Environmental Impacts Of Dairy Systems

S F Ledgard, E R Thom, P L Singleton,
B S Thorrold and D C Edmeades
AgResearch Ruakura, Hamilton
DRC, Hamilton

Summary

- The main environmental impacts of dairying are either on soil quality (eg. by compaction) or water quality (ground and surface waters).

- Soil compaction impacts on pasture production, soil structure and nutrient losses. Winter pugging can decrease pasture growth by 20-80% (depending on soil type) for up to eight months. This can be reduced by restricted grazing of wet soils and through adequate drainage.

- Nitrate levels in groundwater under intensive dairying can exceed recommended limits for drinking water. Levels increase with increasing N fertiliser use and farmlet studies at 3.2 cows/ha on free-draining soils highlight excessive effects from 400 kg N/ha/year.

- Surface waterways show increased sediment, faecal bacteria and aquatic plant growth in intensive dairying areas. These effects can be reduced through use of buffer strips between paddocks and waterways, and by effluent application onto land rather than into pond systems. Appropriate timing and placement of fertilisers can also minimise direct nutrient losses to waterways.

Introduction

Dairy farms are generally characterised by a high stocking rate and intensive management relative to other pastoral farming systems in New Zealand. The intensification of dairying has increased during the past decade, with greater use of forage supplements and other inputs (eg. fertiliser) to improve on-farm productivity. Invariably, increased intensification results in a greater potential for impacts on the environment, either on soil quality or water quality (groundwater and surface waters).

The need to reduce the adverse effects of farming on the environment is increasing with the potential for non-tariff trade barriers and the increased environmental awareness of society. The Resource Management Act also requires that soil and water resources are managed consistent with the principles of sustainability. For the pastoral farmer this is likely to mean that increasing intensification may be allowed only where impacts on the environment are minimised. Many other developed countries (particularly in Europe and the United States of America) have defined limits on the impacts of agriculture on many environmental parameters, and in some cases legislation has been, or is being produced putting specific limits on activities (eg. maximum rates of fertiliser application; Table 1). In contrast, and as a consequence of the Resource Management Act, a Fertiliser Code of Practice is being developed in New Zealand. The purpose of this Code is to manage farm practices to meet desirable thresholds (viz. soil and water quality) rather than to prescribe or dictate specific on-farm activities (eg. stocking rate, fertiliser inputs etc.).

Table 1: Examples of some legal limits set on nutrient levels or inputs for pastoral farming in Europe, to reduce impacts on the environment.

	Maximum permissible limit[1]	Year of introduction	Countries
Nitrate in drinking water	11.3 mg N/litre[2]	1975	Europe
Animal manure application	170 kg N/ha/year	1997	Europe
P (manure + fertiliser) inputs	75 kg P/ha/year	1995	Netherlands
	= P outputs (milk/meat)	c.2000	Netherlands
Cadmium in P fertilisers	110 mg Cd/kg P	1995	Denmark

[1] N = nitrogen, P = phosphorus, Cd = cadmium
[2] Same as current New Zealand value

This paper examines some of the key impacts of dairy farming on soil and water resources. It attempts to outline the main causes of these impacts and discusses some of the management practices which could be used to reduce them.

Soil Quality Effects

Intensive dairying can have a deleterious effect on soil quality. Two aspects of potential significance are soil compaction and the accumulation of heavy metals.

Soil compaction

Current research indicates that soil compaction due to cow treading under intensive dairying may be a problem which is more widespread than previously realised. Soil compaction may adversely affect farm production and have negative impacts on the environment. Compaction occurs when the soil does not have sufficient ‘strength’ to support the weight of the grazing animals. As soil ‘strength’ decreases with increasing moisture content, this problem is worst in winter and is increased further by block-grazing at high stocking rates during long winter grazing rotations.

The consequences of this practice were highlighted in a recent study (Figure 1) which showed that a single intensive grazing during a wet day in August depressed pasture production by 20-80%, depending on soil type, and the effects lasted 4-8 months.

Measurements of soil structure in this study revealed longer term detrimental effects resulting from the single treading event. In the Te Kowhai soil, infiltration rates of water were ten times slower, due to fewer continuous small soil pores (<0.3 mm diameter), which also meant that aeration and water storage were reduced. These effects had not fully recovered within 14 months. Similar effects were noted in the Hauraki soil, but the Horotiu soil appeared to have returned to ‘normal’ in a much shorter time. These impacts of treading on soil structure can result in increased periods of waterlogging and may restrict root growth and nutrient uptake by plants.

Further evidence of the effects of intensive treading by cows is a compacted zone at about five to 10 cm depth. Houlbrooke (1996) indicated these effects for three soil types on the Dairying Research Corporation (DRC) Number 2 Dairy,

Figure 1: Change in pasture production following an intensive treading on one wet August day on Te Kowhai, Horotiu and Hauraki soil types.

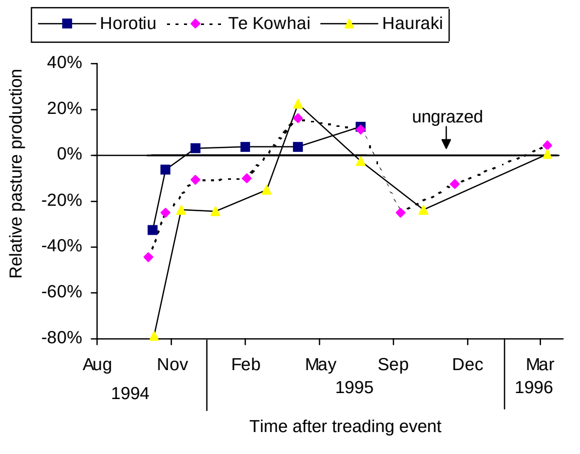


Table 2: Changes in soil bulk density (g/cm^3) at different depths in three soils at DRC Number 2 Dairy in November 1994 (Houlbrooke 1996).

	Soil type		
Soil depth (cm)	**Horotiu silt loam**	**Te Kowhai silt loam**	**Te Rapa silty peat loam**
0-7.0	0.96	1.11	0.64
7-10.5	1.06	1.12	0.71
10.5-14.0	0.94	1.06	0.64
14.0-21.0	0.85	1.06	0.60

from measurements of soil bulk density. The highest bulk density was consistently recorded between soil depths of seven and 10.5 cm (Table 2).

Environmental impacts of soil compaction can be evident through an increase in the emission of greenhouse gases (CO_2, methane, nitrous oxide), and an increase in the runoff of water and nutrients into surface waterways. Indirect environmental effects of increased soil compaction include increased periods of waterlogging and possible restricted root growth and nutrient uptake by plants.

Natural regeneration of soil structure occurs with drying and wetting cycles, and with root and earthworm activity. However, on some soils the natural regenerative processes may be too slow to counter the cumulative effects of intensive management of stock in successive winters. This can lead to compaction of soil to a depth of 20 cm below the soil surface (Greenwood and McNamara 1992).

Minimising soil compaction is best achieved by keeping stock off saturated soils. Practically, this means using a short grazing period and then moving stock to a loafing pad, yard, race, or sacrifice paddock until soil conditions improve. Stock may also have to be moved from the pasture when heavy rain occurs. Avoiding the use of heavy vehicles and machinery on the soil when it is likely to be damaged is also recommended.

Practices which assist soil drainage are also beneficial. Drainage and subsoiling can decrease the duration of soil wetness and so decrease the period over which the soil is likely to be compacted. Soil aeration is another technique which can partly alleviate compaction effects, although there is little data available describing the benefits to production from its application.

In New Zealand, the importance of compaction has been neglected in the past and an increased research effort is currently examining the extent of compaction on a range of soils, the effects on pasture production and soil physics, and quantifying the benefits of alleviating compaction by various techniques. This is being linked with the development and calibration of tests to predict the impact of grazing on compaction and pasture production.

Accumulation of cadmium

The issue of cadmium (Cd) accumulation in soils is currently of concern in New Zealand pastoral farming because of its accumulation in animal tissues and potential toxic effect on humans. A survey of pastoral soils in New Zealand by Roberts *et al.* (1994) showed that Cd concentrations in soil had increased from 0.2 ppm in ‘native’ soils to 0.4 ppm where P fertilisers (which contain Cd) had been applied for many years. However, these levels were low relative to soils in European countries and the USA.

Cadmium does not accumulate in the milk or meat of cows, but it does accumulate in the kidneys. Approximately one-third of kidneys from cows exceed the ‘Maximum Residue Level’ for Cd of 1 µg/g set by the New Zealand Department of Health (Roberts *et al.* 1994). Consequently, the New Zealand Meat Industry now automatically condemns kidneys from cattle over

2.5 years of age, removing them from human consumption.

Although soil Cd levels are currently low by world standards, every effort should be made to minimise further unnecessary accumulation in soils and thus ensure that this issue is not used as a non-tariff trade barrier. The fertiliser manufacturers in New Zealand have implemented a voluntary policy to reduce current Cd levels in fertilisers by one-third by the year 2000.

Effects on Water Quality

Pastoral farming is the major land use in New Zealand and it is unavoidable that such an activity will have some impact on water quality. A recent review (Smith *et al.* 1993) on the effects of agriculture on water quality concluded that the quality of New Zealand rivers was generally good. However, it noted major effects of intensive farming on the condition of small streams and creeks in terms of turbidity, faecal contamination, and aquatic plant growth induced by elevated levels of N and P. The challenge currently facing pastoral farming is to find an acceptable balance between viable economic farming and preservation of water quality (ground and surface waters).

Groundwater nitrate

Nitrogen in the form of nitrate is very mobile in soils and is easily leached in drainage water. In contrast, leaching of P, faecal bacteria and pesticides is usually small because of the filtering effect of soil. Consequently, the major concern with respect to groundwater quality is nitrate.

Surveys of nitrate concentrations in groundwater in various New Zealand regions in the 1970's and 1980's showed enrichment in intensive dairying areas in Taranaki and Waikato under free-draining soils. For example, a 1987 survey of dairy farms in south Taranaki showed that over 40% of the groundwater samples from wells had nitrate-N concentrations exceeding 11 mg/litre (Taranaki Catchment Commission 1987), the maximum acceptable concentration set for New Zealand drinking water (Ministry of Health 1995). This concentration is similar to that set by many other countries (eg. Table 1) and is based on a level which is considered safe for infants who are predisposed to methaemoglobinaemia ('blue-baby syndrome').

During the past ten years there has been a marked increase in use of nitrogen fertiliser on New Zealand dairy farms. The question must be asked, what impact is this trend having on nitrate losses to groundwater?

In June 1993, a farmlet grazing study commenced at the DRC Number 2 Dairy to examine the effects of different inputs, including N fertiliser, on milk production (Penno *et al.,* this proceedings). In conjunction with this study, nitrate leaching losses have been measured. The results show increases in nitrate leaching, particularly at the highest rate of N fertiliser application (Figure 2). Associated measurements revealed that direct losses of fertiliser N were small at the 200 kg N/ha/yr application rate but were about 20 times higher at 400 kg N/ha/year. However, this is affected by season and large direct leaching losses can occur from fertiliser N applied in winter (Table 3), whereas application prior to (eg. August in Table 3) or during rapid pasture growth results in minimal direct leaching.

The main source of the increase in nitrate leaching in the farmlet study (Figure 2) was indirect, via cow urine-N, because of greater pasture consumption by cows. This indicates that N fertiliser is used efficiently by pastures when applied in multiple applications of up to about 200 kg N/ha/year, and that total nitrate leaching from grazed pasture is largely a consequence of the total amount of N cycling in the pasture system and the level of pasture utilisation by cows.

Figure 2: Amount of nitrate-N leached from grazed dairy farmlets receiving different rates of N fertiliser, at DRC No 2 Dairy.

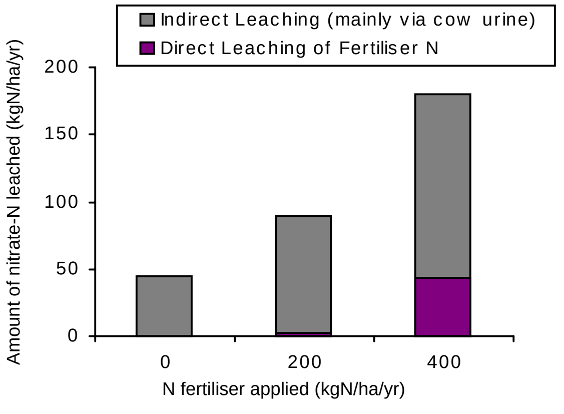
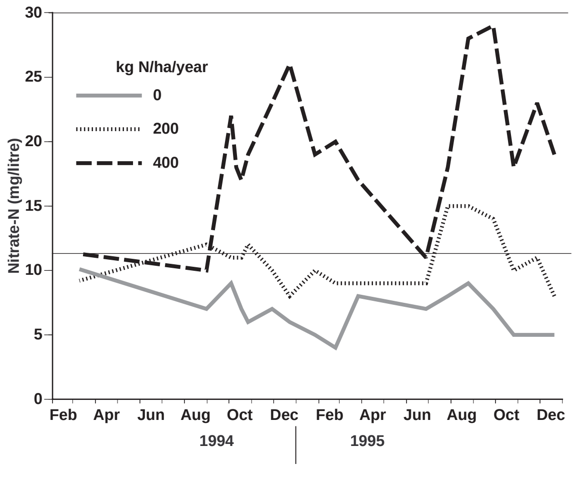


Table 3: Effect of time of application on the fate (as a % of the N applied) of N fertiliser (urea) applied at 50 kg N/ha to a free-draining Horotiu soil (Ledgard *et al.* 1988).

	Month of application		
	May	**June**	**August**
Plant uptake	31	47	63
Immobilisation in soil organic N	32	30	35
Direct loss (largely by leaching)	37	23	2

Effects of the increased leaching losses were also evident in nitrate concentrations in groundwater at 3-5 m depth under these farmlets (Figure 3), with levels in the 400 N farmlet averaging about twice the recommended maximum for drinking water for humans and approaching the recommended maximum for livestock (30 mg nitrate-N/litre). Thus, 400 kg N/ha/year could be considered excessive in terms of the impacts on nitrate losses to groundwater. Additionally, it is unlikely to be profitable (Penno *et al.,* this proceedings). Only a small proportion of farmers currently apply N fertiliser at rates above about 200 kg N/ha/year and it is undesirable that this proportion increases if we are to protect groundwater quality, maintain our 'green' image and avoid legislation, as in Europe, which impinges on our farming practices.

Figure 3: Groundwater nitrate-N concentration under farmlets at No 2 Dairy, as affected by rate of N fertiliser application. The recommended maxima for drinking water for humans and cattle of 11 and 30 mg/litre respectively, are shown as horizontal lines.



Procedures to reduce nitrate leaching losses (excluding reduction in stocking rate) include keeping additional N inputs in fertiliser and purchased supplements to a minimum, and managing N fertiliser use to avoid direct leaching losses by:

- confining N fertiliser use to strategic applications
- keeping the rate of N application to less than 50 kg N/ha/application
- avoiding N applications in winter
- not applying N to recently hard-grazed pasture (allow some regrowth before application).

Nitrate leaching losses are generally greatest in free-draining soils and overseas studies have shown lower losses from heavier-textured and poorly-drained soils. Current research involves examining N losses in different soils, and development of models to predict the impacts of different management practices on N losses to assist farmers obtain the most effective use of N fertiliser while minimising impacts on nitrate in groundwater.

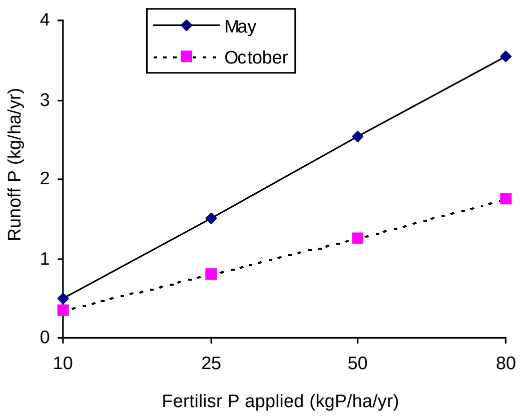
Surface water

Pastoral farming affects surface water quality through the combined effects of erosion, faecal contamination and aquatic plant growth. Growth of aquatic plants and algae in streams, rivers and lakes can be increased through extra N and P inputs. This can adversely affect the aesthetic, cultural, recreational, fisheries, and water-use value of the waters.

Inputs of N to surface waters can occur by runoff from land surfaces (particularly on rolling land with poor-draining soils) and via lateral drainage of groundwater which contains leached nitrate. In the previous section, nitrate-N concentrations in groundwater were compared to the maximum acceptable level for drinking water of 11 mg/litre. However, with surface water the limit for the prevention of undesirable growth of aquatic plants is considerably lower at 0.04-0.1 mg nitrate-N/litre (Ministry for the Environment 1992).

P losses occur via runoff and are mostly associated with erosion of sediment and faeces, with direct losses of fertiliser P being less than 25% of total losses (Thorrold *et al.* 1995). Consequently, the majority of surface water enrichment by P and N is determined by land use and general soil fertility, rather than by fertiliser directly. Nutrient losses may be greater under dairying than other pastoral farming systems because of the greater stocking intensity and higher soil fertility status. A current research programme by AgResearch and NIWA (National Institute of Water and Atmospheric Research), targeted at dairying catchments in Waikato and Southland, is determining nutrient and sediment losses and the overall impacts on surface water quality. This research is being linked with the development of models to predict the consequences of farming practices on water quality in whole catchments. An example of the use of a prototype of a catchment model is given in Figure 4 (discussed later). Ultimately, such models will be used in conjunction with economic production models so that farm management options for managing water quality can be objectively assessed and cost-benefit analyses undertaken.

Figure 4: Effect of time of P fertiliser application on predicted estimates of P runoff from hill country pastures using a water quality catchment model (Thorrold *et al.* 1995).



On-farm management practices can reduce the likelihood of runoff and the enrichment of water draining the farm. Such practices include management of soils to avoid compaction, and maintenance of streamside areas as buffers between the farm and stream to filter sediment and nutrients. Fencing off waterways also prevents direct inputs of excreta and helps control streambank erosion. Trees and shrubs on streambanks can be multipurpose in intercepting runoff, stabilising ground and shading the stream to maintain the habitat for fish and their food. However, in order to achieve these benefits from trees and shrubs it is important to follow appropriate guidelines (eg. Collier *et al.* 1995).

Fertiliser management can reduce the likelihood of direct runoff losses. Timing of P fertiliser application does not affect total pasture responses but it can affect P runoff, with potential losses being greater from application in late-autumn/winter than in spring (Figure 4). This is most evident with capital P applications. Alternatively, split applications could be used. This would also enable the topdressing of recently-grazed paddocks to be avoided, thereby reducing the potential for increased runoff following grazing due to treading effects (Thorrold *et al.* 1995).

Faecal contamination of waterways is being examined in a regional river and stream monitoring programme by Environment Waikato. Data from the past two years indicate that 70% of the sites have levels above Ministry of Health limits to protect direct-contact recreational users (B Huser *pers. comm.*). These levels indicate an unacceptable risk for sickness in recreational users of such waterways. It is believed that dairyshed effluent discharges, farmland runoff and direct defaecation by cattle with access to streams are important sources of faecal contamination in waterways draining dairy farming areas. However, their relative importance is unknown.

Dairyshed effluent application onto pastures, instead of drainage from oxidation ponds, represents a way of reducing the discharge of faecal bacteria and nutrients into waterways, and of recycling valuable nutrients, equivalent to a saving in on-farm fertiliser requirements of 10-12%. Analyses of discharges from oxidation pond systems (Table 4) indicate a low efficiency

Table 4: Average values for water quality variables in dairyshed effluent and in the discharge from oxidation ponds. Data are from a survey by Environment Waikato (Selvarajah 1996).

	Dairy shed effluent	Anaerobic pond discharge	Aerobic pond discharge	(% reduction)
Biochemical Oxygen Demand (ppm)	2000	190	128	(94)
Total P (ppm)	80	30	25	(69)
Total N (ppm)	500	200	100	(80)
Ammonium-N (ppm)	100	150	80	(20)
Nitrate-N (ppm)	0	0	0	
Faecal coliforms (no./100 ml)	2x10^7	1x10^8	3x10^3	(99)

of removal of some nutrients (eg. P). In addition, the BOD (biochemical oxygen demand) may remain above maximum desirable levels (100 ppm in discharge based on current guidelines; or 2 ppm in waterways to prevent sewage fungus growth (Ministry for the Environment 1992)). Ammonia also remains high and a 100-fold dilution by the stream flow is required to avoid toxic effects on fish and other stream life. However, with land-based application systems, it is essential that maximum recommended rates and volumes of effluent application (Environment Waikato 1995) for soils are not exceeded, otherwise leaching of these components through to groundwater and/or increased direct runoff may occur.

Management practices to minimise impacts of farming on ground and surface water quality must be promoted and demonstrated to farmers. Education is more appropriate than legislation. Examples of promoting good environmental management are evident in the Waikato Farm Environment Award and in the Waikato farm study group initiative involving Federated Farmers, researchers and Environment Waikato (Cotman 1996). In both cases, farmers are being directly involved in ensuring that appropriate conditions of practicality, farm profitability and lifestyle are all considered in the process of identifying practical management guidelines to minimise impacts of farming practices on the environment.

Conclusions

Dairy farming may have a wide range of impacts on the environment. Important impacts have been identified on soil quality through compaction of soils, and on water quality through nitrate leaching into groundwater, and runoff of sediments, nutrients and faecal bacteria into surface waterways. However, the key issues affecting these environmental factors are likely to vary between catchments and it is important that these are identified before appropriate remedial strategies are used. Examples of such strategies include:

- avoiding compaction of soils by limiting grazing times during wet conditions
- careful engineering of tracks and bridges to avoid nutrient and sediment runoff into streams
- use of buffer strips between paddocks and waterways, and fencing off waterways
- timing fertiliser applications to avoid periods of high leaching or runoff
- restricting N fertiliser use to strategic applications of less than 50 kg N/ha
- application of dairy shed effluent onto land, rather than into pond systems.

Acknowledgements

We thank Drs N Selvarajah and B Huser from Environment Waikato for provision of data and for valuable discussions.

References

Collier KJ, Cooper AB, Davies-Colley RJ, Rutherford JC, Smith CM, and Williamson RB, 1995. Managing riparian zones: A contribution to protecting New Zealand's rivers and streams. Department of Conservation, Wellington.

Cotman JH, 1996. Farmer perspectives on sustainable farming. Proc. NZ Grassl. Assn. *57: 27-30.*

Environment Waikato, 1995. Changes to Environment Waikato's transitional regional plan; 1. Dairy shed effluent. Environment Waikato Regional Council, Hamilton.

Greenwood PB and McNamara RM, 1992. An analysis of the physical condition of two intensively grazed Southland soils. Proc. NZ Grassl. Assn. *54: 71-75.*

Houlbrooke DJ, 1996. Subsoiling and soil compaction effects on soil physical properties and pasture response. M.Sc. Thesis, University of Waikato.

Ledgard SF, Steele KW, and Feyter C, 1988. Influence of time of application on the fate of ^{15}N-labelled urea applied to dairy pasture. NZ J Agric. Res. 3*1: 87-91.*

Ministry for the Environment, 1992. Water quality guidelines No. 1 - Guidelines for the control of undesirable biological growth in water. Ministry for the Environment, Wellington.

Ministry of Health, 1995. Drinking water standards for New Zealand. Ministry of Health, Wellington: *1-87.*

Roberts AHC, Longhurst RD, and Brown MW, 1994. Cadmium status of soils, plants, and grazing animals in New Zealand. NZ J Agric. Res. *37: 119-129.*

Selvarajah N, 1996. Dairy farm effluent treatment pond performance: A regional survey. Proc. Conf. on tertiary treatment options for dairy shed and piggery wastewaters. Massey University (In press).

Smith CM, Wilcock RJ, Vant WN, Smith DG, and Cooper AB 1993. Towards sustainable agriculture: freshwater quality in New Zealand and the influence of agriculture. MAF Policy Technical Report *93/10. 208 p.*

Taranaki Catchment Commission, 1987. Nitrates in groundwater; Taranaki regional survey. Taranaki Catchment Commission, Stratford: *1-42.*

Thorrold BS, Crush JR and Cooper AB, 1995. Fertilisers and water quality - can fertile land produce clean water? Proc. NZ Fert. Man. Res. Assoc. Conf. (In press).