for 2011/12 was only 1.6 million hectares (Figure 1). In contrast, beef and sheep farms occupy over 8 million hectares. The problem with dairy cows is that they are managed intensively, and concentrations of animals create effluent. In exactly the same way that towns and cities in New Zealand are struggling with human waste disposal, as their sewerage systems become unable to deal with volume as urban conurbation grows, New Zealand dairy farm soils in some areas have become overloaded with effluent nutrients that are escaping into waterways.

DIRTY DAIRYING

In 2001 Fish and Game New Zealand started the 'dirty dairying' campaign to highlight the effect of pollution from dairy farming intensification on the ecological health of freshwater environments. The campaign has been successful in increasing awareness, but has done little to improve urban-rural relationships,

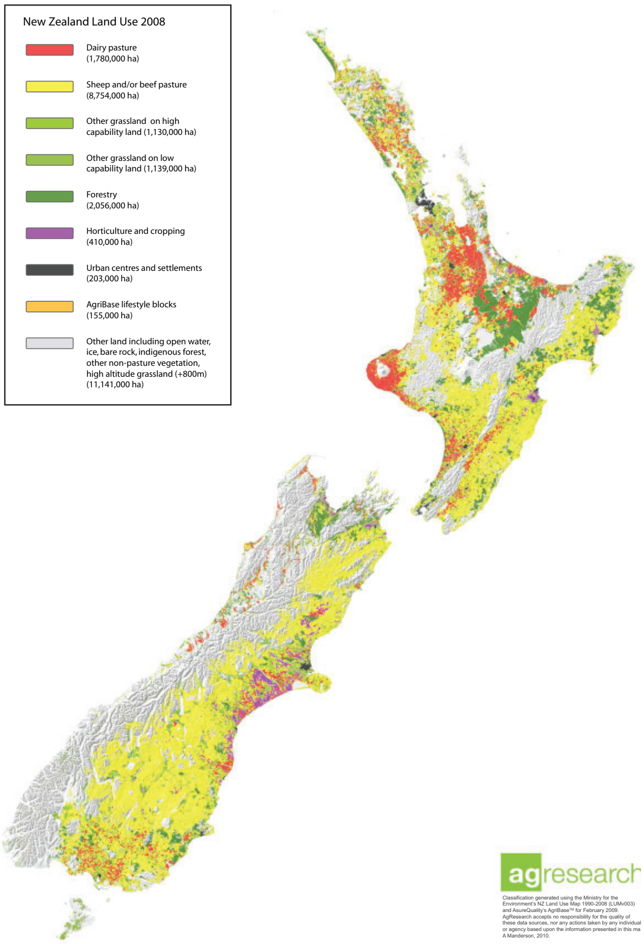

FIGURE 1 New Zealand Land Use (courtesy of AgResearch).

or assist urban dwellers to understand the true sources of pollution or the magnitude of the problem. Under the heading 'how does New Zealand compare', the Ministry for the Environment states, 'Our most nutrient-enriched rivers have about half the average nutrient levels of rivers in Europe, North America, and Asia' (www.mfe.govt.nz).

In order to provide a foundation to inform opinion and public debate, Dr Jan Wright, Parliamentary Commissioner for the Environment, released 'Water quality in New Zealand: understanding the science' (Parliamentary Commissioner for the Environment 2012). The report explains the history, causes and effects of water pollution by examining the data. Sediment, rather than the nitrogen and phosphorus nutrients per se, is the major challenge in New Zealand. Sediment can be linked to deforestation, tillage, recent soils and sand and gravel extraction, the latter being extremely important for infrastructure development. Overall, Wright concluded that New Zealand will have to decide what trade-offs it wants to make in the future, and where the most gain per dollar can be achieved.

THE ECONOMICS

Economics support the on-going growth of the dairy industry. The expected increase in disposable income, particularly in developing countries, has big implications for the international dairy sector (Astley 2012); Fonterra plays a major role in this sector, supplying a third of cross-border dairy trade. The Government's growth agenda involves increasing the ratio of exports to GDP from the current 30% to 40% by 2025. Meeting the challenge without dairying being involved is inconceivable. The main objective of the Dairy Industry Restructuring Act 2001

(DIRA) was to maximise the industry's economic performance by allowing it to evolve in response to the market, and the market is growing (Harrington 2005). (Note DIRA also had minimising regulatory and compliance costs as an objective.)

The dairy industry directly accounts for 2.8% of GDP ($5billion; Schilling et al. 2010), and has export earnings of over NZ$12 billion in 2011, that is 25% of the value of New Zealand's merchandise exports. The New Zealand Institute of Economic research (Schilling et al. 2010) has calculated that each dollar increase paid per kilogram of milk solids is worth $270 to each and every New Zealander. A short-term increase in the price of milk solids generates immediate benefits for the national economy; the $1 per kg increase is a welfare gain of $1.2 billion (Schilling et al. 2010).

Despite the value of dairy products to the country, dairy farmers are not creaming it. In 2011/12, total milk solid income for an average farm was $1.05 million which was essentially the same as for the previous year (Ministry for Primary Industries 2012a). Farm working expenses increased 12% during that time as a result of increased spending in most areas combined with on-farm cost inflation. Spending on repairs and maintenance increased 21%, with expenditure on effluent systems being a major item. In the 2012/2013 season the Ministry for Primary Industries Farm Monitoring report for the National Dairy herd predicted that the drop in the expected payout would result in total income from milksolids falling 20%, compared with 2011/12, and net cash income would decrease by 18%. Inflation-driven cost increases are being faced on feed, fertiliser and fuel, as well as labour. Farm profit before tax is expected to drop 57% compared with 2011/12.

As a consequence, the average farm is currently budgeting to run at a loss for the 2012/13 season. Although many farmers have paid off debt over the past two years, aggregate debt remains high. Few farmers are budgeting for any debt reduction, and approximately 20% of dairy farms with high debt are vulnerable to a drop in pay out. It is the farms that have invested significantly in new technologies that appear to be most vulnerable in terms of debt servicing (Reserve Bank 2012).

TECHNOLOGIES AND PRODUCTION SYSTEMS

Machines

The development and adoption of new technologies underpins New Zealand's leadership in efficient dairy systems. Herd testing began in the Wairarapa in 1909 (to prevent water being added to milk), group herd testing was established in 1922, and the Dairy Research Institute opened in 1927. Bill Gallagher senior developed the first electric fence in 1937, and in 1939 Ruakura and Wallaceville Research Stations were set up to help increase animal productivity. Tanker delivery of whole milk from farm to factory started in 1951, and Waikato farmer Ron Sharp developed the herringbone dairy in 1952, cutting milking time in half. In 1955 Ruakura developed a new milking machine featuring stainless steel and automatic cleaning. A mere 14 years after the herringbone was developed, Taranaki farmer Merv Hicks built the first turn-style dairy, the forerunner to the rotary. The Ruakura milk harvester was developed in 1985, and contained many of the features of modern-day milking. Now 21% of dairies are rotaries milking 800–1000 cows in a couple of hours with two people; the rest are mostly herringbone with a very small and slowly growing number of automatic milking systems.

Feeding

Production systems have changed even more rapidly than technologies, mostly in the last two decades. Before the 1990s, dairying in New Zealand was 'all grass' and most was 'factory supply'. Calving was timed to maximize potential milk production with expected grass growth. Surplus grass was saved as hay (or silage, and more recently, baylage), which was then fed to the herd during periods of slow grass growth. Herds were dried off as pregnancy advanced and grass growth slowed. This gave factories a period of closure for rigorous cleaning. Using ryegrass-white clover pastures, capturing the energy of the sun, New Zealand could produce dry matter for 3-4c per tonne. Turning this cheap energy into milk efficiently, with good animal and human welfare, resulted in New Zealand's reputation for dairy leadership.

Very few herds 'winter-milk' for town supply. Because grass growth does not match potential milk yields and supplements are required to feed the cow, winter milk attracts a price premium (predicted by Fonterra to be 86c per kg of milk solids in 2012/2013).

As milk increased in value, and improved breeding enabled cows to produce more milk during the season, the use of nitrogen to boost grass growth increased. Data for the whole of New Zealand (Figure 2) show that N-use increased from 50 000 tonnes to over 300 000 tonnes in 20 years. During that time the areas

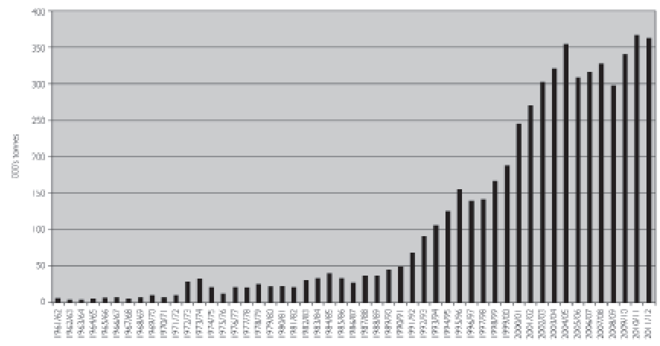

FIGURE 2 Nitrogen consumption in New Zealand, 1961–2012 (Fertiliser Association of New Zealand 2012).

in dairying increased 60% from 1.02 million to 1.64 million hectares, cow numbers increased 93% from 2.40 million to 4.63 million, and milk processed increased 270% from 7077 million to 19 129 million litres. Nitrogen used on pasture and to grow increasing areas of maize (for silage and grain) fuelled the growth.

This century there are considered (Hedley et al. 2006; DairyNZ 2012) to be five types of production systems, which are grouped based on the time of year when imported feed is used. Characteristics of the five dairy farming systems include:

System 1 (10–15% of owner-operated herds): Self-contained – no imported feed. No supplement is fed, except supplement harvested from the effective milking area. There is no grazing away from the effective milking area.

System 2 (25–35% of owner-operated herds): 4–14% of total feed imported, either supplement or grazing off and fed to dry cows.

System 3 (35–40% of owner-operated herds): 10–20% of total feed imported to extend lactation (typically autumn feed) and for dry cows.

System 4 (10–20% of owner-operated herds): 20–30% of total feed imported and used at both ends of lactation and for dry cows.

System 5 (5–10% of owner-operated herds): More than 30% total feed imported for use all year, throughout lactation and for dry cows. Split calving is common to this system.

The overall effect of technology and feeding has allowed more cows to be managed per hectare and per person. Intensification beyond that dreamed possible in 1900 is now the norm, and is likely to continue. DairyNZ (2012) Economic Survey results indicate that in a year of high pay out, system 4 and 5 farmers (high imported feed) are over-represented in the top quartile of operating profit per hectare; although together they represent 19% of owner-operated farms, they account for 30% of top performing farms. In contrast, system 1 farms (all grass) formed 11% of the farms in the survey and accounted for 19% of the farms in the bottom quartile for operating profit.

As pressure to intensify continues, the impact is being calculated through 'ecosystem service models'.

ECOSYSTEM SERVICES

The importance of ecosystem services in dairy enterprises has only relatively recently been explored in New Zealand. Calls for 'farmers to pay the full costs of what they are doing to the land' fails to recognise that farmers manage the ecosystem of their land remarkably well, overall – with some notable, sad, and headlined exceptions.

Dominati et al. (2010a) have gone to some lengths to develop a framework (Figure 3) for dairy farming ecosystem services based on the Millennium Assessment Exercise. The framework allows calculation of the value per ha to dairying that the soils provide (Dominati et al. 2010b). Ecosystem services include the provision of food (including water, nutrients and physical support to plants), provision of support for human infrastructures and animals, flood mitigation, the filtering of nutrients and contaminants, detoxification and the recycling of wastes, carbon storage and greenhouse gas regulations, and the regulation of pest and disease populations. Under a typical Waikato dairy farm operation, on Horotiu silt loam (allophanic), the average annualised value for each of 35 years was NZD 15 000 ha^{-1} yr^{-1} ranging from 10 000 to 21 000 ha^{-1} yr^{-1}. The authors commented that regulating services ($77,000 ha^{-1} yr^{-1}) have a much greater value than provisioning services ($4,900 ha^{-1} yr^{-1}) (Table 1); the two-fold range of values achieved reflects the interaction between climate and soil properties over 35 years. It provides a reminder that using ecosystem services as a regulatory tool would be fraught with uncertainty. The value of approximately $15,000 a year suggests that the actual market price of farm land might be grossly undervalued (Dominati 2011) and also that if farmers were to internalise the costs of the environment into product price, milk would be considerably more expensive than it is.

A similar exercise on Te Kowhai silt loam, which is less well-drained than the Horotiu silt loam, but is another common dairy soil resulted in a value of $11,700 ha^{-1} yr^{-1} (Dominati 2011). The difference in value between the soils reflects differences in physical structure and associated hydraulic properties.

Earthworms have been implicated in improving both productive and environmental aspects; they are 'bio-engineers' and play a key role in the construction and maintenance of pores and aggregate stabilisation (Mackay 2008). In general terms, New Zealand's ryegrass-white clover pastures are favourable for the introduction and survival of earthworms – ryegrass white clover pastures have higher abundance of earthworms than ryegrass alone (Eekeren et al. 2010). However, compared with soils in Europe, worms in agricultural soils in New Zealand are poorly represented and generally have only two or three species. Furthermore, most are from one or two of the niche categories, endogeic, anecic, and epigeic (Mackay 2008). Given research by Lubbers et al. (2013) showing a proportional relationship between earthworm numbers and production of nitrous oxides and carbon dioxide, increasing earthworm numbers in New Zealand soils might not seem sensible, unless they significantly improve other ecosystem services.

TABLE 1 The capital value (in NZD ha^{-1} yr^{-1}) of built infrastructures needed to provide soil services, and the value of provisioning and regulating soil services from a Horotiu silt loam under a typical Waikato dairy farm operation over 35 years. The value of land, infrastructure and shares: $45,000–$50,000 per ha. (From Dominati et al., 2010b)

Ecosystem service		Capital value ($ ha^{-1} yr^{-1})	Value of soil service (($ ha^{-1} yr^{-1})
Provisioning services	Food Quantity	NA	4,155
	Food Quality	NA	38
	Support for human infrastructure	100	17
	Support for farm animals	487	90
	Raw materials	NV	NA
Provisioning total		**587**	**4,300**
Regulating services	Flood mitigation	10,185	1,196
	Filtering of N	NA	554
	Filtering of P	NA	2,922
	Filtering of contaminants	56,112	5,659
	Decomposition of wastes	388	78
	Carbon flows	NA	-36
	Nitrous oxide regulation	NA	14
	Methane oxidation	NA	0
	Regulation of pests & disease populations	NA	210
Regulating total		**66,685**	**10,598**
Total		**67,272**	**14,898**

Grand total of capital value and ecosystem services $82,170

Land-use intensification is generally associated with the biological community in soils becoming dominated by species with shorter generation times, smaller body sizes, rapid dispersal, and a higher incidence of asexual reproduction (Schon et al. 2008). However, in a study where the effects of defoliation and treading pressure by cows were separated, *Apporectodea longa* earthworms (anecic species, i.e. having deep burrows) were found to increase under higher stocking rates (5 cows ha^{-1}) as food availability and physical pressure increased (Schon et al. 2010). This result suggests that increasing the weight of cows will not have a detrimental effect on earthworm function. Schon et al. (2010) reported that the overall earthworm abundance changed little, and suggested that anecic earthworms might be able to substitute for epigeic earthworms (surface dwellers) in intensively managed pastoral systems by incorporating litter, and hence carbon, as well as being important ecosystem engineers.

Carbon

Much research is being done globally on the topic of managing soil carbon to improve ecosystem services. Soil organic matter, which is generally in the order of 60% carbon, is a key determinant of soil quality as it determines soil function in storing, retaining and transforming water, nutrients and contaminants, including xenobiotics, as well as sustaining biodiversity and carbon sequestration, and providing nutrients for biomass production (Black et al. 2010; Bristow et al. 2010; Franzluebbers 2010).

Organic C and N levels in soils of temperate, grazed pastures generally increase with time and development, until equilibrium is reached where plant material inputs equal losses to heterotrophic decomposition (Mackay 2008). In New Zealand, however, there are indications that some pastoral soils have lost organic matter over the last 20–25 years (Schipper et al. 2007), particularly under intensive pasture use on flat land (Parfitt et al. 2007). In contrast, hill country soils under pasture appeared to be gaining organic C and N (Parfitt et al. 2007). Dairy production systems were identified as causing the loss, despite having greater fertiliser inputs than dry-stock systems; removal of C and N in exported products was implied as the cause (Schipper et al. 2010). Recent research (Parsons et al. 2013) has shown that the decreasing soil C occurs when the increase in N inputs necessary for dairy have not been sufficient to sustain soil C and soil N.

Total biosphere C can be substantially reduced by the rate of ingestion by grazing animal (Parsons et al. 2011). The level of C in the system that can be sustained is lower under grazing by lactating (dairy) animals than dry animals. This is due largely to the increased offtake of N (but not C: the C in milk is derived from respiration, which is a loss to the atmosphere under drystock conditions) in the milk (Parsons et al. 2013). As a consequence, sustaining dairy production in grazed pastures involves a substantial additional input of N, and it is concerns about ongoing use of nitrogen with impacts on waterways that fuel environmental concern.

Improving efficiencies

The efficiency of N use is improved when more of that N within the body of the animal is captured, hence reducing the proportion of the total amount of N in the system that is being repeatedly cycled as urine. For the same total intake of N, per animal or per hectare, dairy systems harvest N in milk that would otherwise have been excreted in urine. As a consequence, dairy cows are more efficient environmentally than dry stock (Parsons et al. 2013).

The reason for ongoing confusion about efficiency of animals lies at least partly in the misunderstanding that grazing animals are not the source of N, they are simply recyclers and concentrators (in urine patches) of what they are fed, and therefore what was supplied to the pasture/feed. Furthermore, whereas plants couple C and N into an organic form, animals uncouple much of it. Most of the C is returned to the atmosphere as carbon dioxide CO_2 (and some in methane), but in a lactating cow a smaller proportion of C is released as CO_2, as more remains coupled and harvested in the milk. Hence, fast growing or dairy animals are far more effective in harvesting C and N than would otherwise have been lost to the atmosphere.

A highly producing lactating cow will eat considerably more than a dry-stock cow, and so overall produces more N in its urine, but it is operating more efficiently. Suggestions that New Zealand should reduce cow numbers but feed them better overlooks the national N budget. The strategy would improve energy (C) use per unit of intake and food produced because larger, better fed animals have improved margins of production over maintenance energy (C). It would not, however, improve efficiency of N-use per animal. Indeed, it is likely that such a strategy would lead to increased losses of N through urine. The problem is that N excretion, notably in urine, rises at least linearly as in-take of N rises (Kebreab et al. 2001). In addition, if the same amount of N was excreted by fewer animals, it would be distributed less widely in space and losses of N would be greater per unit of N cycling and in total.

THE CLEAN STREAMS ACCORD 2003

As a reaction to the dirty dairying campaign, and in an attempt to assist with creating clean waterways, Fonterra, the largest dairy company in New Zealand, along with a number of government agencies, instigated the Dairying and Clean Streams Accord in 2003. The aim of the accord was to limit the access of stock to streams, rivers and lakes and their banks (streams were defined as deeper than a 'red band' (ankle depth) and 'wider than a stride', and permanently flowing. Farm races were to include bridges or culverts where stock regularly (more than twice weekly) cross a watercourse. Farm dairy effluent was to be appropriately treated and discharged. Nutrients were to be managed effectively to minimise losses to ground and surface waters. Existing regionally significant or important wetlands (as defined by regional councils) were to be fenced and their natural water regimes protected.

Annual updates on targets were provided, and though decriers existed, environmental awareness and compliance did increase on farm, and community involvement in such activities as tree planting increased.

One such programme, 'The Ripple Effect', was established in the Waikato by SIFE students. SIFE (recently rebranded as Enactus) is an international not-for-profit organization that works with leaders in business and higher education to mobilise university students to make a difference in their communities. The Ripple Effect is an environmental initiative encouraging farmers to plant native trees around waterways in the Waikato by providing the labour. So far The Ripple Effect team has organised planting of over 4000 trees, with support from Beef and Lamb New Zealand, the Waikato Regional Council, South Waikato District Council, The Biodiversity Condition Fund and most recently from Sustainable Coastlines. The team has assisted with protection of a natural lake, as indicated in the Clean Streams Accord, and educated society about what it takes in terms of clearing land, fencing, and planting, to meet the requirements.

In 2013 the Clean Streams Accord concept was broadened to include all dairy companies under the Sustainable Dairying: Water Accord. This accord involves a new set of national good management practice standards aimed at lifting environmental performance on dairy farms. The standards have been agreed between industry body DairyNZ and all dairy companies, with the support and input from a wide range of industry stakeholders. It is anticipated that it will be formally launched in time for the 2013/14 dairy season effective 1 August 2013. Consultation with farmers is underway.

TABLE 2 The cost ($) per kg of nitrogen and phosphorus conserved for different mitigation of loss strategies (McDowell R, pers. comm. 2012; from McDowell and Nash 2012)

	Cost ($) per kg of N & P conserved
Fencing	4–55
Effluent pond	25
P-test	0–25
Tile drain	25–75
Sorbents	300
Constructed wetland	>400

THE COST

The challenge for all farmers reflects the challenge identified by the Parliamentary Commissioner for the Environment (PCE 2012): most effect for each dollar. Dr Richard McDowell, Agresearch, has calculated the cost of implementation of various methods of reducing loss of N and P (Table 2). Data for phosphorus have been published (McDowell and Nash 2012) with the comment that effectiveness of mitigation strategies varies with different farm management systems, topography, stream density, and climate.

In general, on-farm management strategies such as decreasing soil test P, fencing streams from stock, or applying low water soluble P fertilisers (Weatherley et al. 2011) were the most cost-effective way of mitigating P exports (cost range, \$0 to \$200 per kg P conserved). Edge-of-field strategies, which prevent runoff (i.e. irrigation runoff recycling systems), or remove P from runoff (i.e. wetlands) were generally the least cost effective. In New Zealand, the high cost of constructing wetlands is accepted if it is part of a beautification/environmental conservation exercise, as shown by the Farm Environment Award winners (www.bfea.org.nz). Cheaper options such as floating wetlands are also being investigated.

In the mind of the layman, nitrogen is the main nutrient of concern in waterways. This reflects misunderstanding about the role of nitrate in human health. There is considerable evidence to suggest that it is not a problem unless there are confounding factors (Addiscott and Benjamin, 2004; Powlson et al. 2008). This belief also overlooks the fact that inland waterways tend to be phosphate limited (Crawford 2001; McDowell et al. 2009) and so P entering the waterways, from septic tanks and effluent disposal sites for example, is the main culprit of algal blooms (Parliamentary Commissioner for the Environment 2012). Although there have been suggestions that restricting nitrogen in water to the World Health Organisation limit of 11 mg l^{-1} N could be restricting food production (e.g. Powlson et al. 2008), the called for 'comprehensive and independent study to determine whether the current nitrate limit for drinking water is scientifically justified or whether it could be safely raised' has yet to occur.

Calculations (Monaghan et al. 2008) on the projected cost effectiveness, expressed as dollars saved per kilogram of reduced N loss, identify nitrification inhibitors, such as dicyandiamide (DCD) as the best mitigation tool (Table 3). All mitigation options were costed and expressed on an annualized basis which included the opportunity cost of additional capital required for infrastructure, plus depreciation spread across the lifespan of that infrastructure. Running and maintenance costs, plus additional labour, were also included where necessary. Cutting down on N use and building wintering pads resulted in an economic loss. DCD was the only option that resulted in economic gain.

DCD is primarily used to inhibit nitrate leaching into waterways from fertiliser. Considerable research at Lincoln University by Professors Di and Cameron (e.g. Di and Cameron 2007) has shown that using DCD can reduce nitrogen leaching from urine patches and boost grass growth. The general recommendation is that soils under pasture need to be below 12 degrees Celsius. Research for the Waikato dairying region (Doole and Paragahawewa 2011) concluded that the net benefits associated with DCD are positive but too low to warrant their widespread adoption for improved environmental outcomes without direct regulation. DCD has recently been taken off the market because of concerns about food safety.

DAIRY PRODUCT SAFETY

New Zealand has always been concerned about food quality and safety, and has developed a well-deserved reputation for best practice. The Dairy Industry Act of 1908 (a consolidation of previous legislation), with its amendments of 1915, 1922, 1924, and 1926, provided for the appointment of inspectors of dairy stock and factories or other places used for the manufacture of dairy-produce, and power was given to condemn or forbid their use, if necessary. The Act also provided for the registration of co-operative dairy companies, and shareholders were protected in the event of certain contingencies. A dairy company could not include in its registered name the word 'co-operative', unless it was entitled to be registered as a co-operative dairy company under the Act.

Co-operative companies dominate the current New Zealand dairy industry, and have dealt with food quality concerns over the last few years. The latest is the identification of DCD (dicyandiamide) in milk powder at very low levels. Although the headlines indicated that the removal of DCD from use could have a significant and detrimental effect on the environment, as discussed above, its use was limited to 5% of farmers. Of further note is that the DCD concentration found in milk powder was significantly below the level permitted in Europe. The fuss was because there are no global standards.

OPTIMISATION

Optimising land use for multiple ecosystem service objectives might be the direction for the future (e.g. Ausseil et al. 2012) and is unlikely to be a stable result. Ausseil et al. (2012) identified clean water, habitat provision, and water regulation as three different optimisation scenarios for a particular catchment (Waitaki, South Island), and concluded that the current land-use patterns were consistent with optimising ecosystem services. This supports the innate understanding that agricultural production systems are in the areas that require least cost adaptation for that system. Moving dairy, for instance, onto the inter-montane soils of the McKenzie Basin, where there are shallow soils susceptible to nitrate leaching, would have an impact on soil water quality. The alternative would be to build barns or houses to keep the animals off the soil and enable efficient effluent collection, but this would increase the costs of production. However, the authors acknowledged that quantifying ecosystem services is a difficult task and using simple models might overshadow some aspects, such as irrigation, that might have a significant effect on outcome. The authors (Ausseil et al. 2012) suggested that the next step would be to explore that convergence of clean water, habitat provision, and water-regulation with a multi-objective optimisation.

Parsons et al. (2013) used a process-based model to seek the optimum trade off, and the best land-use management for grazed systems, for multiple goals. This allowed consideration of how 'alternative' agricultural systems compare with 'conventional' intensity-driven ones.

Carbon sequestration, nitrogen leaching and food production were the drivers; an important consideration was to avoid a loss of soil services (e.g. organic matter and nutrients) and the release of the substantial quantities of C sequestered beneath grassland to the atmosphere. Parsons et al. (2013) showed that it is possible to sustain C under dairying as great as that under a dry-stock system, but that doing so would require an increased N input. Release of N to the environment increases steeply with the increase in N inputs needed to increase food production, but at a given N input rate the sustainable rate of N loss is lower in high food production

TABLE 3 Cost effectiveness ($ saved per kg of N conserved) of mitigation measures for reducing losses of N from dairy farms in 4 catchments. (From Monaghan et al. 2008)

	Toenepi	Waio-kura	Waika-kahi	Bog Burn
Nitrification inhibitor	10	11	16	–5
Restricted autumn/winter grazing	–5	–5	–6	–1
Nil N fertiliser input	–16	–4	–1	–16
Low N feed	–12	–13	0	–41
Wintering pads	–24	–36	–9	2
APS	–20	n/a	n/a	–52

(e.g. dairy) than in low food production (e.g. dry stock). This is due to the 'offtake' of N in products. A similar analysis for a goal of maximising C sequestration would require low offtake of food products and increased nitrogen inputs and losses. Other authors have also questioned the compatibility of the goal of increased productivity with decreased environmental impact (e.g. Tilman et al. 2002; Lemaire et al. 2011).

LEGISLATION

Regional councils are taking an increasingly regulatory approach to catchment management and water quality. Decisions in the Environment Court have been based on the natural capital approach (e.g. Clothier et al. 2012) for land planning. The natural capital approach (NCA) is a compromise between 'grand parenting', which rewards those who currently leach the most nitrogen, and 'polluter pays', which rewards those who currently leach the least (Marsh 2012). Concerns with NCA are that it bases allocations on one aspect of natural capital while ignoring economic, social, and human capital. It gives two farms on identical soils identical allocations while ignoring the fact that one might be undeveloped and the other might have invested millions of dollars in a dairy conversion (economic capital) and in building up human resources to run it (social and human capital).

An alternative is trading of environmental impacts. For example, if nitrate leaching is an issue in a catchment, then total leached nitrate may be capped and the rights to leach nitrate may be traded among farmers. If the cost of trading is kept low and trading is encouraged, appropriate land use and the best economic outcomes for the region and for the country, could be achieved. The allocation system chosen is important because it will determine whether farmers and local communities broadly support the regulatory regime or whether they will do their level best to find a way around it. For that reason the best allocation system may be the one that farmers and local communities think is fairest (Marsh 2012). A report by Landcare Research released in November 2012 (Ministry for Primary Industries 2012b) concluded that where nutrient loads are high, achieving reduction would be difficult. In the Manawatu catchment, for instance, achieving a 53% reduction in N would reduce catchment net revenue by 22%. As farmers are not making 22% profit, there are concerns about agricultural viability. The report also suggested that the larger the geographical area for trading, the more cost-efficient the programme is likely to be.

EDUCATION

The DairyNZ Dairy Farming Strategy is for 'Sustainable Dairy Farming', focusing on New Zealand dairy farming remaining competitive and being responsible. DairyNZ's biggest expenditure is on research and development to improve competitiveness and address the long-term sustainability issues of the industry. DairyNZ's second largest area of spend is on education and extension (Luxton 2013). With larger and more complex farming businesses and an increasingly complex regulatory environment, the skill level of dairy managers has had to improve rapidly. Smart farmers and smart farming are being enabled through newsletters, field days, seminars, and conferences. At the same time, Massey University is delivering professional development courses on such topics as nutrient management and dairy farm effluent to enable industry personnel to understand best management practice for the environment. It is equally important that the industry professionals then assist the farming community to adopt best practice. Analysis of how best to achieve adoption (Sin 2012) suggests that policies to reward adoption will be most effective.

THE FUTURE

The environmental history of New Zealand has always been one of confrontation between image and reality, inappropriate management systems and ineffective legislation (Holland et al. 2002). The Green lobby and the general public are increasingly urging agriculture to 'clean up' as intensification has reached a point where environmental spillovers are no longer being tolerated (Bell 2012). Policies to improve waterways and make agriculture 'clean up' are ahead of science and have the potential to remove New Zealand's competitive advantage in agricultural production. A framework for a whole system collaborative process is required (Bell 2012) involving:

- Setting objectives
- Defining limits (based on science not public perception)
- Determining contributors to the problem
- Dividing required actions amongst contributors
- Monitoring, evaluation, and refinement.

The Parliamentary Commissioner for the Environment (2012) report on water quality provides a good starting point for the first 3 points. However, debate on sustainability continues because of the difficulties of defining what constitutes true sustainability. Smyth and Dumanski (1994) formed the following definition accepted by the soil science community. Sustainable land management combines technologies, policies, and activities aimed at integrating socio-economic principles with environmental concerns so as simultaneously to:

1. maintain and enhance productivity
2. decrease risks to production
3. protect the potential of natural resources and prevent the degradation of soil and water quality
4. be economically viable
5. be socially acceptable.

These five objectives of productivity, security, protection, viability, and acceptability can be used to identify areas of concern (Cornforth 1999), defined as 'any factor able to influence the ability of a production system to meet the five objectives of sustainable land management'. Of particular note is that environmental indicators used to monitor areas of concern must be sensitive to management actions and must be related in a functional way with those parts of the system at risk. Furthermore, they should have critical values beyond which a particular system of land management is no longer sustainable.

Cornforth (1999) noted that critical values for indicators often depend on an understanding of the relationships between management and the final arbiter of sustainability. They might vary, depending on the characteristics of the system, but should be independent of management, although management will influence the rate at which an indicator approaches its critical value. This means there is increasing onus on the regulator to understand the environment being regulated, and to understand the limitations of the tools used to create regulations.

Understanding is required globally. Institutional change has been highlighted by environmental economists Ehrlich and Ehrlich (2013), pointing out that an accelerating extinction of animal and plant populations and species, which could lead to a loss of ecosystem services essential for human survival, is part of the global crisis. The Ehrlichs urge a restriction on agricultural expansion (to protect ecosystem services) while improving efficiency in the use of fertilisers, water and energy to improve food yields. Similarly, The Global Partnership on Nutrient Management report (2013) calls for an inter-governmental effort to show how improved management of N and P would assist in improving water, air, soil, climate, and biodiversity, while improving food and energy security, with net social and economic benefits. The report states that international consensus and authorisation of the global nutrient focus is essential, and requests an assessment of scientific evidence, and a sharing of best practices.

New Zealand's role could be to develop the systems, including the rewards for the farmers, which maintain ecosystem services while increasing efficiencies of production. Doing so would involve yet another change in farming system, perhaps to housing of animals, but the New Zealand farmer has been adaptable in the past. Agriculture has moved a long way from cows wandering free and eating meadow flowers whilst producing cream (Appendix 1) and the New Zealand farmer has been in the lead in developing efficient production systems based originally on pasture and increasingly on supplementary feed. The challenge of economic viability will remain, however, and whatever the solution(s), the price of milk will inevitably increase.

The question for society continues to be, how much are you prepared to pay for primary production involving natural resources and, hence, ecosystem services?

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REFERENCES

Addiscott TM, Benjamin N 2004. Nitrate and human health. Soil Use and Management 20: 98–104.

Astley M 2012. Increasing global income will have 'big implications' for dairy sector – FAO. www.dairyreporter.com (accessed 7 November 2012).

Ausseil A-GE, HerzigA, Dymond JR 2012. Optimising land use for multiple ecosystem services objectives: a case study in the Waitaki Catchment, New Zealand. In: Seppelt R, Voinov AA, Lange S, Bankalmp D eds 2012 International Congress on Environmental Modelling and Software, Managing Resources of a Limited Planet. Sixth Biennial Meeting, Leipzig, Germany.

Black HJI, Glenk K, Lilly A, Artz R, Watson C, Colombo S, Brown I, Towers W 2010. What are the opportunities for enhancing ecosystem services from soils through management of soil carbon? Proceedings of the World Congress of Soil Science, Brisbane, published on DVD. Pp. 33–34.

Bell B 2012. Agricultural productivity and environmental sustainability: are we going to throw the baby out with the bathwater? New Zealand Agricultural Resource Economics Society, 30–31 August 2012, Nelson.

Bristow K, Marchant SM, Deurer M, Clothier BE 2010. Enhancing the ecological infrastructure of soils. Proceedings of the World Congress of Soil Science, Brisbane, published on DVD. Pp. 13–16.

Burke C, Fowler C 2007. Fertility in New Zealand dairy herds: Industry situation and a way forward for improving on-farm reproductive performance. Proceedings of the SIDE Conference, 18–20 June, Lincoln University. Pp. 194–202.

Clothier B, Mackay A, Dominati E 2012. Natural capital and New Zealand's Resource Management Act (1991). New Zealand Agricultural Resource Economics Society, Nelson, New Zealand. 30–31 August 2012.

Cornforth IS 1999. Selecting indicators for assessing sustainable land management. Journal of Environmental Management 56: 173–179.

Crawford S 2001. Water quality and our changing agricultural landscape. In: Proceedings of the Southland Dairy Forum. Pp. 11–15.

DairyNZ 2012. DairyNZ Economic Survey 2010–2011. 60 p.

Di HJ, Cameron KC 2007. Nitrate leaching losses and pasture yields as affected by different rates of animal urine nitrogen returns and application of a nitrification inhibitor – a lysimeter study. Nutrient Cycling in Agroecosystems 79: 281–290.

Dominati EJ 2011. Quantifying and valuing the ecosystem services of pastoral soils under dairy use. Unpublished PhD thesis, Massey University, Palmerston North, New Zealand.

Dominati E, Patterson M, Mackay A 2010a. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics 69: 1858–1868.

Dominati E, Mackay A, Green S, Patterson M 2010b. The value of ecosystem services for nutrient management. In: Currie LD, Christensen CL eds Adding to the knowledge base for the nutrient manager, http://flrc.massey.ac.nz/publications.html. Occasional Report No. 24. Fertilizer and Lime Research Centre, Massey University, Palmerston North. 8 p.

Doole GJ, Paragahawewa UH 2011. Profitability of nitrification inhibitors for abatement of nitrate leaching on a representative dairy farm in the Waikato Region of New Zealand. Water 3: 1031–1049.

Eekeren van N, Bokhurst J, Brussaard L 2010. Roots and earthworms under grass, clover and a grass-clover mixture. Proceedings of the World Congress of Soil Science, Brisbane. Pp. 27–30.

Ehrlich PR, Ehlrlich AH 2013. Can a collapse of global civilization be avoided? Proceedings of the Royal Society B 280: 20122845.

Fertiliser Association of New Zealand 2012. Fertiliser Matters, March 2012.

Franzluebbers AJ 2010. Depth distribution of soil organic matter as a signature of soil quality. Proceedings of the World Congress of Soil Science, Brisbane. Pp. 1–4.

Harrington A 2005. The contribution of the primary sector to New Zealand's economic growth. New Zealand Treasury Policy Perspectives Paper 05/04.

Hedley P, Kolver E, Glassey C, Thorrold B, van Bysterveldt A, Roche J, Macdonald K 2006. Achieving high performance from a range of farm systems. Proceedings of the 4th Dairy3 Conference. Pp. 147–168.

Holland P, O'Connor K, Wearing A 2002. Remaking the grasslands of the open country. In: Pawson E, Brooking T eds Environmental Histories of New Zealand. Oxford University Press. Pp. 69–83.

Kebreab E, France J, Beever DE, Castillo AR 2001. Nitrogen pollution by dairy cows and its mitigation by dietary manipulation. Nutrient Cycling in Agroecosystems 60: 275–281.

Lemaire G, Hodgson J, Chabbi A 2011. Grassland productivity and ecosystem services. Wallingford, UK, CAB International.

Lubbers IM, Groenigen KJ van, Fonte SJ, Six J, Brussaard L, van Groenigen JW 2013. Greenhouse-gas emissions from soil increased by earthworms. Nature Climate Change DOI: 10.1038/NCLIMATE1692

Luxton J 2013. A political perspective from New Zealand. Oxford Farming Conference www.ofc.org.uk/files/ofc/papers/john-luxton-oxford-lecture-3.pdf (accessed 20 February 2013).

Mackay AD 2008. Impacts of intensification of pastoral agriculture on soils: current and emerging challenges and implications for future land uses. New Zealand Veterinary Journal 56: 281–288.

Marsh D 2012. Is natural capital best for nitrogen leaching limits? Primary 7: 30–31.

McAloon J 2002. Resource frontiers, environment and settler capitalism 1769–1860. In: Pawson E, Brooking T eds Environmental Histories of New Zealand. Oxford University Press. Pp. 52–-66.

McDowell RW, Nash D 2012. A review of the cost-effectiveness and suitability of mitigation strategies to prevent phosphorus loss from dairy farms in New Zealand and Australia. Journal of Environmental Quality

41: 680–693.
McDowell RW, Larned ST, Houlbrooke DJ 2009. Nitrogen and phosphorus in New Zealand streams and rivers: Control and impact of eutrophication and the influence of land management. New Zealand Journal of Marine and Freshwater Research 43: 985–995.
Ministry for Primary Industries, 2012a. Farm Monitoring Report 2012 – National Dairy.
Ministry for Primary Industries. 2012b. Evaluation of the impact of different policy options for managing to water quality limits. MPI Technical Paper No: 2012/46.
Monaghan RM, de Klein CAM, Muirhead RW 2008. Prioritisation of farm scale remediation efforts for reducing losses and faecal indicator organisms to waterways: a case study of New Zealand dairy farming. Journal of Environmental Management 87: 609–622.
New Zealand Year Book 1900. Statistics New Zealand. www.statistics.govt.nz. Accessed January 2013
Parfitt R, Arnold G, Baisden T, Claydon J, Dodd M, Ross C, Schipper L 2007. Changes of C and N from NZ profiles under pasture over 20 years, Poster paper. Proceedings of the 3rd International Conference on Mechanisms of Organic Matter Stabilisation and Destabilisation in Soils and Sediments.
Parsons AJ, Rowarth JS, Thornley J, Newton P 2011. Primary production of grasslands, herbage accumulation and use, and impacts of climate changes. In: Lemaire G, Hodgson J eds Grassland Ecosystems: Productivity and Environmental Issues. CAB International. Pp. 1–16.
Parsons AJ, Thornley JHM, Newton PCD, Rasmussen S, Rowarth JS 2013. Soil carbon dynamics: the effects of nitrogen input, intake demand and off-take in animals. In: Bolan NS, Kirkham MB, Saggar S eds Soil as a source and sink for greenhouse gases. Special issue of Science of the Total Environment dx.doi.org/10.1016/j.scitotenv.2013.02.019.
Parliamentary Commissioner for the Environment 2012. Water Quality in New Zealand: understanding the science. Wellington, Parliamentary Commissioner for the Environment. 93 p.
Powlson DS, Addiscott TM, Benjamin N, Cassman KG, de Kok TM 2008. When does nitrate become a risk for humans? http://digitalcommons.unl.edu/agronomyfacpub/102 (accessed 28 February 2013).
Reserve Bank of New Zealand 2011. Financial Stability Report, November 2012.
Schilling C, Zuccollo J, Nixon P 2010. Dairy's role in sustaining New Zealand – the sector's contribution to the economy. New Zealand Institute of Economic Research report to Fonterra and DairyNZ, 39 p.
Schipper LA, Baisden WT,Parfitt RL, Ross C, Claydon JJ, Arnold GC 2007. Large losses of C and N from soil profiles under pasture in New Zealand during the past 20 years. Global Change Biology 13: 1138–1144.
Schipper LA, Parfitt RL, Ross C, Baisden WT, Claydon JJ, Fraser S 2010. Gains and losses in C and N stocks of New Zealand pasture soils depend on land use. Agriculture, Ecosystems & Environment 139: 611–617.
Schon NL, Mackay AD, Yeates GW, Minor MA, Hedley MJ 2008. Soil fauna in grazed New Zealand hill country pastures at two management intensities. Applied Soil Ecology 40: 218–228.
Schon N, Mackay A, Yeates G, Minor M 2010. Separating the effects of defoliation and dairy cow treading pressure on the abundance and diversity of soil invertebrates in pastures. Applied Soil Ecology 46: 209–221.
Sin I 2012. The adoption of environmentally friendly technologies in agriculture. MOTU Note 12. 15 p.
Smyth A J, Dumanski J 1994. Progress towards an International Framework for Evaluating Sustainable Land Management (FESLM). 15th World Congress of Soil Science, Mexico 6a: 373–378.
Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S 2002. Agricultural sustainability and intensive production practices. Nature 418: 671–677.
The Global Partnership on Nutrient Management. 2013. Our nutrient world: the challenge to produce more food and energy with less pollution. 116 p.
Weatherley AJ, Quin BF, Dassanayake, KB, Rowarth JS 2011. Runoff losses from irrigated dairy pastures treated with phosphorus of differing solubility in south-eastern Australia. Soil Research 49: 633–641.