Client Report

Prepared for Environment Bay of Plenty

June 2004

Land Use Impacts on Nitrogen and Phosphorus Loss and Management Options for Intervention

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Table of Contents

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   i

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   ii

1.   Executive Summary

The amounts of N and P loss from different agricultural land uses are summarised and the main sources of losses are reviewed for the New Zealand scene using literature published up until 2003. Also presented is a summary of the main land management options known to reduce N and P losses.

Of the land use systems considered in this report, the potential for causing nitrate leaching typically follow the order: forestry < sheep/beef/deer farming < arable/mixed cropping < dairy farming < vegetable cropping. Insufficient information is available to establish the order of orcharding and organic farming within this framework.   The lowest nitrate leaching losses are in forestry systems which average about 3 kg N ha^{-1} yr^{-1}, whereas the greatest losses are in intensively managed vegetable cropping systems at an average of 177 kg N ha^{-1} yr^{-1}. In typical dairy farm systems, nitrate leaching losses average approximately 40 kg N ha^{-1} yr^{-1}. The majority of the N leaching occurs during winter when soil drainage is greatest.

In grazing systems, the main source of leached nitrate is from patches of deposited urine, which can have high N concentrations equivalent to between 500 and 1000 kg N ha^{-1} depending on the animal type (e.g. sheep versus cattle). Direct leaching of fertiliser N has only a marginal effect on nitrate leaching under grazing and only when N applications are excessive (>400 kg N ha^{-1} yr^{-1}) or untimely (e.g. $\geq$ 50 kg N ha^{-1} in winter).   In contrast, in cropping systems, the main sources of leached nitrate are from fertiliser N and crop residues that remain in the soil following harvest. In addition, the amount of nitrate leached is greatly influenced by the length of the fallow period following crop harvest and the subsequent timing of cultivation.

To reduce nitrate leaching from these sources a range of management options are available.   These options relate to making improvements to various components of individual land use types, such as: grazing management, cultivation practices, winter crop management and fertiliser N management. In grazing systems, the most significant gains in reducing nitrate leaching from animal urine are achieved by minimising the time animals spend on pasture during winter to reduce urine N inputs. In a dairy system, grazing cows off over winter or the use of a feed-pad during winter can reduce nitrate leaching by up to 60%. Other more novel approaches (e.g. low feed N supplements and nitrification inhibitors) show potential but their role in reducing nitrate leaching has yet to be quantified. In arable cropping systems the timing of cultivation and the presence of a winter cover crop are management strategies which can markedly reduce nitrate leaching.   By cultivating soon after harvest (e.g. late summer) and planting a winter cover crop to utilise released N, nitrate leaching losses can be reduced by up to 80%.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   3

Under vegetable cropping, matching the rate of applied N fertiliser to crop requirements in conjunction with splitting, placement and timing of fertiliser N applications are the best strategies for reducing nitrate leaching. Using this type of tactical fertiliser management can decrease nitrate leaching losses by between 24% and 45% depending on the technique of N application.

Compared to N losses, P losses from agricultural systems are generally much less (e.g. 21-177 versus 0.11-1.60 kg ha^{-1} yr^{-1}, respectively), but can still have a critical impact on the eutrophicaton of surface waters. The main mechanism leading to increased P in waterways is through elevated P concentrations in surface run-off. In contrast, N run-off is minor relative to leaching losses on most soils.

The amount of P in run-off from different land uses has been less researched than N losses. Nonetheless, in general, forestry seems to contribute the least amount of P to waterways, followed by hill country sheep farming. The P losses from forestry systems range from 0.07-0.10 kg P ha^{-1} yr^{-1}, whereas in hill country sheep farms P transfer to waterways is in the range of 0.11-0.75 kg P ha^{-1} yr^{-1}. When cattle are a component of the grazing system (e.g. sheep and cattle systems), P losses can be up to 1.60 kg P ha^{-1} yr^{-1}. However, a recent study showed extreme losses of 10 kg P ha^{-1} yr^{-} from a dairy catchment in an extremely high rainfall area of Westland. Unfortunately, there is only limited information on the amount of P lost from typical dairy and cropping systems (e.g. vegetable cropping). P losses from these more intensive land uses are likely to vary dramatically with differences in animal stocking rate, soil type, topography, cultivation, fallow periods, cover crop and P fertiliser management. Further research is required in intensively managed New Zealand agricultural systems to determine their importance in contributing P to surface waters.

High risk periods for P loss are generally during late winter and early spring when high rainfall and soil moisture often coincide leading to the potential for run-off and P transport. In general, the majority of P (up to 80%) in run-off is in the form of particle-bound P (e.g. bound to sediment or organic material) while less than 20% is present as dissolved P. The main factors affecting the amount and type of P in run-off from different land uses are a mix of edaphic features and farm management practices, and jointly include: topography, soil type, soil P status, animal treading, and fertiliser management. To reduce P losses from agricultural systems appropriate management options are required to minimise the impact of these factors. Five key areas of system management should be targeted: (1) P fertiliser management (2) grazing management (3) riparian management (4) post-harvest crop management (5) whole-system management.

For example, in grazing systems animal treading damage should be minimised so the risk of increased sediment in run-off and increased P in waterways is reduced. This

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   4

could be achieved by winter and spring grazing management strategies that incorporate a stand-off pad (in a non-critical area) to restrict grazing-time on pasture. In cropping systems, where harvesting removes the protective vegetation cover (e.g. forestry, vegetable cropping, and mixed/arable cropping), post-harvest management strategies should be utilised to reduce the potential for surface run-off and erosion during storm events (e.g. zero tillage, cover crops, timing of cultivation).

Many of these management strategies serve a dual purpose in terms of reducing both N and P losses from agricultural systems suggesting that a more holistic approach is worthwhile. At the whole system level, more complete approaches include farm nutrient budgeting and precision farming to integrate the different components of individual agricultural systems. Whole system nutrient budget models can predict the amount of nitrate leaching and P run-off loss based on N and P inputs and outputs while considering the different management strategies of the land use involved. This enables management decisions to be made that will minimise N and P losses to the environment. Similarly, precision farming can assist in minimising N and P losses by considering the spatial and temporal variability of soil attributes and crop characteristics within a farm/field and assist in the decision-making process for selecting and adopting appropriate site-specific levels of management (e.g. critical source areas).

A diagrammatic summary of the main factors affecting N and P losses and mitigation strategies are provided in the following figure (Figure 1).

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   5

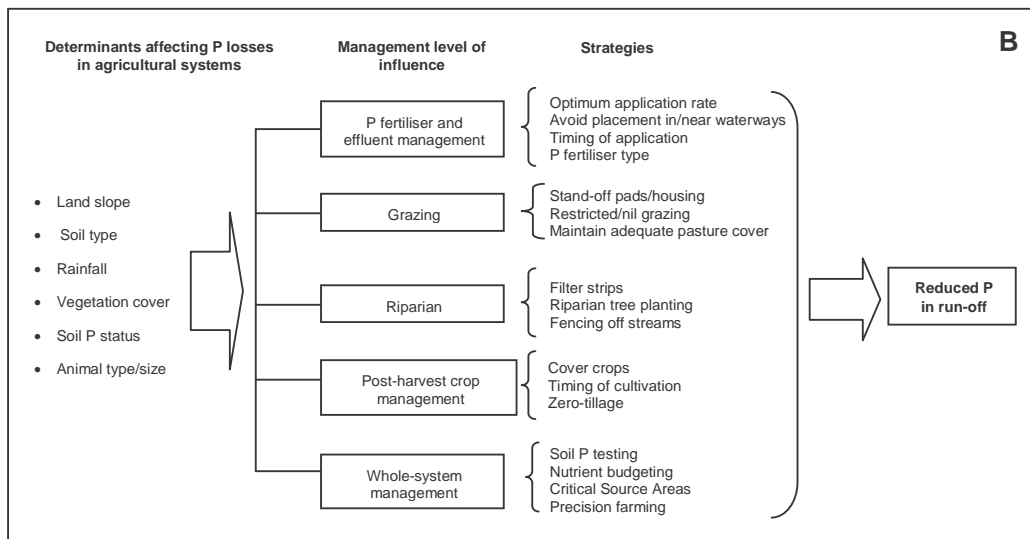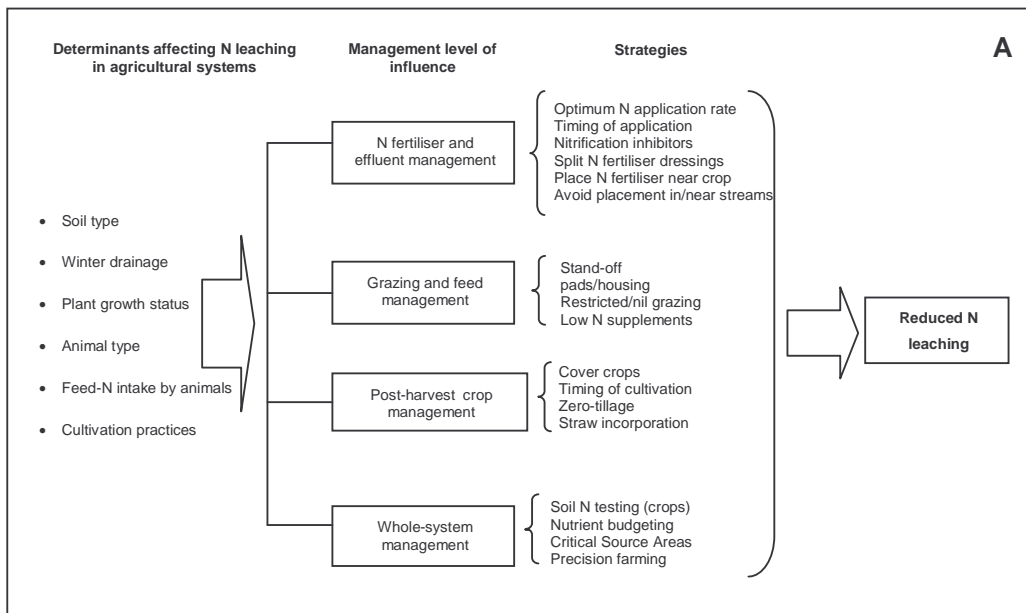**Figure 1:** Main determinants affecting (A) N, and (B) P losses in agricultural systems and key management strategies for mitigating losses.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   6

2. Introduction

In New Zealand there is widespread concern that nitrogen (N) and phosphorus (P) originating from agricultural land is causing contamination of ground and surface waters and leading to nutrient enrichment of our lake systems. Most losses of N and P from agricultural systems are due to the leaching of nitrate (for N losses) and elevated P concentrations in surface run-off (for P losses). The exact amount of N and P lost from agricultural systems varies dramatically depending on the land use type (e.g. dairy versus forestry) and management practices.

In all agricultural systems, N and P are essential elements for plant growth, crop and/or animal productivity and farm profitability. Attempts to reduce N and P contamination to surface waters should therefore centre on implementing specific system management strategies that do not overly compromise the economic viability of the agricultural system.

This report summarises the typical N and P losses from New Zealand farming systems, including sheep and beef, dairy, forestry, mixed cropping, arable and vegetable cropping land uses. It then discusses the major factors that affect their transfer from agricultural land to ground and surface waters, and outlines the management options that are known to reduce N and P losses.

3. Nitrate leaching in different agricultural systems

Agricultural systems can be broadly separated into three groups: those associated mainly with animal production and crop production, and those that have a combination of the two. In this section, the principal land use types associated with these three groups, namely: cattle grazing, sheep grazing, mixed cropping, arable farming, vegetable cropping, orcharding, forestry, and organic farming are discussed with regard to their contribution to nitrate leaching and the principal sources of N loss. In general, with grazing systems the primary source of leached N is from excreted animal urine, with fertiliser N being of secondary importance. In contrast, in cropping systems fertiliser N and crop residues are the main sources of leached nitrate.

3.1 Cattle systems

In cattle grazing systems, N from urine and dung patches and applied fertiliser N are the major potential sources of N loss by leaching from the root zone. Estimates of N leached from pasture vary widely (15-115 kg N ha^{-1} yr^{-1}; Table 1), which is primarily due to differences in farm management (e.g. level of N fertiliser use), seasonal effects on plant growth, and soil drainage. Generally, the greatest N losses measured in grazing systems are those under intensive grazing management (e.g. dairy systems) which produce large quantities of animal excreta and often rely heavily on N fertiliser.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   7

Table 1: Summary of researched N losses from different land uses in New Zealand covering a range of fertiliser N inputs.

Land use type	N leaching loss (kg N ha^{-1} yr^{-1})		References
	Range	Mean	
Market gardening	80–292	177	Williams et al. (2003); Francis et al. (1992 ; 2003).
Dairy pasture	15–115	65	Ledgard et al. (1999, 2000 and unpublished research); Roach et al. (2001); Steele et al. (1984); Monaghan et al. 2000); Silva et al. (1999).
Mixed cropping or arable farming	35–110	61	Francis et al. (1994; 1995); Adams and Pattinson (1985); Ludecke and Tham (1971).
Orcharding	50[a]	50[a]	Ledgard et al. (1992).
Sheep	6–66	21	Brock et al. (1990); Ruz-Jerez et al. (1995); Heng et al. (1991); Magesan et al. (1994, 1996); Burden (1980).
Forestry	3–28	3[b]	Parfitt et al. (1997, 2002, 2003); Magesan et al. (1998).

[a]Single study with Kiwifruit.

[b]Best estimate for undisturbed exotic forestry.

In dairy systems, for example, N leaching of up to 115 kg N ha^{-1} annually has been measured from pasture soils receiving large inputs of urine and fertiliser N (Table 1). Published estimates from research studies of N leaching show large variation from year to year. For example, Ledgard unpublished, measured annual nitrate leaching losses ranging from 25-101 kg N ha^{-1} yr^{-1} over a 5 year period in grazed dairy pasture receiving fertiliser N at 200 kg ha^{-1} yr^{-1}. In the same study, but in the grazed nil fertiliser N control treatment annual nitrate leaching losses ranged from 12-74 kg N ha^{-1} yr^{-1}.

In intensively managed grazing systems, animal urine is the principal source of leached N. The amount of N under a cow urine patch, for example, is equivalent to approximately 1000 kg N ha^{-1}, and is in a form that is readily converted to nitrate. These N levels are well above the N uptake requirements of pasture and consequently significant leaching losses can occur. In particular, during winter when soil drainage is high, and plant growth and N uptake are slow, more accumulated nitrate from urine is leached than at other times of year. Winter leaching of N can be further exacerbated by dry summer conditions and an associated slowing down of plant growth, which results in a build-up of

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   8

nitrate levels in soil by autumn. In comparison to urine N, dung N is mostly in slowly-available organic forms and is far less susceptible to leaching.

The amount of fertiliser N (or effluent N) applied to pasture affects the amount of nitrate leaching loss. Ledgard et al. (1999, 2000) showed that leaching losses under intensive dairy grazing was much lower (by about 50%) at an annual application rate of 200 kg N $ha^{-1} yr^{-1}$, compared to 400 kg N $ha^{-1} yr^{-1}$ (Figure 2). In that study, the greater importance of urine N compared to fertiliser N in contributing to nitrate leaching was clearly highlighted. Direct N leaching from fertiliser N was only evident in significant amounts at the higher N application rate (400 kg N $ha^{-1} yr^{-1}$) where soil N availability was obviously in excess of plant N demand. At the N application rates of 200 and 400 kg N $ha^{-1} yr^{-1}$, the larger contribution of urine N to leaching (c.f. 0 kg N $ha^{-1} yr^{-1}$) was due to increased urine inputs resulting from greater animal intake of the N-stimulated pasture. Thus, as total N inputs to pasture increases (e.g. by N fertiliser or legume N_2 fixation) a greater amount of N is cycled through grazing animals which leads to increased nitrate leaching. A recent summary (Ledgard, 2001a) of data from New Zealand and overseas studies has shown that nitrate leaching increases exponentially with increased N inputs (Figure 3).

For the New Zealand scene, published data from research studies on N leaching from cattle grazed systems indicates a range of 15-115 kg N $ha^{-1} yr^{-1}$ with an average of 65 kg N $ha^{-1} yr^{-1}$. However, most of these studies included high rates of N fertiliser and the average fertiliser N use of a New Zealand dairy farm is only approximately 100 kg N $ha^{-1} yr^{-1}$. Therefore the typical N loss is approximately 40 kg N $ha^{-1} yr^{-1}$. Furthermore, this suggests that within farm systems, opportunities to achieve reductions in nitrate leaching from pasture soils lie only to a small extent in sound fertiliser management (section 4.3), but mainly by strategic grazing management strategies (see section 4.1) to minimise urine additions to pasture.
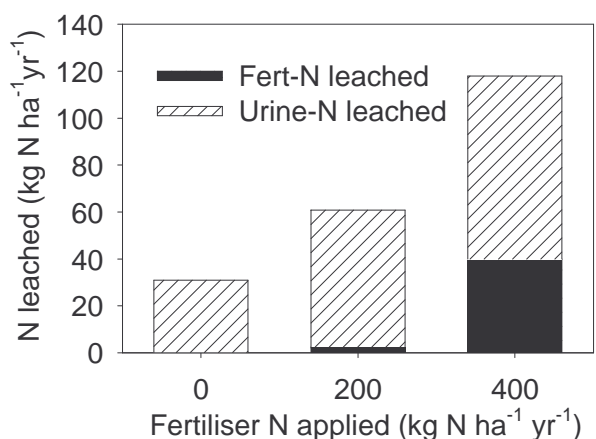
Figure 2: Effect of rate of N fertiliser application on nitrate leaching in dairy pasture stocked at 3.3 cows ha^{-1} (Ledgard et al., 1999, 2000).

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   9
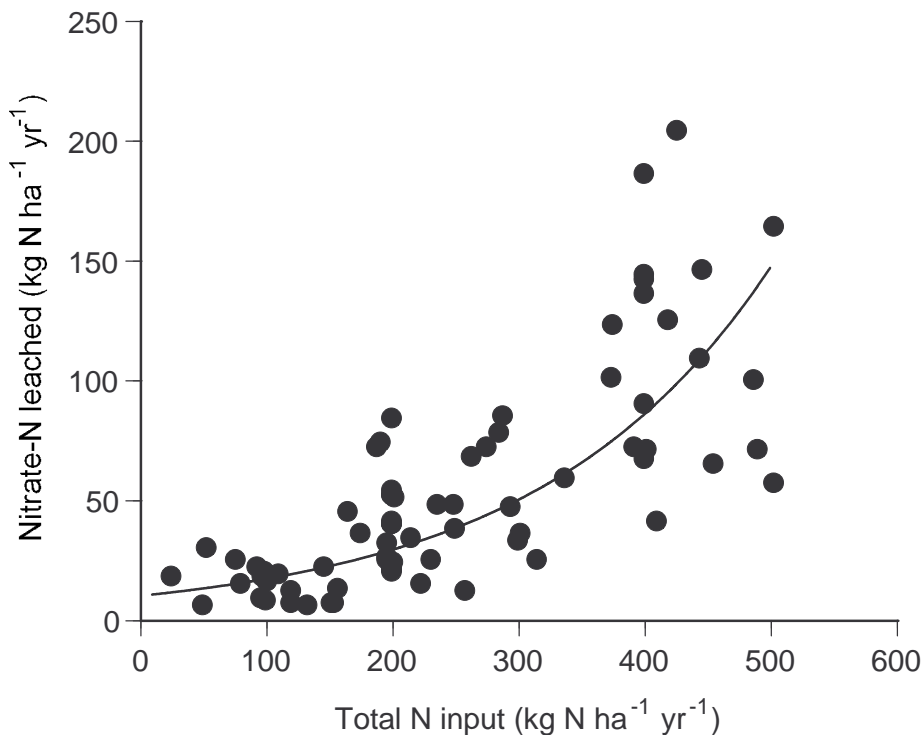
Figure 3: Nitrate leaching from grazed pasture systems as affected by total N input from N_2 fixation and/or N fertiliser application. Data are a summary of studies in New Zealand, France, and the United Kingdom. The line of best fit is an exponential function obtained by fitting the data on the log scale (Ledgard, 2001a).

3.2 Sheep Systems

For sheep-grazed pastures, annual nitrate leaching losses (e.g. 6-66 kg N ha^{-1} yr^{-1}; Table 1) are generally lower than for cattle. This is mostly because sheep have a smaller bladder and urinate more often in smaller volumes, and partly because low amounts of fertiliser N are used on sheep farms (e.g. 20 kg N ha^{-1} yr^{-1}; Morton et al., 1993). Consequently, the N loading rate under a sheep urine patch is lower (about 500 kg N ha^{-1}) than under cattle urine patches (1000 kg N ha^{-1}). However, due to the strong camping behaviour of sheep (e.g. beneath trees, around gateways, and on ridges and hill crests in hill country pastures) areas of pasture can have greater N loadings and potential for leaching, or losses via run-off in hill country. For example, measurements in hill country show that 60% of the dung and 55% of the urine are deposited on campsite areas that occupy 15-31% of the land area (Saggar et al., 1988). Notwithstanding, losses of N in

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   10

run-off from hill country sheep pastures are low, ranging between 2 to 11 kg N ha^{-1} yr^{-1} (Lambert et al., 1985; Sharpley et al., 1983).   To date, no research has investigated the significance of N losses via nitrate leaching from sheep camping areas in hill country pastures.

On lowland sheep pastures, animals are often managed more intensively, and because of this there is less tendency for animals to camp.   Thus, N losses occur principally from the leaching of nitrate from the surface soils rather than by run-off.   In these more intensive sheep systems research has shown high losses of up to 66 kg N ha^{-1} yr^{-1} (Table 1) under high N fertiliser use.   However, in New Zealand a more typical estimate of N leaching for a sheep and beef farm is approximately 10-20 kg N ha^{-1} yr^{-1}.

3.3   Mixed cropping and grazing

In mixed cropping systems in New Zealand, grass/clover pasture is usually grown in 2-5 year rotations that alternate with an arable crop.   The main arable crops are wheat, barley, oats, peas and maize (Dunbier and Bezar, 1996).   There are considerable differences in the way that these crops are grown and managed (e.g. cultivar, cultivation practices, crop rotation, and crop residue management practices) which affect the amount of N leached (e.g. 35-110 kg N ha^{-1} yr^{-1}; Table 1).

Normally, the amount of N leached from mixed cropping systems is related to the timing of cultivation and the release of N from soil organic matter (e.g. Haynes and Francis, 1990).   During the pastoral phase of the rotation, considerable N is stored in soil organic matter within the soil surface layers.   When pastures are cultivated in preparation for planting the arable crop, a large amount of this soil organic N and pasture residue is converted by soil bacteria through a process called N mineralisation into potentially leachable forms of N.   For example, if pasture is ploughed in late summer and left fallow over winter up to 110 kg N ha^{-1} of the N released by mineralisation is leached as nitrate from the root zone (Francis et al., 1994; Ludecke and Tham, 1971).

After 2-3 years of arable cropping without fertiliser inputs leaching losses of nitrate are apparently relatively low (30-40 kg N ha^{-1}, Francis et al., 1994).   However, by this time the N fertility of the soil has declined to such an extent that fertiliser N additions are necessary to achieve reasonable yields, or alternatively, the soil is returned to the pastoral phase of the rotation to enable soil organic N to rebuild.

Another factor apparently not previously considered in mixed cropping systems is the common practice of grazing stubble or plant residue by livestock.   This practice could potentially contribute leached N from urine patches since no N is being removed from soil by plant growth.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   11

3.4   Arable Farming

Arable cropping differs from mixed cropping in that crops are usually grown continuously without any intervening pastoral phase. Leaching losses between 30-60 kg N ha^{-1} are not unusual, but could be greater when fertiliser N is applied at more than 200 kg N ha^{-1} yr^{-1} (Haynes, 1997). Most of the nitrate leaching occurs between autumn and spring, and is derived mainly from crop residues following harvesting in late-summer. During the fallow period after harvesting, nitrate in soil accumulates and is prone to leaching since there is no vegetation to take up N from the soil. When the soil is cultivated, mineralisation of soil organic N may be further stimulated, thus compounding the problem.

To maintain economic crop production in arable systems, fertiliser N applications of about 200 kg N ha^{-1} yr^{-1} are usually applied to meet crop N demands. Applications of N are usually carried out as one or two large additions rather than frequent small ones. However, since fertiliser N is mostly applied during periods of rapid plant growth and N uptake (e.g. late-spring to summer), the potential for fertiliser N leaching during the growing season is usually low, unless N applications are excessive and there is high water input (Di and Cameron, 2002a). By harvest-time, previously spring-applied fertiliser N has mainly been incorporated into plant tissue with very little remaining in soil. For example, after a crop of wheat about 30-60 kg N ha^{-1} may be present as mineral N in soil (Haynes, 1997), some of which is from the applied fertiliser N, and some from soil organic N. During the fallow period following harvest, an additional 20-30 kg N ha^{-1} is mineralised from soil organic N and plant residue (e.g. roots and stubble) before cultivation in autumn (Di and Cameron, 2002a; Haynes, 1997). Thus, by the commencement of the winter leaching season soil mineral N may be as high as 90 kg N ha^{-1}, representing the primary source of leachable N before replanting occurs in spring.

3.5   Vegetable Cropping

On a per unit area basis vegetable cropping systems (or market gardening) produce by the far the largest nitrate leaching to groundwater than any other land use type. Leaching losses of up to 321 kg N ha^{-1} yr^{-1} have been recorded in New Zealand, but typically leaching losses range from 80-292 kg N ha^{-1} yr^{-1}, depending on the amount of rainfall and the type of crop grown (Table 1). The main factors responsible for nitrate leaching in these systems are: high N use (fertiliser and manure), frequent cultivation, relatively short periods of plant growth, low nutrient use efficiency by many vegetable crops, and crop residues remaining after harvest (Di and Cameron, 2002a).

Compared to other agricultural systems, market gardens are the most intensively fertilised and cultivated production systems - hence their propensity to leach N. Fertiliser

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   12

N application rates used in vegetable crops can be as high as 600 kg N ha^{-1} yr^{-1} (Wood, 1997). Large application rates are used to ensure maximum growth because vegetable crops have sparse root systems that are inefficient at recovering applied fertiliser. Also, vegetables typically have short growing periods and are also grown over winter when plant growth and N uptake is slow (Haynes and Francis, 1996; Haynes, 1997). Therefore, the recovery of applied N by vegetable crops is often less than 50%, and can be as low as 20% (Di and Cameron, 2002a). Consequently, a large quantity of fertiliser N remains in the soil surface layers and is susceptible to leaching during rainfall or irrigation. Additionally, following crop harvest large amounts of plant residues are usually incorporated into the soil which, following decomposition, release mineral N into soil. The amount of mineral N derived from fertiliser and crop residue that is present in the soil after harvest can be as high as 200-300 kg N ha^{-1}, and is the major source of leached N, indicating that fertiliser N management strategies are the key to nitrate leaching intervention in these systems (see section 4.3).

3.6 Orcharding

Little is known about the significance of nitrate leaching from horticultural systems (e.g. orchards and vineyards). In one study (Ledgard et al., 1992), nitrate leaching losses from a kiwifruit orchard were about 50 kg N ha^{-1}. N leached from these systems (which are normally not cultivated and have grassed rows) will be derived primarily from applications of fertiliser N and possibly from rejected fruit and leaf litter. The quantity of fertiliser N used in horticultural systems varies widely depending on the particular requirements of different crops (Clarke et al., 1986).

In New Zealand, common horticultural enterprises include pip and stone fruit orchards (e.g. kiwifruit, apples and peaches), and vineyards for wine production. Many of these systems apply fertiliser N and irrigation simultaneously to meet plant N demands and to boost fruit size. The amount and type (e.g. trickle vs. sprinkler) of irrigation is likely to have a significant influence on the amount of nitrate leaching. Most irrigation occurs in the spring-summer period when leaching losses would normally be expected to be minimal. However, this would depend on the amount of N applied, plant utilisation of fertiliser N, and soil drainage. Other factors that will affect N losses in horticultural systems are the frequency of cultivation and the presence of cover crops compared with bare ground. Both frequent cultivation and bare ground between rows will have the effect of increasing mineralisation of soil organic N and releasing the potentially leachable nitrate N.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   13

3.7 Forestry

For New Zealand forest systems little information exists regarding the amount of N lost via leaching to the environment. Nonetheless, indications are that water draining from established forest plantations contains only low levels of nitrate amounting to about 3-28 kg N ha^{-1} yr^{-1} (Table 1). Relatively high nitrate leaching (e.g. 20-28 kg N ha^{-1} yr^{-1}; Parfitt et al. 2002) is usually associated with pine forests grown on certain volcanic soils that have a naturally high N status. More commonly, nitrate leaching losses of between 3-5 kg N ha^{-1} yr^{-1} occur in undisturbed exotic forests grown in New Zealand (e.g. Parfitt et al., 1997; Magesan et al., 1998).

The greatest potential for nitrate leaching from forestry systems probably exists when pasture is first converted to forest, and then later when the forest is felled. Recent studies (e.g. Parfitt et al., 1997), have shown that the high level of soil organic N present in established pastures decreases markedly when the pasture is planted in pine forest. This would reflect the mineralisation of soil organic N to other forms of N, some of which are potentially leachable. Possible outcomes for this released N would include: N uptake by plants, leaching, or denitrification. Recently, nitrate leaching (to below 250 mm soil depth) from a newly converted pasture-pine plantation was measured at approximately 18 kg N ha^{-1} over 15 months (Parfitt et al., 2002).

At forest harvest, the clear-felling of trees and subsequent mineralisation of harvest residues leads to a build-up of soil organic N and can increase nitrate leaching (Dyck et al., 1981; Parfitt et al., 1998). However, the amount of N leached is usually low, and has been estimated to be <10 kg N ha^{-1} yr^{-1} for the first 2 years after clear-cutting of pine forest (Dyck et al., 1981; Parfitt et al., 1997; Smith et al., 1994). Even taking into account differences in nitrate leaching losses associated with forest establishment, maturation, and harvesting, forest systems appear to be the least prone to leach nitrate compared to other land uses. The exception could be in forestry systems receiving waste effluent or fertiliser N (e.g. aerial topdressing) where the amount of nitrate leaching losses are unknown but are probably higher than unfertilised forests, as indicated by studies using intact soil cores (e.g. Magesan et al., 1998). In the study by Magesan et al. (1998), nitrate leaching losses from large soil cores collected from a forest that had received municipal wastewater irrigation on a weekly basis for 4 years and were subjected to continuous simulated rainfall, amounted to 11 kg N ha^{-1} compared to 3 kg N ha^{-1} from soils receiving no wastewater irrigation.

3.8 Organic Farming

Organic farming is often touted as being a solution to reducing N losses since synthetic N fertilisers are not used in these systems. However, this is usually counteracted by the

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   14

heavy use of animal manures and the ploughing-in of legume-based pastures or legume crop residues in cropping systems which would lead to nitrate leaching.

Although, no New Zealand studies have compared organic and conventional farms and determined the level of nitrate leaching losses, overseas research has shown that in many cases the quantity of nitrate leached between systems is similar – or in some cases greater in organic systems. To more fully understand N dynamics and nitrate leaching in organic systems and the impact of different management practices (e.g. types of animal manure used and tillage practices) further research is required.

It has been postulated that legume-based pastures (e.g. grass/clover pastures), which rely on N fixed by the legume, are less vulnerable to nitrate leaching than grass pastures receiving high rates of fertiliser N. However, studies in grazed dairy pastures by Sprosen et al. (1997) measured similar N leaching from N fertilised grass pastures and clover-based pastures with similar N inputs (from fertiliser or clover N_2 fixation).

4. Management options for reducing nitrate leaching

Management strategies for reducing nitrate leaching losses from agricultural systems should target four main areas of system management: (1) grazing management, (2) post-harvest management in cropping systems, (3) N fertiliser management, and (4) whole-system management. Depending on the type of agricultural system, the main aims are to reduce nitrate leaching by controlling fertiliser N use (e.g. vegetable cropping) and urine inputs to soil (e.g. grazing systems), and to minimise the accumulation of soil N following crop harvest and cultivation (e.g. arable/mixed cropping systems).

It should be made clear that implementing alternative management strategies to mitigate N (or P) losses need not necessarily be associated with decreased intensification of agricultural systems or reduced farm productivity. In fact, some management strategies can enhance overall nutrient-use efficiency by plants and animals and increase production while minimising losses of N and P. For instance, strategic use of a feed-pad during winter in dairy systems and the subsequent irrigation of collected excreta onto paddocks can increase pasture growth and milk production while markedly reducing nitrate leaching (de Klein et al., 2000).

4.1 Strategic grazing and farm management practices

In pastoral systems, the primary aim of management intervention should be to reduce the amount and/or concentration of urine N deposited on pasture to lower the risk of nitrate leaching. This is achievable by altering grazing management and feeding practices to improve the N use efficiency of grazing animals and pasture. Some marginal gains in reducing nitrate leaching can also be had by careful fertiliser N management.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   15

4.1.1 Nil grazing or restricted grazing systems

Recent studies suggest that both nil and restricted grazing systems can reduce nitrate leaching (de Klein et al., 2000). Under both management types, animals are kept off paddocks and the pasture is harvested and fed to the animals in a housing shed or on a feed-pad. With restricted grazing, animals are kept off paddocks when the risk of nitrate leaching is greatest (e.g. late-autumn/winter). The animal excreta is collected from the housing shed/feed-pad and applied evenly to the pasture by irrigation. In several recent studies (e.g. Figure 4; Chadwick et al., 2002; de Klein et al., 2000) on Taranaki and Southland dairy farms, nitrate leaching was reduced by 50-60% (e.g. from 28 to 14 kg N ha^{-1} in Taranaki) when animals were on a feed-pad for four months during late-autumn-winter compared with year-round grazing.
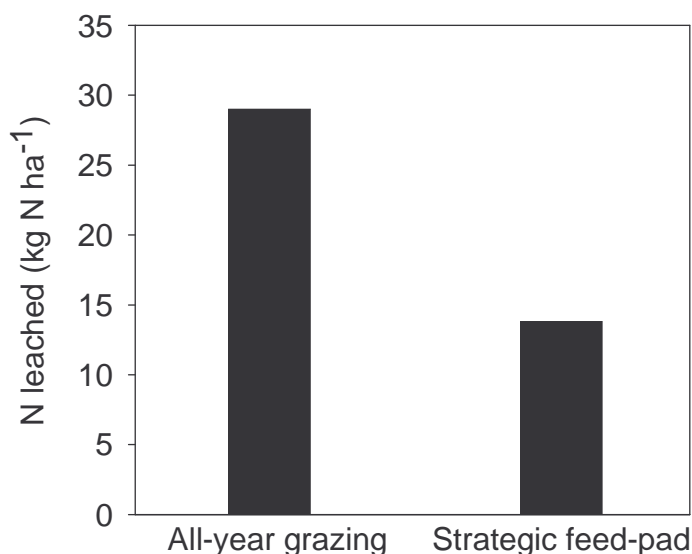
Figure 4: Effect of grazing management on nitrate leaching in a dairy farmlet study in Taranaki, New Zealand (Chadwick et al., 2002).

More recently, research on a Taupo dry-stock farm (Ledgard et al., unpublished) has shown that strategic de-stocking of cattle during autumn and winter can also have a positive effect by reducing the amount of nitrate leached from extensive grazing systems. Although this research is only in the preliminary stages, avoiding winter grazing was shown to reduce N leaching by 60% (from 13 to 5 kg N ha^{-1}). A similar reduction in N leaching was also gained from not grazing for the entire year (e.g. cut and carry system). Currently, only a few intensively managed dairy systems (e.g. dairy goats and cows) operate full year cut and carry systems in New Zealand. This is because of the large labour requirement and housing costs involved, which in most cases makes cut and carry systems not economically sustainable. As yet no field studies have investigated the potential benefit of continuous cut and carry for reducing nitrate leaching in dairy

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   16

systems. Given the greater costs associated with this type of intensive management it is unlikely to be a realistic management option for many farmers, especially if similar gains in reducing nitrate leaching can be achieved by partial restrictions on grazing (e.g. winter feed-pad use).

4.1.2   Low-N feed supplements

Using feed supplements such as maize silage as an alternative to using fertiliser N boosted grass lowers the amount of N excreted in urine and could reduce nitrate leaching (Ledgard et al., 2000, 2001b). The total N concentration of maize silage is typically less than half that of N-stimulated pasture. However, the production of maize for silage is also associated with high nitrate leaching through cultivation and N mineralisation, which could offset any benefit that maize supplements have for reducing nitrate leaching under grazing. Further research is required to evaluate if astute cultivation practices (see section 4.2) that reduce nitrate leaching losses under maize, and the use of that maize as a low N supplement, would result in an overall benefit to the farm system as a whole in terms of reduced nitrate leaching. Nevertheless, the benefit in reduced N leaching per kg milksolids could be achieved in a sensitive catchment if the maize crop is grown in non-N-sensitive areas.

4.1.3   Reduced stocking rate

There is a common perception that reducing the stocking rate will lead to a decrease in the amount nitrate leaching from pasture. However, this is only possible if the lower stocking rate results in a decrease in the amount of urine N excreted onto pasture. Often, at lower stocking rates more pasture is available for animal intake which means that N intake, N excretion and nitrate leaching may in fact be similar to higher stocking rates. Indeed, Sprosen et al. (2002) measured a trend for increased N leaching with decreased stocking rate in dairy farmlets with the same feed availability and attributed it to differences in patterns of N excretion and increased compaction and gaseous N losses with higher stocking rates. To achieve reduced N losses by lowering stocking rates a corresponding reduction in fertiliser N or supplementary feed inputs would also have to be made, and this will inevitably lead to a reduction in farm productivity. Thus, reducing animal numbers to mitigate losses of nitrogen does not always present itself as an economically viable management option.

4.1.4   Biochemical inhibitors to reduce nitrification

Certain chemicals (e.g. dicyandiamide) are available that inhibit the conversion of soil ammonium-N to nitrate-N by soil bacteria (the process of nitrification) which reduces nitrate accumulation in the soil surface layers. Potentially, nitrification inhibitors could be applied to pasture soils to slow down the production of nitrate from urine patches, thus

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   17

reducing nitrate leaching. In experiments using large intact soils cores, applied dicyandiamide has been shown to reduce nitrate leaching from a single urine application by between 40% and 76% depending on the season (spring or autumn) of treatment application (Di and Cameron, 2002b). These results are preliminary findings only, and represent the maximum potential benefit and require further validation and testing under field conditions.

Table 2: Relevant strategic management options for reducing N losses from different land uses in New Zealand

Management level	Management strategy	Percentage decrease in N leaching from control	Some relevant references
Grazing management	Restricted grazing	30-60%	Ledgard et al. (1999, 2000 and unpublished research); Steele et al. (1984); Monaghan et al. 2000); Silva et al. (1999); Sprosen et al. (2003).
	Zero grazing	50-60%	
	Low N supplements	not known	
	Reduced stocking rate	minimal	
Post-harvest management in cropping	Timing of cultivation	60-80%	Francis (1994); Adams and Pattinson (1985); Ludecke and Tham (1971).
	Cover crops	60-80%	
	Straw incorporation	not known	
	Zero-tillage	not known	
Fertiliser management	Limit N application rates	10-40%	Williams et al. (2003); Di and Cameron (2002b); Spiers (1996) Ledgard et al. (1992, 1996a).
	Limit N use in winter	up to 30%20-50%	
	Inhibitors		
	Split dressings	up to 45%up to 24%	
	Placement of fertiliser		
Whole farm management	Precision farming	not known	
	Nutrient budgeting	50-60%	Wheeler et al. (2003).

4.2   Post-harvest management in cropping systems

The best opportunity to reduce N losses from cropping systems exists in implementing management strategies to avoid the build-up of soil mineral N following crop harvest and during fallow periods. This can be achieved through the removal of mineralised soil N by plants and soil bacteria (called N immobilisation) and timely cultivation to minimise build-up of mineralised N.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   18

4.2.1   Cover crops

Planting cover crops (in autumn and winter) after harvesting has been shown to decrease nitrate leaching compared to soil left fallow. Cover crops are particularly beneficial in late winter because plant uptake of N reduces the amount of mineral N in the soil at a time when drainage is often high and soils are most prone to N losses. In New Zealand, research (Francis, 1995; Francis et al., 1998) has shown that to maximise plant N uptake from soil and reduce the risk of nitrate leaching, cover crops (e.g. lupins and oats) are best planted in early autumn. Using this approach, Francis (1995) showed that plant growth and N uptake was rapid going into winter, and this reduced nitrate leaching by between 60 and 80% (e.g. from 23 to 5 kg N ha^{-1}) depending on the amount of rainfall and subsequent soil drainage. Other studies (Francis et al., 1995; McLenaghen et al., 1996) have shown various winter cover crops can have different impacts on reducing nitrate leaching depending on plant type. For example, ryegrass and ryecorn (*Secale cereale*) were found to be more effective at reducing nitrate leaching compared to field beans (*Vicia faba*) and lupins (*Lupinus augustifolius*) (McLenaghen et al., 1996; Figure 5). Under ryegrass, nitrate leaching was only 2.5 kg N ha^{-1} compared with 33 kg N ha^{-1} in fallow soil. Legumes (e.g. lupins and beans) derive some of their N from N_2 fixation so are less effective at reducing soil mineral N compared to non-legumes.

If cover crops are grown during winter then care must be taken in the management of their residues (Francis, 1995). The incorporation of cover crop residues often stimulates the soil bacteria to immobilise N because of the large amount of carbon relative to nitrogen (C:N ratio) in the residue. This can reduce soil mineral N availability which depresses the yield and N uptake of the subsequent spring sown crop. Francis (1995) suggested that this problem could be overcome by grazing cover crops once or twice during winter before incorporation in spring, which increases the N in soil via excreta and by stimulating net N mineralisation. However, this practice could lead to increased nitrate leaching from urine patches since there is no crop immediately present to utilise the excreted N. An alternative, and more tactical approach, would be to apply a strategic application of fertiliser N (e.g. 50 kg N ha^{-1}) to overcome the depressed yield and N uptake of the spring sown crop (Francis, 1995) (see section 4.3). In this situation, soil and plant tissue analysis would give an indication of the amount of soil N available for release to plants and assist in determining the fertiliser N requirement before crop yield is overly affected.
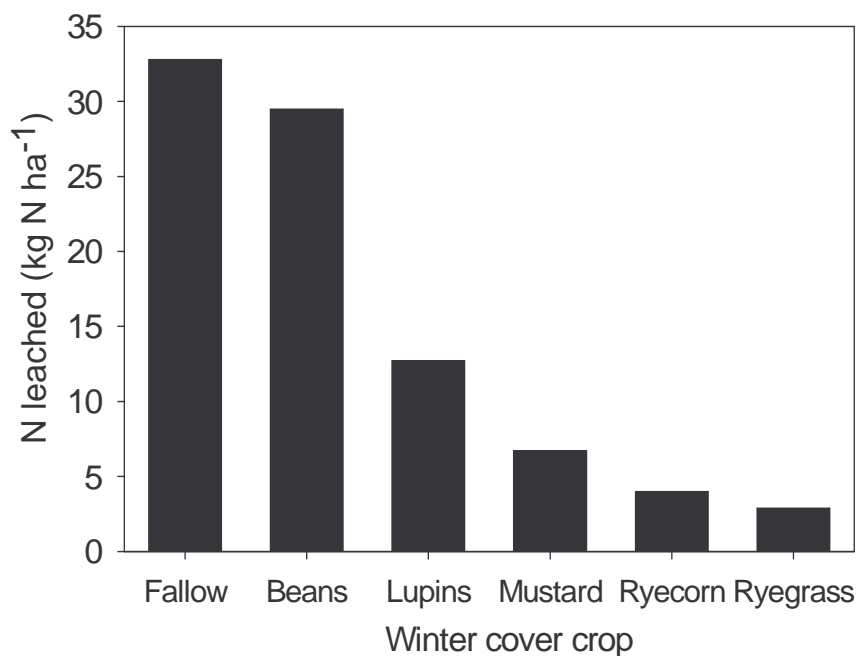
Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   19

Figure 5: Nitrate leaching losses under different winter cover crops compared with that under fallow after cropping in Canterbury (McLenaghen et al., 1996).

4.2.2 Timing of cultivation

Selecting the optimal timing for cultivating soil following crop harvest or when pasture is converted to cropping, has a major influence on the resulting amount of nitrate leaching in cropping systems. If pasture is ploughed in late summer or early autumn and left fallow, then there is ample time for N mineralisation to occur, resulting in the accumulation of mineral N in the soil profile before the winter leaching season (Haynes, 1997). Ploughing later (e.g. late autumn) will shorten the period of N mineralisation and can reduce nitrate leaching. This is partly due to the lower soil temperatures in late autumn which reduces the activity of bacteria that carry-out N mineralisation as well as the length of the fallow period between ploughing and winter leaching.

In Canterbury, Francis (1995) found that early ploughing in March followed by a period of fallow resulted in large amounts of nitrate leaching (72–106 kg N ha^{-1}) during winter. When ploughing was delayed until May the amount of nitrate leached was much less (8-52 kg N ha^{-1}). In that study, nitrate leaching losses were reduced by the late ploughing and shorter fallow period, resulting in lower soil mineral N in levels and a reduction in the total amount of drainage in the soil profile before the start of leaching.

4.2.3 Biochemical inhibitors to reduce nitrification

In cropping systems, using a nitrification inhibitor (e.g. dicyandiamide, DCD) has the potential to reduce nitrate leaching compared with fallow soil (Francis, 1995). Research

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   20

has shown that applying DCD to pasture prior to ploughing in mixed cropping systems can decrease the accumulation of nitrate in the soil surface layers and reduce N leaching losses (by between 25% and 50%; Francis, 1995). Francis (1995) showed that the most effective time to apply the DCD was when pasture was ploughed early in autumn (rather than in early winter), to give a longer period of inhibition and for the accumulation of the less leachable form of N, ammonium-N. This tactic had no effect on the yield of the following spring crop, and in fact the accumulated soil mineral N was almost fully removed by the subsequent crop (Francis, 1995). However, Francis (1995) also showed reductions in N leaching by at least the same magnitude by better timing of cultivation (section 4.2.2).

4.2.4   Incorporation of straw into soil

Incorporating cereal straw at the ploughing stage in autumn is sometimes assumed to reduce nitrate leaching. This is due to the high C:N ratio in the straw that encourages soil bacteria to immobilise N as the straw is decomposing. However, various overseas studies (e.g. Thomsen and Christensen, 1998) have had mixed results using this practice, with some finding minimal benefits for reducing nitrate leaching (Catt et al., 1998). The reason for these different results will be related to the effect of incorporated straw on N mineralisation, probably because of differences in the N content of straw types, increases in the soil organic N pool over time, and a build-up of organic matter over the long-term that balances out the processes of mineralisation and immobilisation. In New Zealand, further research is required to increase our understanding of the N dynamics following straw incorporation and its impact on nitrate leaching.

4.2.5   Conventional tillage versus zero-tillage

Several New Zealand researchers have shown that direct seed drilling (zero-tillage) compared with conventional cultivation and sowing can slow N mineralisation and potentially reduce nitrate leaching (e.g. Francis and Knight, 1993; Francis, 1995). However, limited overseas research has shown contradictory results with higher and lower nitrate leaching losses observed under direct drilling compared with conventional cultivation (Meek et al., 1995; Turpin et al., 1998). These inconsistencies may be due to improved soil structure under zero tillage which would allow rapid bypass flow of drainage water down macropores to below the root zone (Di and Cameron, 2002a). The usefulness of direct drilling compared to conventional cultivation for reducing nitrate leaching still needs to be more fully assessed under New Zealand conditions.

4.3   Strategic use of N fertiliser in agricultural systems

Efficient fertiliser use can have a major influence on N losses, especially in cropping systems. The key aim of farmers should be to improve the efficiency of fertiliser N use by

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   21

plants by considering climatic factors (e.g. rainfall and soil drainage) and seasonal patterns of plant growth, and selecting an appropriate fertiliser N management to optimise plant N uptake and minimise nitrate leaching losses.

4.3.1 Limit N fertiliser use during winter leaching

Limiting the amount of N fertiliser applied prior to or during autumn-winter when evapotranspiration by pasture is low and soil drainage is high decreases the risk of nitrate leaching (Di and Cameron, 2002a). In New Zealand, slow pasture growth in winter may result in a shortage of feed for grazing animals and is sometimes remedied by the application of N fertiliser (or effluent) to stimulate growth. This practice should be carried out with caution and only limited amounts of N applied to pasture so that the chances of surplus N in the root zone and the potential risk of nitrate leaching are lessened (O'Connor, 1982).

Ledgard et al. (1988) showed that leaching of fertiliser N applied to pastures in winter can result in direct leaching of up to 30% and a relatively low pasture growth response. They noted that applying N in autumn results in larger pasture responses to N, which can be carried through for winter grazing, and minimises direct leaching of fertiliser N.

4.3.2 Limit N application rates

Reducing the rate of N application in high N use systems (e.g. vegetable cropping and dairy farming) can help alleviate the problem of nitrate leaching (Ledgard et al., 1999; Williams et al., 2003). Optimum levels of N fertiliser, however, will depend on the particular production system concerned. In grazing systems (e.g. dairy farms), if application rates do not exceed about 200 kg N ha^{-1} yr^{-1} and are synchronised with pasture growth, then direct N losses from N fertiliser are negligible (e.g. Ledgard et al., 1999, 2000).

In vegetable cropping systems, N losses from fertiliser are the main source of leached N (c.f. grazing systems). Thus, limiting N application rates in these systems can have a major impact on reducing nitrate leaching. This was shown recently (Williams et al., 2003) under winter spinach where lowering fertiliser N application from 400 to 200 kg N ha^{-1} yr^{-1} decreased nitrate leaching by up to 40% (from 167 to 105 kg N ha^{-1}). However, as a consequence, spinach yield decreased by 20%, and this would have to be considered when assessing the feasibility of adopting lower fertiliser N application rates under vegetable cropping.

Finally, in agricultural systems that apply waste effluent to land a significant component of the effluent N is absorbed by plants. Hence, any fertiliser N applications should be adjusted to take into account the N loading of the applied effluent.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   22

4.3.3   Tactical N use to meet plant N demands

A strategy to avoid mineral N accumulation in the soil surface layers and reduce nitrate leaching is to synchronise N supply with plant growth and N demand. This strategy requires a sound understanding of the seasonal patterns of plant growth so that fertiliser N can be applied at a time when plants are growing vigorously and are able to utilise most of the applied N source. To be most effective, soil and plant tissue analysis is necessary to give an indication of the amount of soil N available for release to plants and to estimate the fertiliser N requirement (Di and Cameron, 2002a). In practice, the annual fertiliser N application rate is usually split into a number of applications that match plant growth and N demand. In a vegetable cropping system with winter spinach, Williams et al. (2003) recently showed that when 400 kg N ha^{-1} yr^{-1} was split into 3 applications of 40, 200, and 160 kg N ha^{-1} and timed to synchronise with crop growth, nitrate leaching losses were 135 kg N ha^{-1} compared to 246 kg N ha^{-1} when the annual fertiliser was split into only 2 less timely applications (350 and 50 kg N ha^{-1}). N loss reductions of this magnitude are less likely to occur in grazing systems where the main source of leached nitrate is from urine patches. In addition, it is common for dairy farmers to apply N fertiliser in split dressings (typical maximum of 50 kg N ha^{-1} per application) at different amounts depending on the season and pasture growth.

An alternative strategy to tactical N use is to apply a slow release N fertiliser which gives a more gradual supply of N to soil for plant uptake than a conventional fertiliser. This may prevent N accumulation in soil and potentially reduce the amount of nitrate leaching (e.g. Deiz et al., 1994; Martin et al., 2001). The difficulty with this technology is matching the release characteristics of the fertiliser with that of plant N demand, which could affect plant production and make the adoption of slow release fertilisers a less feasible option. While it may increase N efficiency in cropping systems it would be of minimal benefit for grazed pasture systems.

4.3.4   Placement of N fertiliser

In cropping systems where plants are usually grown apart and in separate rows the placement of fertiliser N can influence nitrate leaching losses. For example, in vegetable cropping the banded application of fertiliser N compared to the more indiscriminate practice of broadcasting has been shown to reduce nitrate leaching losses by 24% (from 246 to 186 kg N ha^{-1}; Williams et al., 2003). Better use of fertiliser N occurs when applications are banded because of the sparse root systems of many vegetable plants that are inefficient at recovering applied fertiliser unless it is close to the plant.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   23

4.4 Whole-system approaches

In the future, it will be necessary to consider entire agricultural systems and the total impact of their individual components (e.g. different land uses within systems or differences in topography/soil type) to more accurately evaluate and mitigate nitrate leaching losses. Currently, approaches to achieve this level of management intervention are being carried out by using technologies such as precision farming and whole-system nutrient budgeting.

4.4.1 Precision farming

Precision farming considers the spatial and temporal variability of soil attributes and crop characteristics within a farm/field and adopts appropriate site-specific levels of management to minimise N losses while still maintaining productivity (Dawson, 1997). For example, in grazing systems, critical source areas (CSA's) where nitrate leaching may be relatively high or have a direct impact on adjacent ecosystems (e.g. free draining soils near streams), could be identified and appropriate management strategies adopted (e.g. restricted grazing). In its most advanced form this type of management can involve the use of geographical information systems (GIS) along with global positioning systems (GPS) to provide precise spatial information about field-scale characteristics such as altitude, aspect, slope, vegetation cover, soil physical, chemical and biological properties, rainfall, and drainage patterns (Robert, 2002). Although this level of precision farming has rarely been adopted in New Zealand, in the USA it is often used as a tool to selectively manage N-deficient areas of fields relative to adjacent areas containing sufficient soil N levels (i.e. variable rate application of fertiliser N) and so better control losses of N (Robert, 2002).

4.4.2 Whole farm nutrient budgeting

Nutrient budgets are useful tools for assessing the sustainability of nutrient flows within farm systems, and identifying opportunities for reducing N losses (Wheeler et al., 2003). In New Zealand, the recently modified OVERSEER® nutrient budget pastoral model allows users to perform this task for N as well as P, K, and S. The model enables the amount of nitrate leaching loss to be calculated on the basis of N inputs and outputs for different land use types utilising different management strategies. For example, if the nutrient budget indicates that excess nutrients are being added to the system, then the nutrient management policies of the agricultural system can be reviewed (e.g. fertiliser N policies).

A difficulty with using nutrient decision support models in grazing systems is their inability to specifically account for the spatial and temporal variability of N concentrations in urine patches in pasture. Notwithstanding, nutrient decision support models are still a valuable

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   24

tool for evaluating the impacts of management practices on nitrate leaching under grazing, where they have been validated against data from grazing systems. For example, the OVERSEER® nutrient budget has been used to evaluate the potential impacts of strategic winter feed-pad use on nitrate leaching, estimates of which were subsequently compared to actual field measurements (Chadwick et al., 2002). In that study, use of a feed-pad was predicted to reduce nitrate leaching by similar amounts (e.g. up to 50%) to values previously measured in the field.

5. Phosphorus losses in run-off water from different agricultural systems

The range of P losses from agricultural systems is generally much less than N losses (e.g. 0.11-1.6 versus 21-177 kg ha^{-1} yr^{-1}, respectively) and appears to be minor in comparison. However, aquatic primary producers (e.g. freshwater algae) can be extremely sensitive to even small increases in P, especially in waterways where P is limited (McDowell et al., 2004). In New Zealand, agricultural systems are the primary source of P loss to waterways which mainly occurs through the hydrological process of surface run-off, and to a much lesser degree by subsurface flow. Shallow subsurface flow in soil is typically mediated by preferential flow pathways (e.g. worm burrows) and is often considered of less importance than run-off, unless the agricultural system utilises artificial drainage (e.g. tile drains) that may move percolated P to waterways. Notwithstanding, the significance of subsurface flow in contributing drained P in different land use types (e.g. vegetable cropping) still requires further quantification. For example, P leaching from coarse-textured pumice soils in the central North Island may be significant but there is no published data on it.

New Zealand studies (e.g. Gillingham and Thorrold, 2000) have generally shown the majority of P (up to 80%) in run-off is in the form of particle-bound P (e.g. bound to sediment or organic material) while less than 20% is present as dissolved P. However, these values will vary depending on whether land is cultivated, or susceptible to erosion, and the level of fertiliser P used. In general, the amount of P in waterways is related to the development of high P levels in surface soils; the zone most susceptible to removal by run-off processes. Although particulate P is not all readily available, much of it can be a long-term source of P for aquatic biota (McDowell et al., 2004) and so represents a key component for determining P enrichment of waterways.

In this section the magnitude of P losses in different land uses are summarised and the main factors (e.g. topography, soil type, grazing management and fertiliser management) affecting P losses are discussed in the context of management strategies to reduce P enrichment of waterways.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   25

5.1 Sheep and cattle grazing systems

Direct measurements of annual P losses in run-off from sheep- and cattle-grazed pasture land range from 0.11 to 1.60 kg P ha^{-1} yr^{-1} (Table 3) (Gillingham and Thorrold, 2000). Typically, the higher levels are associated with greater losses of particulate P predominantly in the form of inorganic and organic sediment material originating from either pastoral topsoil, and/or eroding stream banks. Consequently, large storm events have an important influence on the amount of P loss from pastures, especially in hill country farms. McColl et al (1977) found that about 70% of particulate P losses from hill country pasture occurred during large storms and that these comprised about 55% of total P losses for the year.

Because of the large contribution of P via eroded sediment it is tempting to relate the amount of P loss from a catchment to the rate of erosion (or sediment yield). However, several studies (e.g. Gillingham, 1978) have shown a poor relationship between the P yield and sediment yield from catchments, over a range of situations. Often low sediment yielding catchments have a greater sediment P enrichment because of the type of sediment transported (e.g. topsoil, plant material, and dung). In contrast, in high sediment yielding catchments, sediment P enrichment is often less and more typical of subsoil or unfertilised land.

Another consideration for grazed pastoral systems is the extent that animals (particularly cattle) have access to streams and channel banks during grazing and the associated disturbance and slumping of such banks in addition to any direct inputs of dung.

In dairying systems the lower contribution of particulate material in run-off tends to give lower P losses (<0.5 kg P ha^{-1} yr^{-1}) than sheep and cattle hill country farms (Wilcock et al. 1999). This is probably because dairy systems are usually developed in lowland landscapes where erosion and run-off are minimal. However, recent research (Smith and Monaghan, 2003, and unpublished data) has shown that higher P losses (up to 1 kg P ha^{-1} yr^{-1}) in dairy systems can be expected where soil drainage is poor and animal treading causes damage to the soil surface layers. Similarly, a recent summary of stream P data from grazed dairy catchments in extremely high rainfall areas of Westland indicate losses may be up to 10 kg P ha^{-1} yr^{-1} (Davies-Colley and Nagels 2002). Thus, the climatic, soil and management practices can have a large effect on the magnitude of P losses.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   26

Table 3: Measurements of annual losses of P from grazed pasture and the predominant P form (from Gillingham and Thorrold, 2000).

Reference	Total P Loss (kg ha^{-1}yr^{-1})	P Form	Comments
McColl et al. (1977)	0.29	62% particulate P	Sheep grazing; 20% gorse cover.
Bargh (1978)	1.60	76% particulate P	Sheep and cattle grazing; Silt loam soils. Some sheet, rill and stream bank erosion.
McColl and Gibson (1979)	0.11	total P	Sheep grazing; Low total run-off; Silt loam soils.
van Roon (1982,1983)	0.40	total P	Grazed pasture; Volcanic ash-derived soils
Smith (1987)	0.75	80% particulate P	Sheep grazing; Volcanic ash-derived soils
Lambert et al. (1985)	0.70	85% particulate P	Sheep grazing; Silt loam soils from tertiary sandstone, siltstone and mudstones.
Lambert et al. (1985)	1.50	91% particulate P	Cattle rotational grazing on hills.
Smith and Monaghan (2003)	0.09 Drained 0.23 Undrained	Total P	3.0 cows ha^{-1}; Cattle rotational grazing. Heavy silt loam soils.

Report prepared for Environment Bay of Plenty:
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention

June 2004

27

5.2 Forestry

In general, forestry systems make the least contribution of P to waterways. Reports show that forested catchments produce only 0.01 – 0.10 kg P ha^{-1} yr^{-1} (Table 4). Forest production systems are usually based on soils of lower P status compared to grazing systems, and receive less frequent fertiliser applications (about once every 10 years rather than 1-3 years as in most pastures). In addition, forest vegetation intercepts and prevents significant amounts of rainfall reaching the soil surface thereby reducing the likelihood of run-off. For example, research by Duncan (1980) showed that 8-10 year old pines in a completely afforested catchment (Moutere, Nelson) reduced total steam flow by 84% compared with that from pasture. As a result the potential for P run-off losses to streams is lower in forestry compared with pastoral situations (Table 4).

Comparisons of pine forest versus grazing systems show that in all situations the total P losses from pine plantations are in the order of 24-57% of that from pasture catchments. Under either of these land uses the greatest losses of P are associated with elevated flood flow following storm events, with most P (about 80%) in the particulate form rather than dissolved P (about 20%) (Table 4).   Surface run-off during storm events may occur for only short periods each year but it often contributes the majority of total run-off and P loss from a catchment. McColl et al (1977) observed that in exotic forest, particulate P comprised about 70% of total P losses during large storms and this constituted about 40% of total P losses annually.

An additional factor for consideration in forest plantations is the impact of harvest and replanting, which usually occurs on a 25-30 year cycle. Several researchers (e.g. Bekunda et al., 1990; Parfitt et al., 1998) have shown that inorganic P levels in soil can increase after clear-felling due to decomposition of harvest residues. In combination with a recently deforested landscape, increased levels of soil P could potentially result in greater P losses due to the likelihood of increased surface run-off during storm events. If harvest residues are left undisturbed the accumulation of inorganic P in soil following harvest is usually gradual as plant residues slowly decompose (Bekunda et al. 1990). However, if harvest residues are incorporated into soil by ploughing the net accumulation of inorganic P has been shown to double in the subsequent 8 months (Bekunda et al. 1990). In a study by Neary et al. (1978) the clear felling and subsequent burning of harvest residues of a beech-podocarp-hardwood forest (West Coast of the South Island) caused increased stream flow yields of N, P and cations. Concentrations of P increased by 2-5 times that in normal flow, and in the 92 days following logging, P output was 94% of normal annual output. Therefore, it is important that post-harvest management strategies (e.g. minimal soil disturbance, and/or immediate replanting/resowing) are carried out to reduce soil erosion, surface run-off and to

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   28

increase vegetation cover (by planted trees and regenerating vegetation) and lessen the opportunity for increased P losses.

5.3 Cropping and horticultural systems

There is an absence of literature on the amount of P in surface run-off from New Zealand cropping systems. Rutherford (1987) estimated that particulate - associated P losses from cultivated land could be up to 2 kg P ha^{-1} yr^{-1}. Overseas estimates range from <0.3 up to 22 kg P ha^{-1} yr^{-1} (Baker and Laflen, 1983) for ploughed land, compared with 1-5 kg P ha^{-1} yr^{-1} for no-till managed areas. However where no-till involves leaving crop residues and fertiliser on the soil surface, then P concentrations in surface run-off can be greater than from ploughed land (e.g. 0.73 cf 0.18 mg L^{-1} respectively; Baker, 1970).

In most cases the effects of cropping systems on P run-off losses are likely to be closely related to the erosion loss of particulate organic and inorganic material. Many cropping enterprises are located on flat land and therefore the potential for erosion is minimal. However, cropping systems often have greater inputs of fertiliser P; therefore, although sediment losses may be minimal the P enrichment can be very large. For example, in cropping systems growing winter vegetables and receiving large P inputs the movement of sediment from between cultivated rows may lead to large concentrations of P in waterways. If vegetable crops are grown on sloping land (e.g. Pukekohe) then P losses could be further enhanced. Clearly, in these cropping systems the transport of soil in surface run-off (and P losses) will be closely related to slope and vegetation cover at the time of heavy rainfall.

In certain horticultural enterprises (e.g. orchards and vineyards) the presence of established shelterbelts and grassed swards between rows reduces surface run-off and enhances the capture of transported P.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   29

Table 4: Amounts and forms of P in streams under contrasting land use types (kg ha yr^{-1}).

Author	P Form	Flow type	Pasture	Pine
Cooper & Thomsen (1988)	Total P	Baseflow	0.120	0.038
		Storm flow	1.550	0.057
		Total	1.670	0.095
	Dissolved P	Baseflow	0.037	0.017
		Storm flow	0.330	0.019
		Total	0.367	0.036
Wilcock (1986)	Total P	Total	0.400	0.100
	Dissolved P	Total	0.090	0.030
McColl et al. (1977)	Total P	Low Flows	0.042	0.005
		Floods	0.207	0.042
		Total	0.249	0.047
	Dissolved P	Low Flows	0.007	0.002
		Floods	0.023	0.007
		Total	0.031	0.009

Table 5: Main factors affecting P loss from agricultural systems and management options for reducing P enrichment of waterways.

Determining Factor		
Site factors	**Farm-system factors**	**Management Options**
Soil type	P fertiliser use	Riparian management
Topography	Grazing management	Restricted grazing
Soil P levels	Dairy effluent system	Strategic P fertiliser management
Vegetative cover	Land use type	Land application of dairy effluent
Season		Cover crops
Critical source areas		Zero tillage
		Precision farming
		Nutrient budgeting

Report prepared for Environment Bay of Plenty:
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention

June 2004

30

6. Management options for reducing P losses

The main factors affecting the amount of P in run-off/surface waters from agricultural land are associated with both the edaphic features and management attributes of the agricultural system and jointly include: land slope, soil type, soil P status, animal treading, and fertiliser and effluent management (Table 5). For example, in grazed pasture, measurements of soil P status have shown that increased soil P content leads to an increase in the concentration of P in surface run-off, but that this varies strongly with soil type (worse on poorly drained soils, Figure 6; McDowell et al., 2003b; Morton et al., 2003; Sharpley et al. 1977; Lambert et al. 1985; Gillingham et al. 1997; Blennerhassett, 1998) and season (Gillingham et al., 1997). Depending on the type of land use, on-farm strategies for reducing P losses from agricultural systems should take into account landscape features and agro-system attributes by operating through 5 key areas of system management: (1) P fertiliser management (2) grazing management (3) riparian management (4) post-harvest management, and (5) whole-system management.

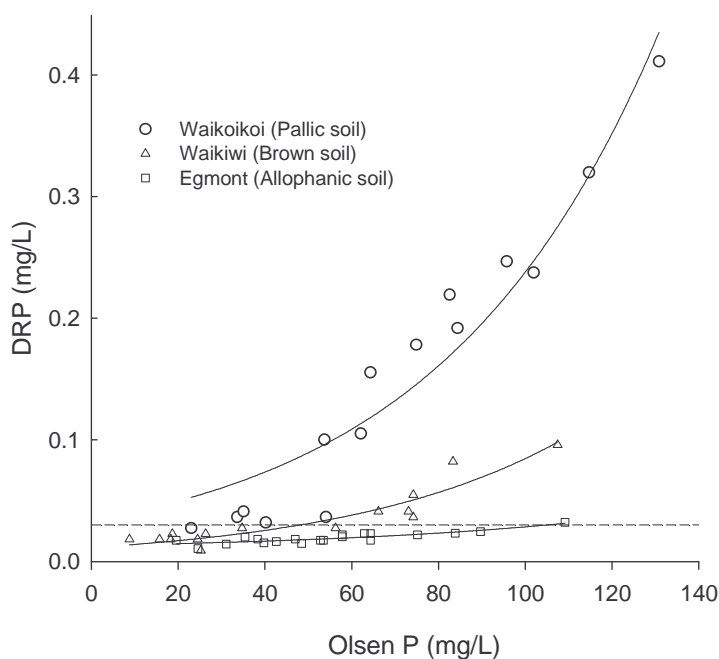**Figure 6:** Effect of soil P status (Olsen P) and soil type on the dissolved reactive P concentration (DRP) in surface run-off from ungrazed plots (McDowell et al., 2003a; Morton et al., 2003).

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   31

6.1 P fertiliser management

6.1.1 P fertiliser application rate and nutrient budgeting

Application of fertiliser P at rates in excess of pasture or crop requirements results mainly in a rise in soil P status rather than an immediate loss through drainage or run-off. The presence of high soil P levels raises the potential for increased P losses in run-off and necessitates the need to minimise the use of excess P fertiliser. This applies particularly to land adjacent to waterways or water bodies. Soil testing and nutrient budgeting are therefore essential for determining optimal use of P fertiliser to meet plant demand and can be carried out using nutrient models such as OVERSEER®. In addition to calculating maintenance fertiliser P requirements for contrasting on-farm situations, the OVERSEER® nutrient budget model also estimates the risk of P loss from fertiliser application under contrasting soil types, soil P status, rainfall and month of fertiliser application.

Additionally, it takes account of other sources of P inputs, such as in supplementary feed and dairy shed effluent. The OVERSEER® fertiliser recommendation model can be used to determine the economic-optimum P requirements of pastoral farming systems.

6.1.2 Timing of P fertiliser application

The timing of P fertiliser application is unimportant for production but has an important effect on the amount of P in run-off and subsequent waterway P enrichment. Most surface run-off usually occurs in winter and early spring when rainfall and soil moisture are greatest. Thus, application of P fertiliser in other seasons reduces the risk of P run off (McDowell unpublished).

6.1.3 P fertiliser placement

Application of fertiliser directly into waterways has been observed to rapidly elevate P levels in water, but for periods of only a few days (Sharpley and Syers, 1979; Cooke, 1988). However, the effects of fertiliser P enrichment of stream sediments have been measured for up to 6 months (Cooke, 1988). These effects may be significant. Cooke (1988) estimated that 20% of the annual P export from one small catchment could be accounted for by P from aerial fertiliser application falling directly in the waterway or onto permanently saturated soils, which were significant surface run-off sources. This fertiliser comprised about 5% of the total applied to the catchment. In the study by Rutherford et al (1987) the proportion of P fertiliser falling directly (e.g. aerial topdressing) into streams was estimated to be only 0.5-0.6% of the fertiliser applied.

In general, the effects of fertiliser addition on the dissolved P content of surface run-off are much greater from sloping land and the increase is more prolonged than direct P

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   32

fertiliser input effects on streams (Sharpley and Syers, 1976; Gillingham et al., 1997). A consistent pattern was for run-off P concentration to increase up to about 300 fold above background values immediately after fertiliser application then to decline exponentially with time to be no longer detectable after 50 to 100 days. Therefore, the degree to which fertiliser application contributes to run-off P losses is closely related to the length of the time interval between fertiliser P application and any run-off events. Accurate fertiliser placement near waterways will be more easily achieved with well-granulated fertilisers (90-95% >1.0mm granule diameter) which are least susceptible to wind drift.

6.1.4   P fertiliser type

In New Zealand, research on the effects of differing P fertiliser forms on P losses in surface run-off from pasture are few and have been confined to small plot experiments. Early studies (e.g. Sharpley et al., 1978) compared different P fertilisers and showed that more soluble fertilisers (e.g. dicalcium-phosphate) gave lower total P losses than less soluble fertilisers (e.g. superphosphate). In both studies fertiliser was applied shortly before the run-off season, and it is clear from the results obtained that the timing of the experiment, the physical properties of the fertiliser material, and the risk of particle erosion from the site are all key factors which will affect the results from experiments comparing fertiliser type effects on run-off.

Recent studies (e.g. McDowell et al., 2003b) have shown larger short-term losses (e.g. within 2-3 months) from soluble P fertiliser than from reactive phosphate rock (RPR). However, this study indicated that soils with similar soil P status established using superphosphate or RPR gave similar levels of P run-off (except during the initial period after annual application). Thus when P fertiliser is applied during periods of high run-off risk, losses of P are less from RPR than soluble P fertiliser whereas, differences may be relatively small during low-risk months.

6.2   Managing land-based applications of effluent

Land application of dairy shed effluent is the preferred use on free-draining soils. The two-pond effluent processing system is relatively ineffective at P removal and results in about 30% (Ledgard et al. 1996b) of effluent P exiting the second pond and going into drains. This equates to about 0.5-1.5 kg P ha^{-1} yr^{-1} on a whole-farm basis and can represent the main source of P loss to waterways.

Land application of dairy shed effluent is a common practice in many farming regions of New Zealand and can represent a significant contribution of P to pasture (e.g. about 15-20 kg P ha^{-1} yr^{-1}). Management of land-based effluent disposal systems should therefore take into account many of the factors that are considered when applying P fertiliser (e.g. plant P requirements, proximity of applied effluent to waterways, and seasonal

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   33

influences) to avoid effluent related P losses. If effluent is applied strategically (with regard to slope, rainfall and plant growth) the potential for direct losses of P-enriched run-off will be minimal. In addition, to avoid surplus P in the soil surface layers farmers will need to ensure that in areas where both effluent and P fertiliser are applied onto the same pasture that the applications rates reflect the inputs of the two P sources. Nutrient budgeting is effective in accounting for all P inputs including dairy shed effluent.

6.3 Nil grazing or restricted grazing systems

Animal treading damage to soil typically coincides with the main period of greatest soil moisture content (e.g. winter/early spring) and therefore dramatically increases the potential for sediment in surface run-off (Figure 7). The key requirement of grazing management should be to minimise animal treading damage so that the risk of increased sediment in run-off and increased P in waterways is reduced. Therefore, during winter and spring, grazing management strategies may require the incorporation of a stand-off pad (in a non-critical area) or some form of restricted grazing to avert damage to soil and the possibility of increased sediment or excreta in run-off (see section 4.1). Obviously, in selecting a suitable site for animal stand-off the farmer should consider any adjacent key landscape units (e.g. streams) that may be negatively affected by localised damage to the soil surface layers or increased excreta in run-off.
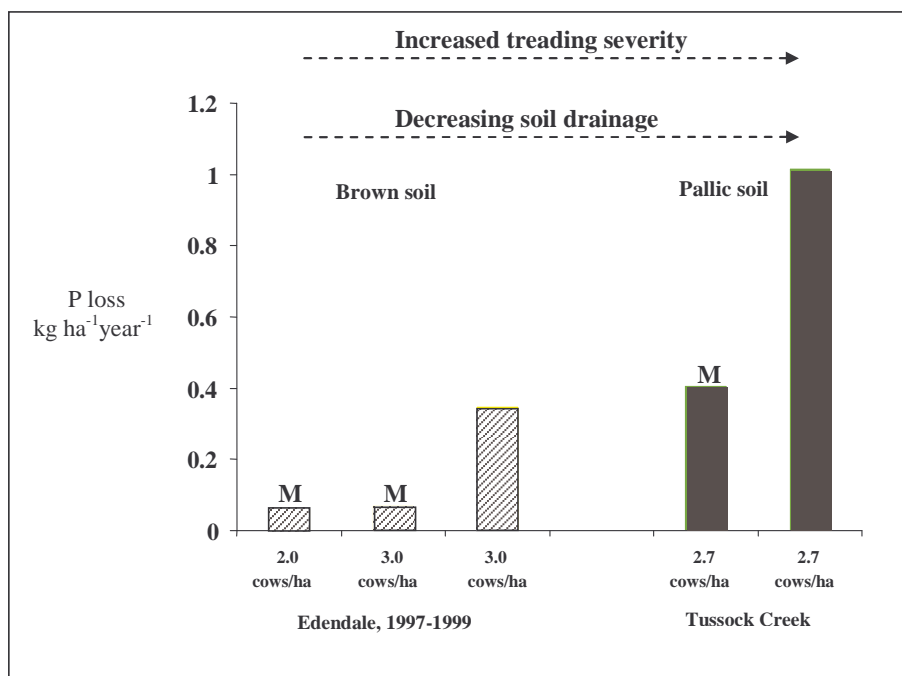
Figure 7: Effect of treading by dairy cows at different stocking rates on P loss in soils with different drainage characteristics; M=mole-tiled drainage (Smith and Monaghan et al., 2003 and unpublished data).

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   34

6.4   Management of riparian zones

In order to comply with the Code of Practice for Fertiliser Use (NZFMRA, 2002) farmers must minimise the likelihood of fertiliser being applied directly to streams and other water-bodies.   In practice, this may involve the use of riparian or filter strips besides waterways or the adoption of practices to minimise the likelihood of fertiliser nutrients directly contaminating waterways.

Riparian zones can be described as any land that adjoins or directly influences, or is influenced by, a body of water or an area where water accumulates periodically, and includes land immediately alongside streams and rivers, areas immediately surrounding lakes, river floodplains and associated wetlands, and estuarine margins where streams and rivers exit (MFE, 2000). The rationale for adopting riparian management strategies is based on recognition of the fact that most surface run-off that enters streams comes from only a small proportion of a catchment and that this area is close to the stream bed. These high risk source areas have been termed critical source areas (CSA's, Zollweg et al. 1997) of which the size varies with such factors as storm intensity, soil conditions and vegetation cover.

The riparian zone intercepts surface run-off and acts as a filter for sediment and associated nutrients entering the stream, as well as reducing the surface run-off volume and rate of entry into waterways. For example, Smith (1992) estimated that 9 year old Pinus radiata trees planted in a 25-35m wide strip around the stream channel and lower slopes of two pasture catchments (comprising 20% of the total area), reduced run-off by 21-55%.

In some instances, control of the most significant erosion sources may not lead to a direct proportional reduction in P loss from a catchment. This was illustrated in the Ngongataha catchment in Rotorua where an intensive riparian retirement programme reduced sediment export by 85%, but reduced total P and dissolved P losses by only about 27% (Williamson et al, 1996). In the Ngongataha catchment, extensive stream bank erosion was observed prior to the riparian scheme being implemented, and it seems likely that this was originally the main source of sediment in the catchment. However, it appears that highly enriched P sources such as dissolved P, or fine particulate P, in surface run-off were the dominant P sources both before and after riparian retirement. This reinforces the results of Hoare (1980) who observed that a large proportion of P input into waterways around Lake Rotorua is as dissolved P. Notwithstanding, the 27% reduction in P losses due to riparian management at Ngongataha is a considerable reduction and highlights the importance of this form of streamside management for controlling surface run-off. In many other studies (see

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   35

review of Quinn et al., 1993) riparian buffer strips have been shown to be an effective means of reducing sediment transport into surface waters.

Two cautionary notes emerge from the New Zealand research. First, Smith (1992) showed that although riparian afforestation within pasture catchments can significantly reduce run-off, sediment yield and P and N concentrations and loads may actually increase. In the study of Smith (1992), this was because afforestation reduced the density of under-storey pasture cover and resulted in enhanced riparian zone and stream channel erosion. Riparian tree planting should therefore not be so dense to cause canopy closure and the shading of ground cover species. Alternatively, fast growing shrub species that tolerate shading could be inter-planted at some later stage once the trees are reasonably established. Second, the effectiveness of buffer strips in removing the majority of P from run-off may also decline with time. Cooper et al. (1995) showed that 20 years after retirement of a riparian buffer strip from grazing, P had accumulated to the extent that outflows of dissolved P were matching the trapping of in-flowing, sediment-bound P. This effect would be expected to occur in many riparian strips unless their P storage ability was periodically recharged in some manner. In addition, surface run-off can become channelised, thus overwhelming buffer strips and negating their filtration effect.

6.5   Post-harvest management in cropping systems

In agricultural systems where harvesting removes the protective vegetation cover (e.g. forestry, vegetable cropping, and mixed/arable cropping) alternative management strategies should be utilised to reduce the potential for surface run-off and erosion during storm events. These strategies have been previously described in section 4.2 (e.g. zero tillage, cover crops, timing of cultivation) and have positive effects on nitrate leaching, and so serve a dual purpose in terms of reducing both N and P losses from agricultural systems.   For example, in arable cropping systems, post-harvest management strategies such as zero tillage, cover crops, and the timing of cultivation will reduce P losses (in addition to N leaching) by retaining soil structure, protecting the soil surface, and ensuring cultivated soil is not exposed at critical times (e.g. late winter).

6.6   Whole system management

The whole system approach for managing and reducing N losses has been outlined in section 4.4. Equally, a similar approach can be adopted for mitigating P losses from different land uses. For example, one approach to minimise P losses in run-off is to obtain appropriate advice on the fertiliser requirements for the agronomic needs of individual land units that comprise an agricultural system. Within hill country farms, steep, dry slopes require less phosphate than more productive land zones and therefore

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   36

should not receive the same fertiliser rates as other areas. This strategy allows fertiliser P application to be optimised for the P requirement of individual blocks within the farm. Such a precision-agriculture type of approach to hill country farming has recently been shown to be economically worthwhile (Gillingham et al. 2003).

In orchards, Sale (1995) commented that many growers now use leaf and soil analysis to determine fertiliser requirements. This results in improved nutrient use efficiency compared with earlier rule of thumb methods.

For both agronomic guidance and environmental protection purposes the use of a nutrient budget model is to be recommended where new fertiliser application strategies are being developed. This will be especially important where capital expenditure of P fertiliser is required to raise soil P status to a satisfactory operating level for the land class. Of particular concern will be land areas in close proximity to waterways. These are likely to be on easier slopes and of higher potential productivity than the steeper, general catchment areas, and therefore may be able to economically justify higher than average rates of fertiliser application. Use of a whole farm system nutrient budget model (e.g. OVERSEER®) can also account for all sources of P inputs (e.g. including those in supplementary feed, farm dairy effluent and irrigation water) and P transfers (e.g. to stock camps, farm lanes, the farm dairy and feed pads).

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   37

7. Diagrammatic representation of factors affecting N and P losses in agricultural systems, and management options for intervention

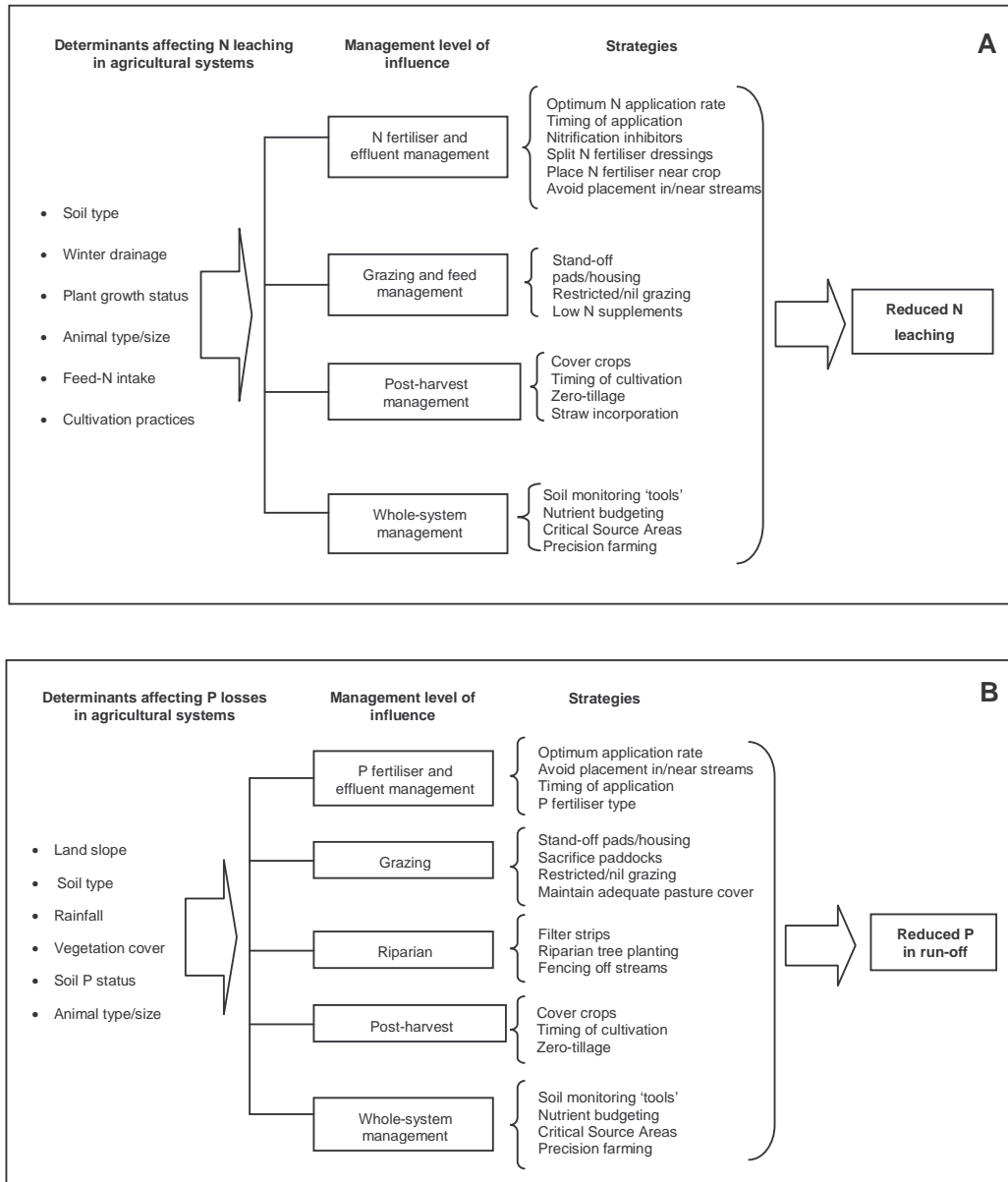**Figure 8:** Main determinants affecting (A) N, and (B) P losses in agricultural systems and key management strategies for mitigating losses.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   38

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Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   39

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Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   40

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Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   41

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Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   42

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Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   43

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Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   44

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Management Options for Intervention   45

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Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   47

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Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   48

9. Appendix 1: Summary table of current New Zealand research relevant to land use impacts on N and P losses from agricultural systems

Organisation	Programme title and main objectives	Key elements	Funding agency and research period
AgResearch Ltd	***Nitrogen and Lake Taupo:*** 1. Reduced nitrogen emissions through improved knowledge of key determinants and new technologies 2. Increased land use efficiency through optimising spatial differences in the landscape 3. Improved multiple outcomes through user-involved evaluation of management and land use changes 4. Improved outcomes for Maori through social research on factors influencing adoption of new land use practices 5. Developing equitable processes for policy outcomes	(a) Development and testing of improved land use practices and new technologies based on manipulation of different components of the nitrogen cycle to reduce. (b) Use of nutrient models to predict effects of alternative land use practices on environmental quality and economics. (c) Assessment of new network analysis methods, and collaborative development of a model framework to predict nitrogen leaching to groundwater, removal by denitrification in wetland and riparian areas, and movement to streams and the lake. (d) Understanding of factors influencing adoption of new practices by Maori, policy options to achieve equitable environmental, economic and social outcomes.	2003-2005 plus Foundation of Science Research and Technology.
	Enhancing surface water quality in managed landscapes: 1. Integrated management of farms and catchments	(a) Provide management strategies that minimise nutrient/contaminant leaks and contain potential contaminants within the farm. Emphasis on P and N surface run-off and spatial management.	2003-2005 plus Foundation of Science Research and Technology.
	Livestock intensification: 1. Development of Sustainable Dairy Farm Systems (in collaboration with Dexcel Ltd)	(a) Monitoring systems at 1m depth and in ground water, on farmlets with increasing intensification and mitigation (stand-off pad practices; diet manipulation) will determine the leaching of N and other major minerals. (b) Nutrient inputs from fertiliser, effluent, bought-in feed and clover N fixation will allow a nutrient budget comparison for each system.	2003-2005 plus Foundation of Science Research and Technology.
	Commercial Research: Reducing nitrogen leaching through new fertiliser N technologies (e.g. Ballance N-care product).	(a) To investigate and evaluate the use of N-care fertiliser on nitrification and nitrate losses from soil.	2003-2005

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   49

Organisation	Programme title and main objectives	Key elements	Funding agency and research period
New Zealand Institute for Crop & Food Research Ltd	**_Land Use Change:_** 1. Defining rules for land use change effects on soil quality, integrity and plant performance 2. Best management practices under land use change 3. Soil processes 4. Plant processes and performance 5. Environmental impacts 6. Scaling, validation and scenario testing	(a) Develop quantitative rules for predicting the suitability of different soils for land use change based on their susceptibility to degradation as well as management practices that will minimise this degradation. (b) Quantify key plant factors that govern the performance of major crops and forages in order to predict their behaviour under a range of soil and water conditions. (c) Determine the combined effects on plants and soils of changes in land use and the consequences for nitrate leaching below the root zone to groundwater. (d) Develop an integrated, modular system based on new and existing paddock and farm scale models and knowledge that will predict the effect of any combination of crops, forages and soil/water conditions on plant performance and nitrate leaching.	2003-2005 plus Foundation of Science Research and Technology.
Landcare Research New Zealand Ltd	**_Soil Services:_** 1. Land-based effluent treatment 2. Regional-scale nitrate modeling	(a) Developing methods to predict the movement of land-based effluent through the topsoil, vadose zone and in to groundwater using models of by-pass flow. (b) Optimising soil characteristics to enhance treatment of nutrients in land-based effluent treatment systems and to minimise the potential for ground water contamination. (c) Determining sensitivity factors in modelling nitrate leaching. (d) Determining the capacity of our soils to accumulate nitrogen and time remaining before capacity is exceeded.	2003-2005 plus Foundation of Science Research and Technology.
Dexcel Ltd	**_Sustainable Dairying:_** 1. Framework for development of sustainable dairy systems 2. Integration of new technologies for future dairy farm systems	(a) Redesigning current dairy systems to allow for greater profitability coupled with better control of environmental consequences, particularly related to nitrogen, greenhouse gases and water use. (b) Linking the Dexcel Whole Farm Model with crop, water and nitrogen models.	2003-2005 plus Foundation of Science Research and Technology.
Lincoln Ventures Ltd	**_Groundwater Quality:_** 1. Temporal and spatial variability of leachate flux through the vadose zone 2. Dispersion and attenuation of contaminants in groundwater 3. Ground water and contaminant flow paths in rolling catchments. 4. Cumulative effects of land-use on the quality of ground water	(a) Increase our understanding of contaminant transport and transformations in the vadose zone and ground water. (b) Develop tools for predicting the dynamic response of ground water quality to the timing and magnitude of land use change and intensification, at spatial scales ranging from field-scale to catchment scale. (c) Increasing the capacity of iwi to participate in RMA processes and bring about change to more sustainable land use practices.	2003-2005 plus Foundation of Science Research and Technology.

Report prepared for Environment Bay of Plenty: June 2004
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention   50

Organisation	Programme title and main objectives	Key elements	Funding agency and research period
National Institute of Water and Atmospheric Research Ltd	**Sustainability of Aquatic Ecosystems and Water Resources:** 1. Sediment processes and dynamics 2. Nutrient cycling and ecosystem effects 3. Lake habitats 4. Water flows and pathways	(a) Focus on knowledge of the fundamental processes that operate in discrete freshwater, estuarine and coastal ecosystems and environments. (b) Focus on the core issues of water and land use that affect the quantity and quality of ecosystems, such as abstractions/diversions, sediments, nutrients and pathogens, and follows these from the catchment through to the coast. Will provide a predictive capacity of how particular activities will affect the environment.	2003-2005 plus Foundation of Science Research and Technology.
	Land Use Intensification: Sustainable Management of Water Quantity and Quality: 1. Frameworks and capacity 2. Managing the land-water interface to intercept contaminants	(a) Find practical methods of preventing pollutants (sediment, nutrients and pathogens) from entering streams in intensively farmed areas. (b) Catchment-scale planning tools that help assess the impacts of land use, water use, and mitigation measures on environmental, social and Maori cultural values.	2003-2005 Foundation of Science Research and Technology.
	Restoration of Aquatic Ecosystems: 1. Thresholds and key values 2. Land-water interfaces 3. Enhancing aquatic ecosystem biodiversity	(a) Enhance management of the ecological functions of land-water interfaces (e.g., riparian areas, ephemeral streams, salt marshes) to restore local and/or downstream habitats.	2003-2005 plus Foundation of Science Research and Technology.
Puketapu Group Blocks (involving AgResearch and Dexcel)	New profitable systems for the Lake Taupo catchment	The opportunity (and necessity) for all farmers in the catchment is to develop new farm systems that capture the potential productivity gains available, while meeting the nitrate leaching targets for Lake protection. The aim is to field test new management systems for sheep, beef, deer and dairy farms that will reduce nitrate leaching while allowing increased profitability.	July 2002 - Mar 2005 Sustainable Farming Fund - Ministry of Agriculture and fisheries
Farmers in Catchment of Lake Rerewhakaaitu (involving AgResearch and Dexcel)	Project Rerewhakaaitu	Specifically the project will: (a) Undertake a personal survey of all farmers in the catchment (approximately 30) to obtain information on farming practices and fertiliser inputs. The Overseer model will be used to calculate N and P inputs to the lake. (b) Determine the impacts of the disposal of farm dairy effluent by pond and land application. The former is still the dominant practice in the area. (c) Work with the farmers to change effluent practices and determine how best to use information from our associated Northland Lakes project and implement it into the farmer's own management programmes in the Rerewhakaaitu catchment. The whole programme will be a participatory approach which will encourage strong farmer commitment.	July 2002 - Mar 2005 Sustainable Farming Fund - Ministry of Agriculture and fisheries Dairy Insight

Report prepared for Environment Bay of Plenty:
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention

June 2004

51

Organisation	Programme title and main objectives	Key elements	Funding agency and research period
Innovative Dairy Effluent Action and Solutions (IDEAS) Group	Riparian zone coppicing hardwoods for reduction of nitrate leaching from dairy farm effluent discharge	This project will determine the efficacy of using poplars and willows in a self-renewing, coppicing system to reduce the amount of nitrate leaching from dairy shed effluent that would normally be applied to pasture. Secondary to this objective will be the determination of the potential nutritional value of the coppiced plant material for dairy cows and/or other livestock classes.	July 2001 - June 2004 Sustainable Farming Fund - Ministry of Agriculture and fisheries
Lincoln University	Development of advanced environmental management systems	Investigating nitrogen losses to groundwater in irrigated dairy systems using innovative fertiliser technologies (e.g. Eco-N)	2004-2005 Foundation of Science Research and Technology. Ravensdown Fertiliser.
Fonterra	Tile Drainage (Massey University)	Effluent irrigation effects on nutrient losses in mole/tile drained dairy systems	2003-2004 Dairy Insight
	Catchment Studies (AgResearch, Dexcel, NIWA)	(a) Monitoring of soil quality and water quality in four catchments. (b) Identification of regional issues relating to soil and water quality. (c) Encourage the adoption of industry guidelines and improved management practices in the catchments. (d) Communicate results of project to farmers.	2003-2004 Dairy Insight
	Advanced Pond systems (NIWA)	Developing a biological system for treating farm dairy effluent to a standard it can meet regional council requirements for discharge to water-ways.	2003-2004 Dairy Insight
Collaborative Research	***Integrated Research on Aquifer Protection (IRAP partnership)*** Partners: AgResearch, NIWA, Landcare research, Crop and Food, Aqualinc, Environment Waikato, Environment Canterbury.	To integrate science and policy research on biophysical, social and economic issues to do with managing land use effects on water quality.	2004-2005 plus
	Cross Departmental Research Pool (CDRP) Partners: AgResearch, HortResearch, NIWA, Landcare research, Crop and Food, Aqualinc, Harris Consulting, Environment Waikato, Environment Canterbury.	(a) To develop a Computer Based GIS Decision Support Tool(s) that is nationally applicable, and regionally and catchment relevant, which will assess the links between rural land-use, land use change, and catchment-level (but scalable down or up) effects on surface and groundwater quality. (b) To provide a "sustainable development" context allowing for community, social and economic inputs in considering the effects of land use, land use change on water quality.	Until June 2006 Ministry of Agriculture and fisheries

Report prepared for Environment Bay of Plenty:
Land use Impacts on Nitrogen and Phosphorus Loss and
Management Options for Intervention

June 2004

52