Section

7

7. Nutrient Cycles and Nutrient Budgeting

7.1 Nutrient Cycles and Nutrient Budgeting on Dairy farms

Key Learning Objectives

After studying this section you should be able to:

1. Describe the processes that create losses and lead to gains of plant-available N, P, K and S on a dairy farm.

2. Describe the processes that influence the pool of plant-available N, P, K and S on a dairy farm.

3. Describe the system management factors that influence the losses of plant-available N, P, K and S from soil-plant-animal systems.

4. Describe how soil testing can be used with nutrient balance models to manage soil fertility on a dairy farm.

Introduction

To sustain milk and meat production, the long-term management of dairy farming systems must minimise and replace the steady loss of nutrients from the plant-soil-animal. These losses occur through the sale of farm produce, leaching of nutrients in drainage waters and the within-farm transfer of nutrients to non-productive areas (e.g. deposition of cattle excreta on raceways and yards and deposition of cattle excreta or crop residues on land areas with already greater than optimum soil fertility status). To minimize and/or replace these nutrient losses in an *environmentally acceptable* manner requires that:

- the current soil fertility status is known and further nutrient addition is judged appropriate on the basis of the relationships between soil fertility status and desired plant or animal productivity and potential environmental risk.

- the form, amounts and pathways of the nutrient loss is known, which means that the nutrient cycles within farming systems and between farming systems and the wider environment must be understood.

In Sections 3 and 4 you studied information on nutrient cycles and on methods of soil fertility evaluation (*soil and plant testing)*. In this section 'quantitative' information on the form, amounts, transformations and loss pathways for nutrients in soil-plant-animal systems is provided.

The relationship between indices of soil fertility status and desired plant, or animal, productivity is reinforced in this section with respect to soil phosphate, potassium and sulphur status. For nitrogen and phosphate, which are highly biologically active nutrients, the potential environmental risks from increasing the soil nutrient status is also examined.

Dairy Farms

MANAGING SOIL PRODUCTIVITY

For optimising milk production on dairy farms we regularly improve the soil's ability to supply phosphorus (P), sulphur (S), nitrogen (N) and potassium (K) and to a lesser extent calcium (Ca), magnesium (Mg) and trace elements by supplementing soils with lime, manures and/or fertilisers. Addition of nutrients fulfils two requirements:

(a) raising the plant-available pool of a nutrient in soil to a level that does not inhibit grass and clover (pasture legume) growth. Vigorous clover (legume) growth is required to provide the major input of nitrogen through biological fixation.

(b) replacing losses of major nutrients created by the farming system including: losses in farm product, uneven transfer of nutrients within the farming system and losses of nutrients from the farm in drainage and run-off waters.

Raising the plant available pool of nutrients in the soil to near optimum levels, increases pasture growth, increases stock carrying capacity per hectare and increases the rate of nutrient cycling per unit land area.

ENVIRONMENTAL CONSEQUENCES

Increasing farm productivity by use of manures and fertilisers, or by bringing on additional stock feed inevitably increases nutrient cycling and, in turn, nutrient losses in run-off and drainage waters also increase. Therefore, if we are to preserve the high quality of water in our streams, lakes and aquifers, we must reach a compromise and adopt nutrient management practices that minimise adverse impacts on water quality, whilst maintaining acceptable levels of farm productivity.

THE ROLE OF NUTRIENT BUDGETING

Nutrient budget modelling can help us quantify the acceptable amounts of nutrients that should be applied to dairy farms as manures and fertiliser or brought on to the property as supplementary feed. To construct a nutrient budget we must understand the behaviour and fate of the nutrient in the soil-plant–animal system. In the next section the quantitative behaviour of the major nutrients in a dairy farm system is examined.

Nutrient Cycles

We begin by following the flow of phosphorus (P) in the soil-pasture-cow system to understand what is meant by a 'nutrient cycle' (Haynes and Williams 1993).

THE PHOSPHORUS CYCLE

Firstly, consider the flow of the nutrient P in Figure 7.1.1. In one year, the grass and clover roots of a dairy pasture supporting 2.7 Friesian cows[1]/ha on a volcanic soil in Taranaki, New Zealand, will take up approximately 46 kg P/ha/year as the soluble phosphate ion ($H_2P0_4^-$) from the soil water (illustrated conceptually in Figure 7.1.1) that bathes the roots and allows transfer to tillers and leaves.

These large (550 kg) Friesian cows ingest 85% of the pasture grown, which amounts to approximately 4300 kg DM/year of grass (dry matter basis) per cow or 11,577 kg DM/ha/year for 2.7 cows/ha. At 85% pasture utilization, 2.7 cows/ha will ingest 39 kg P/ha/year in pasture leaves (containing 0.34%P on a dry weight basis) and 6 kg P/ha/year in supplements whilst 7 kg/ha/year of the plant P will return to the soil as litter to be decomposed by soil micro-organisms into soil organic matter (humus). Of the P ingested by the cow, approximately 17 kg of P/ha/year is lost in milk and meat sold from the farm (see later discussion), 4 kg P/ha/year is transferred as excreta (P excreted in dung only) to raceways, unproductive areas such as yards and over-fertile camp sites (see later discussion on transfer loss) and approximately 24 kg of P/ha/year is returned in dung to the productive areas of the paddocks.

P returned as dung is decomposed by soil micro-organisms into soil organic matter (humus). During this decomposition, some P is released in soluble inorganic form ($H_2P0_4^-$) to the soil water to be either taken up by the plant roots again or absorbed by the soil minerals. Some P in volcanic soils is irreversibly adsorbed by iron and aluminium oxides on the surfaces of soil clays. Depending on the anion sorption capacity of the soil and the likelihood of dissolved and sediment P losses via erosion and run-off, around 1-10 kg P/ha can be lost to the environment via surface water movement and drainage (leaching). Very small, almost negligible amounts (typically 0 – 0.6 kg/ha/year) of P will be lost via drainage/leaching. However, concentrations of P in drainage waters from well-fertilised pastures (soil Olsen P values > 30 mg P/L) may exceed 0.15 ppm, which is sufficient to stimulate weed and algal growth in receiving waters.

To maintain the pool of plant available P in the soil, manure or fertiliser P must be added in the same amount as the losses (product loss+ transfer loss + irreversible adsorption loss in the soil + environmental P loss).

Maintenance fertiliser P = P lost via animals + P lost in soil + environmental P loss.

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[1] Cow stocking rate also can be expressed as standard cows/ha or as a standard stock unit /ha. A standard cow consumes 4000 kg DM/ha/year. A standard stock unit (ssu, one ewe plus lamb) consumes 550 kg DM/ha. The large Friesian cows in our example are approximately equivalent to 1.15 standard cows or 8.36 ssu. Overseer® uses the term relative stock unit (RSU), which is 550kg fresh ryegrass/clover pasture with a metabolisable energy of 10.9 MJ ME/kg DM. 1 RSU = 6000 MJ ME.

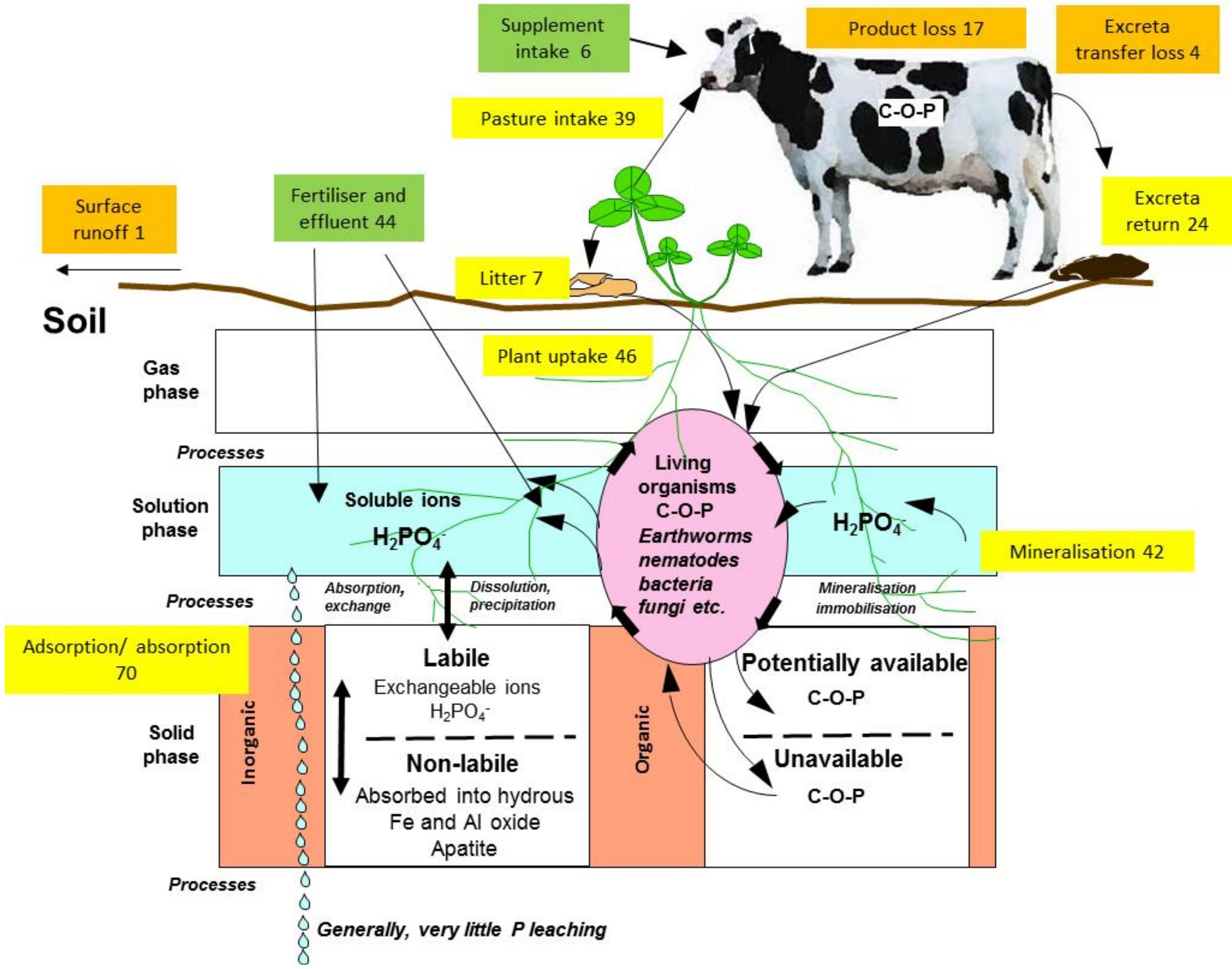

Figure 7.1.1. Example of the phosphorus cycle for a dairy pasture soil (2.7 Friesians/ha) on a volcanic soil in Taranaki, New Zealand. Assumed 125 t DM good quality pasture hay, 150 t DM maize silage and 150 t DM barley brought on to 200 ha farm. Assigned values are kg P/ha/year and based on Overseer®.

The same concepts outlined for P (Figure 7.1.1) apply to the other nutrients, S and K, except in these cases there are a greater number of gain and loss processes, including atmospheric inputs (S, Figure 7.1.2), nutrient release from soil minerals (K, Figure 7.1.3) and leaching losses (K and S). The N cycle (Figure 7.1.4) contrasts with the other nutrients in that a large amount of N can enter the farm cycle by biological fixation in the clover root nodules.

To calculate these losses accurately for a given farming system requires more detailed information than can be given in this unit. Nevertheless, estimates of losses can be made with quite limited information, and these estimates can often be very useful. We will now consider the animal losses which have not previously been covered in Sections 3 and 5 in more detail.

Losses Via Animals

Losses due to grazing animals occur in two ways:

(a) Losses in animal products –animal product such as milk and meat (Table 7.1.2) which is shipped off the farm represents a loss of nutrients. Also nutrients that are retained in the body as an animal grows represent a net loss to the cycling pool and must eventually be replaced. For dairy farms, nutrient budget models estimate nutrient loss in product from the milk solids production per cow and the meat lost in culling approximately 25% of the herd per year plus culling approximately 75% of the calves.

(b) Losses due to transfer by excreta – the major portion of nutrients eaten by grazing animals are not retained but are excreted in dung and or/urine (Figures 7.1.1-4). If this dung or urine is not deposited on the area where the original pasture was growing, then a transfer of nutrients has occurred. This transfer can lead to losses. An obvious example is where dung and urine deposited in yards and races represents a clear loss of nutrients from the pasture system. Less obvious is the loss of nutrients due to transfer on to stock camping areas induced by shade trees or camping areas induced by rolling or hill land. The soil fertility in the camping area is already at optimum levels, therefore transfer of more nutrients in excreta results in no further pasture production but represents a loss of nutrient from the non-camping areas. To estimate the size of the transfer loss, nutrient budget models simply try to estimate the proportion of time an animal spends camping or in raceways and yards; nutrient return in excreta is apportioned accordingly. On a dairy farm the transfer loss of nutrients to the yards can be recovered when effluent is captured and reapplied to approximately 10-13% of the effective grazing area of the farm. The quantities of nutrient in effluent recycling should be considered when calculating the fertiliser requirements of the paddocks receiving effluent.

Examples of Product and Transfer Losses for Dairy Farming

Pastures take up large amounts of nutrients that are ingested by animals and either returned in the form of dung and urine or used to produce animal tissue. The range in the amounts of nutrients that are taken up by good quality pasture producing 12 to 14 tonnes of herbage dry matter per hectare each year is shown in Table 7.1.1.

Table 7.1.1 Total annual uptake of nutrients by a good quality grass-clover pasture.

Element	kg/ha/year
Nitrogen (N)	400-500
Potassium (K)	300-450
Phosphorus (P)	40-60
Sulphur (S)	35-45
Magnesium (Mg)	25-40

The grazing animals eat around 85% of the pasture grown and, therefore, the nutrients it contains. Under rotational grazing, there may be 10 grazing events per year. Thus, nutrients consumed in the early grazings may be recycled through excreta and contribute to pasture growth later in the year. Researchers have found that although the paddock area covered by excreta each year is less than 30% of the total area, more than 50% of the pasture production originates from the high soil fertility created in excreta patches. The fate of the nutrients ingested by lactating dairy cows is shown in Table 7.1.2. On dairy farms, one important source of loss is milk; note that considerable N, P and Ca are lost in milk.

Table 7.1.2 Example of the fate of minerals ingested by lactating dairy cows (consuming approximately 10 kg DM/day of pasture) (During 1984 and [1]Gustafson et al., 2007).

Element	Consumption Kg /week	Percentage in			
		Faeces	*Urine*	*Milk*	*Retained*
N	2.54	26	53	17	4
P	0.23	66	-	26	8
K	1.72	11	81	5	3
S[1]	0.23	66	18	13	3
Mg	0.23	80	12	3	5
Ca	0.72	77	3	11	9
Na	0.27	30	56	8	6

Urine and dung excreted on areas such as races (tracks), under hedges, around gateways, watering areas and on camping sites are another source of loss. It has been estimated that about 10 to 15% of excreta may be involved. Assuming that 10 to 15% of the excreta are deposited on unproductive sites and that milk and animal product is exported from the farm, each dairy cow may cause approximate annual losses of nutrients as shown in Table 7.1.3.

Table 7.1.3 Estimate of annual loss of nutrients through dairy cows (During 1984).

Nutrient Element	kg/year/cow*
Nitrogen	40-50
Potassium	20-30
Phosphorus	6-8
Sulphur	7-8
Magnesium	2-3

*higher values = Friesian cows, lower values = Jersey cows

Losses and Gains in the Soil

The losses and gains of nutrients below ground are considerably more difficult to measure than those above ground. We will discuss the ways of estimating the losses and gains in the soil of each nutrient individually (see also Section 3).

THE SULPHUR CYCLE

Unlike P, the major loss of sulphur (S) is through leaching (Figure 7.1.2). The factors that influence the amount of leaching are:

- Rainfall
- Anion retention capacity of the soil.
- Stocking rate (because animals concentrate sulphate in urine patches and thus make it more susceptible to leaching).

In the case of S there can be inputs to the system, other than through fertiliser. Uptake from the subsoil is one such source but this is poorly understood and can be ignored. Inputs of S from the atmosphere can be significant near the coast. The amounts involved range from 12 kg S/ha/year at the coast to 2 kg S/ha/year at distances more than 20 km inland (Ledgard and Upsdell, 1991)

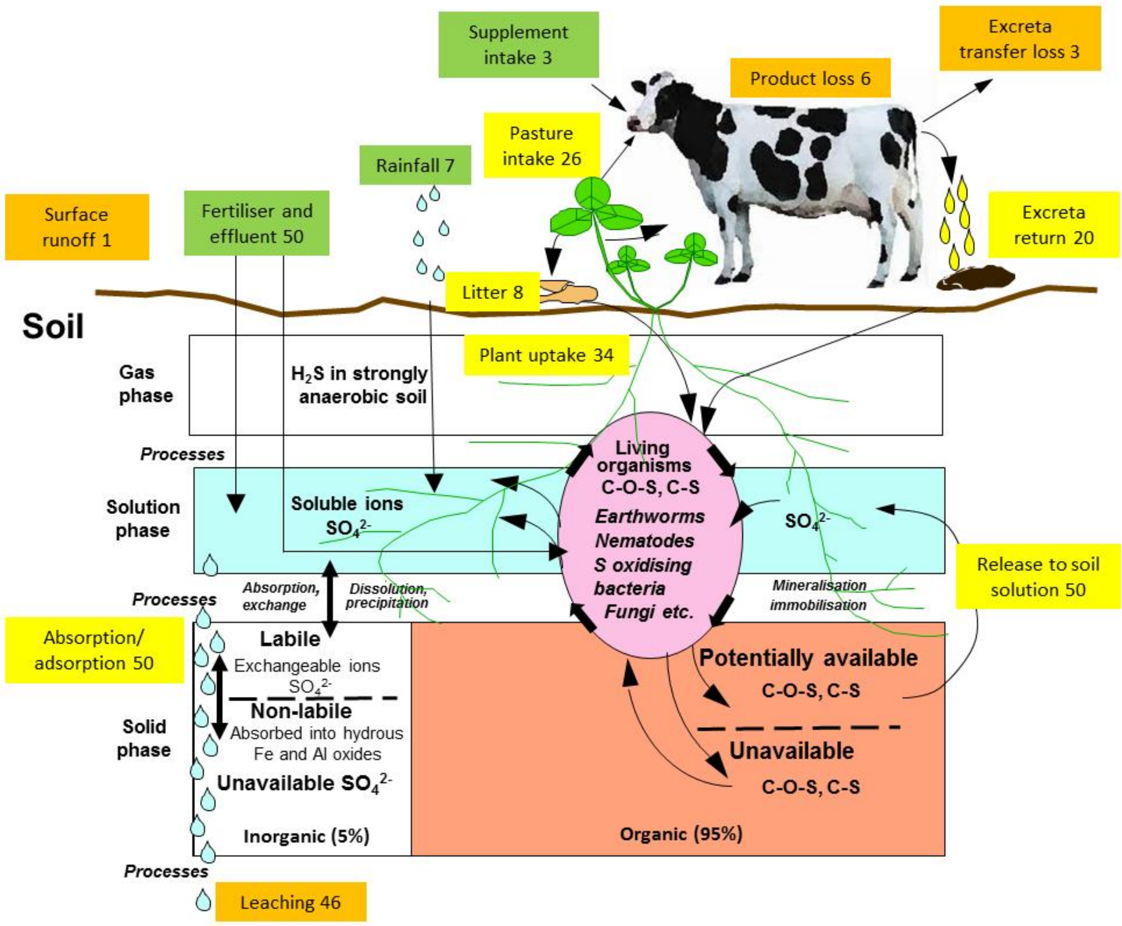

Figure 7.1.2. Example of the sulphur cycle for a dairy pasture soil (2.7 Friesians/ha) on a volcanic soil in Taranaki, New Zealand. Assumed 125 t DM good quality pasture hay, 150 t DM maize silage and 150 t DM barley brought on to 200 ha farm. Assigned values are kg S/ha/year and based on Overseer®.

The major source of S for plants is from the decay of organic matter in the soil. As soils were converted from forest to pasture it was common for topsoil organic matter content to increase under pasture from the accumulation of decaying pasture litter and roots. In this case, S accumulated in the soil until the rate of soil organic matter increase equalled the rate of soil organic matter decomposition. During pasture development, much available S will be lost to the increasing store of slowly decomposing soil organic matter; phosphate may also be made temporarily unavailable in the accumulating soil organic matter. In the organic matter accumulation phase, S is lost from the plant available pool and must be replaced with fertiliser S.

In well-developed dairy pastures, it can be assumed that the rate of soil organic matter accumulation and decay are equal (this has been termed the 'maintenance phase') and there is no net loss or gain of S from the soil organic matter. In a well-developed pasture at maintenance, release of S from the large decaying organic matter store will act to replenish available sulphate after winter drainage events (leaching). Although the amounts of S cycling in the grazed pasture are similar to P, one major contrast between the P and S cycles is that unlike phosphate, sulphate-S is not strongly adsorbed by the soil and is prone to leaching. The other contrast is that up to 60% of the excreta S may be sulphate in urine, which of course produces concentrated sulphate-S patches from which accelerated sulphate leaching may occur.

THE POTASSIUM CYCLE

Similar to S, soluble potassium (K) is also prone to leaching from soils (Figure 7.1.3). Leaching losses of potassium are generally small except under high rainfall (> 1500 mm) on coarse textured soils derived from sand or pumice, or on peats. In these situations leaching losses can be high. The amount of K leached depends on the stocking rate and the amount of K being ingested because up to 70% of the excreted K appears in urine, resulting in potential accelerated leaching of K from urine patches (Williams et al., 1990).

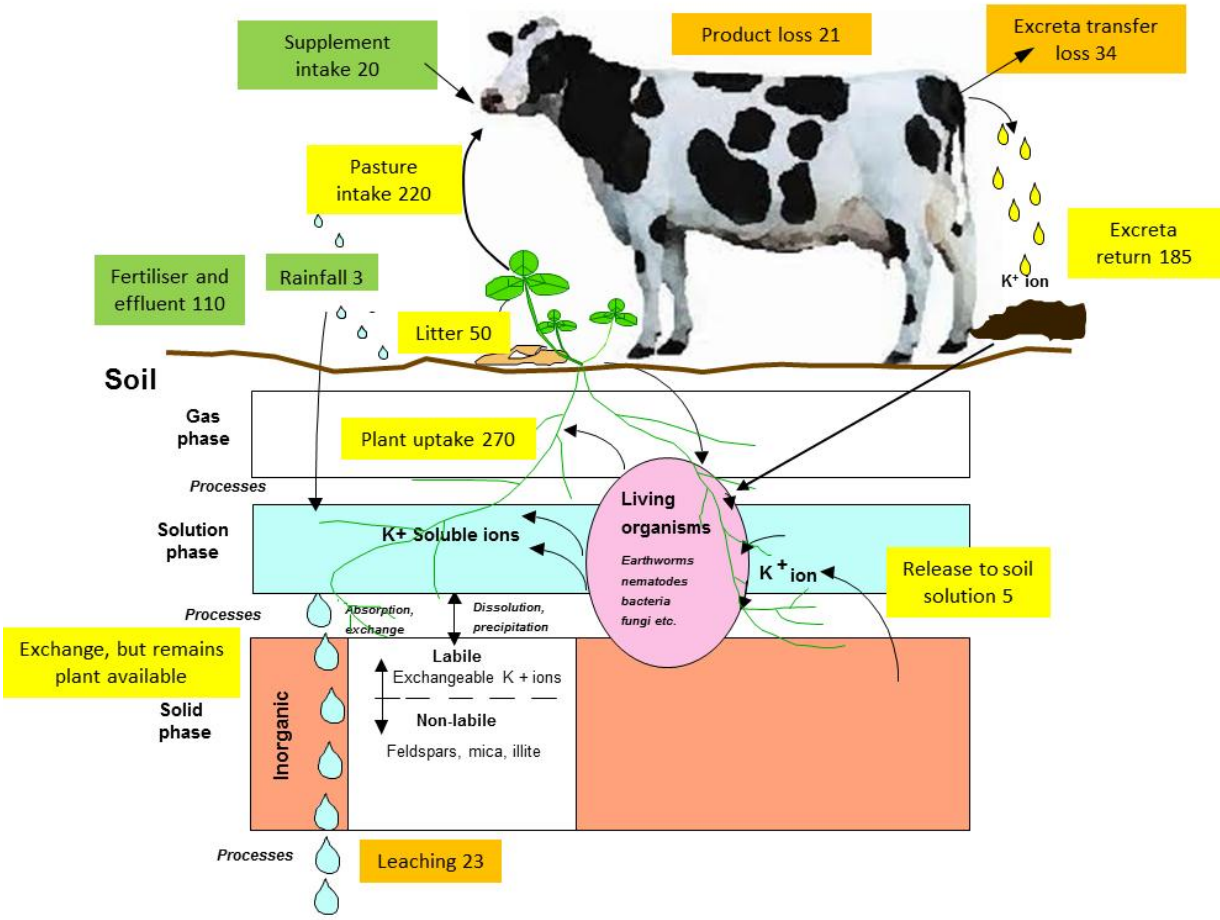

Figure 7.1.3. Example of the potassium cycle for a dairy pasture soil (2.7 Friesians/ha) on a volcanic soil in Taranaki, New Zealand. Assumed 125 t DM good quality pasture hay, 150 t DM maize silage and 150 t DM barley brought on to 200 ha farm. Assigned values are kg K/ha/year and based on Overseer®.

This leaching loss is accounted for in Overseer® along with loss via animals to give the total K loss from the farm system. Many soils can supply substantial amounts of K through the weathering of minerals, feldspars and 2:1 micaecous clays. Recent alluvial soils and other little-weathered soils of sedimentary origin can supply up to 50 – 100 kg K/ha/year resulting in no requirement for fertiliser K until the rate of K release from soil minerals decreases.

At the other extreme, some soils derived from some volcanic ashes and rhyolitic pumice, highly weathered soils, coarse sands and peats can supply little (0-10 kg K/ha/y) or no K from this source. In these soils, the K replacement requirement is essentially the sum of the losses calculated above.

When this is modelled in Overseer® you may find that for less intensive enterprises, little or no potassium is required. This accords with actual practice, whereby potassium is normally used only on the more intensive enterprises.

THE NITROGEN CYCLE

A dairy pasture (Figure 7.1.4) supporting 2.7 Friesian cows/ha on a volcanic soil in Taranaki, will take up approximately 545 kg of N per year. Approximately 119 kg of that N will have been derived from atmospheric nitrogen gas by biological nitrogen fixation in the nodules of clover roots, the remaining 426 kg N will have been taken up as ammonium (NH_4^+) and nitrate (NO_3^-) derived from the decomposition of soil organic N sources, mostly recycled dung and urine. At 85% pasture utilization and a pasture N concentration of approximately 4%, the cows will ingest 463 kg of N in the shoots, whilst 82 kg of the plant N will return to the soil as litter to be decomposed by soil micro-organisms into soil organic matter (humus).

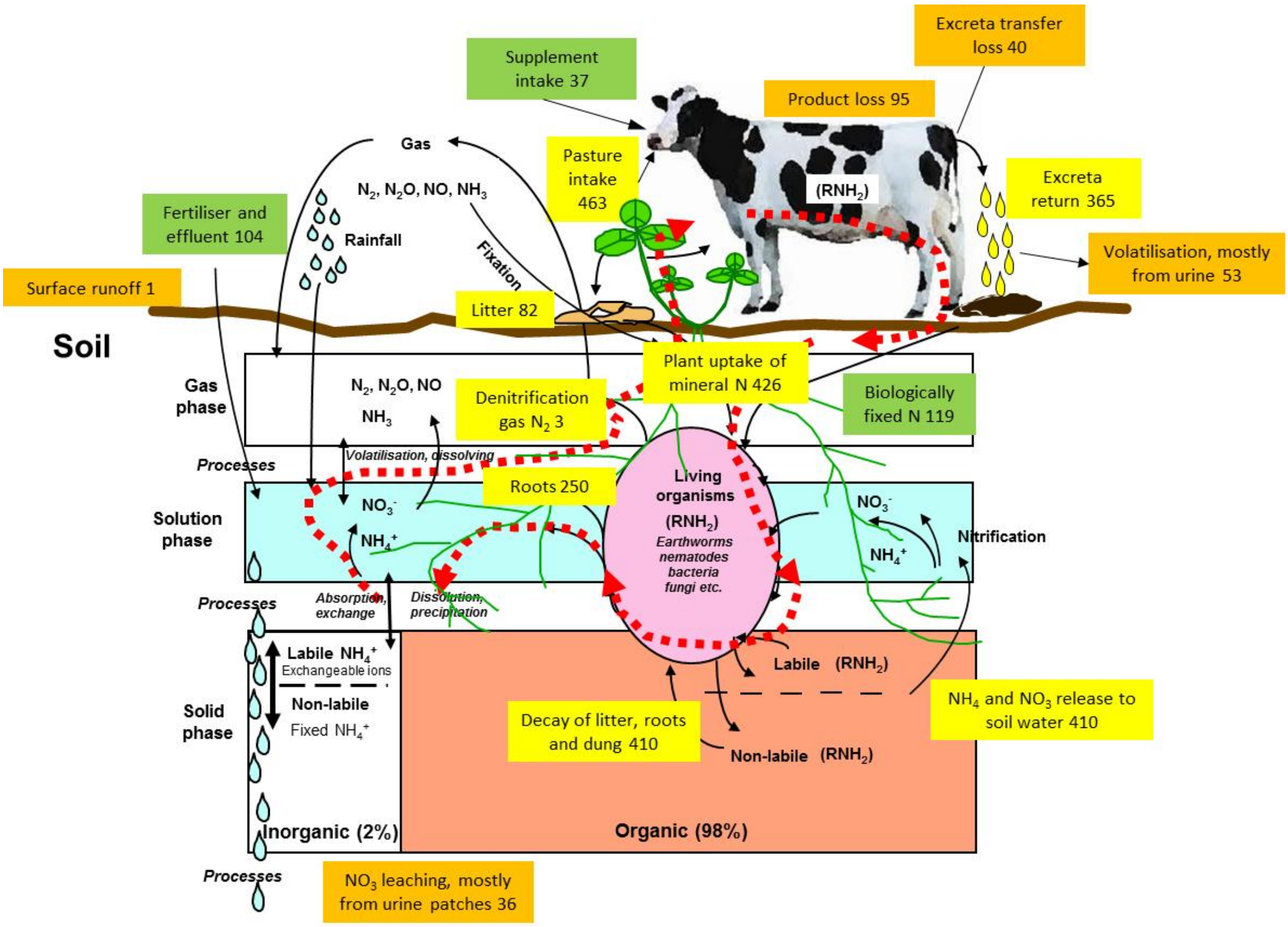

Figure 7.1.4 Example of the nitrogen cycle for a dairy block (2.7 Friesians/ha) on a volcanic soil in Taranaki, New Zealand. Assumed 125 t DM good quality pasture hay, 150 t DM maize silage and 150 t DM barley brought on to 200 ha farm. Assigned N values are kg N/ha/year and based on Overseer®.

Of the N ingested by the cow, approximately 95 kg of N is lost in milk and meat sold from the farm, 40 kg N is transferred as excreta to raceways, yards and unproductive areas and 365 kg of N is returned in dung and urine to the productive areas of the paddocks. Fresh urine and dung patches tend to have high pH values which encourages the volatilisation of ammonia (NH_3) gas (53 kg N/ha/year, includes loss from fertiliser) to the atmosphere, however, the majority of urine N is converted firstly to ammonium and then to nitrate in the soil and either retaken up by plants, leached in drainage water (36 kg N/ha/year) or denitrified to nitrogen gas (3 kg N/ha/year), which is lost to the atmosphere.

N returned as plant litter, dying roots and dung is also decomposed by soil micro-organisms into soil organic matter (humus). During this decomposition some ammonium (NH_4^+) and nitrate (NO_3^-) is released in soluble form to the soil water to be taken up by the plant roots again or leached from the soil.

Pasture Conservation and Maize Silage

Table 7.1.4 highlights the large concentrations of N and K that are contained in common livestock feeds. It is important that these nutrient sources are accurately accounted for when undertaking a nutrient budget. Additional nutrient must be applied to replace nutrients removed in conserved pasture if hay or silage is not fed back on the areas on which it was grown.

*Table 7.1.4 Nutrient content of selected livestock feeds**

Feed Type	% (dry weight basis)			
	N	P	K	S
Pasture hay	2.72	0.40	2.32	0.26
Pasture silage	2.20	0.30	2.30	0.24
Barley grain	1.76	0.44	0.57	0.17
Maize Silage	1.28	0.23	1.20	0.13

Data from DairyNZ Farmfact (2008), Gourley et al. (2010) and Kolver (2000).
Nutrient concentrations of additional feeds are presented in Section 3.

Conversely of course, areas on which hay or silage are fed out need less fertiliser by the amounts shown in the table above. In particular, large quantities of maize silage are used on some farms.

Test Your Knowledge

1. List the sources of P which are imported and exported from dairy farms.
2. List the sources of N which are imported and exported from dairy farms.
3. What is the major form of N loss from a dairy farm system and what factors may influence the amount of N lost via this pathway?

4. Why is it important to account for imported feed supplements when calculating a nutrient budget?

References

DairyNZ FarmFact (2008). 1-71 Palm Kernel Extract (PKE) http://www.dairynz.co.nz/file/fileid/36249

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Gourley CJP, Dougherty WJ, Aarons SR, Hannah M (2010) Accounting for Nutrients on Australian Dairy Farms. Department of Primary Industries, Ellinbank, Victoria. pp. 50-52. Final Report.

Gustafson, G. M., Salomon, E. and Jonsson, S. 2007 Barn balance calculations of Ca, Cu, K, Mg, Mn, N, P, S and Zn in a conventional and organic dairy farm in Sweden. Agriculture, Ecosystems and Environment 119 (2007) 160–170.

Haynes, R. J. and Williams, P.H. 1993 Nutrient cycling in the grazed pasture ecosystem. Advances in Agronomy 49, 119-199.

Kolver, ES (2000). Nutritional guidelines for the high producing dairy cow. Proceedings of the Ruakura Farmers' Conference 51, 78-87, 2000.

Ledgard, S. F. and Penno, J.W., Sprosen, M. S. and Brier G.J. 1996. Impact of nitrogen fertilizer application on nitrate leaching from grazed dairy pasture. In Recent developments in understanding chemical movement in soils: Significance in relation to water quality and efficiency of fertilizer use. (Eds L.D. Currie and P. Loganathan). Occasional Report No. 9. Fertiliser and Lime Research Centre, Massey University, Palmerston North. pp 45-53.

Ledgard, S. F. and Upsdell, M.P. 1991. Sulphur inputs from rainfall throughout New Zealand N.Z J. Agri. Res. 34, 105 - 111.

Williams, P.H., Gregg, P.E.H. and Hedley, M.J. 1990. Mass balance modelling of potassium losses from grazed dairy pasture. New Zealand Journal of Agricultural Research 33: 661-668.

7.2 Understanding Overseer® as a nutrient budgeting model

Key Learning Objectives

Study of this section and the readings provided should help you:

1. Gain an understanding of the concepts and assumptions used in the Overseer® nutrient budgeting model.
2. Learn how Overseer® Nutrient Budgets are used:
   - as a decision support tool for fertiliser recommendations.
   - for documentation in the Code of Practice for Nutrient Management.

Introduction

Overseer® is a nutrient budgeting model to assist in fertiliser and lime recommendations for pastoral agriculture and has restricted use within the fertiliser industry. Overseer® Nutrient Budgets is a model that provides estimates of the fate of the nutrients N, P, K and S. These models contain a number of databases for nutrient concentrations of fertilisers, animals, products, crop framework, and crop residues. These are used for estimating the nutrient inputs or outputs on a per-hectare basis. Figure 7.2.1 provides a conceptual model summarising the main nutrient flows used in the Overseer® Nutrient Budgets model.

Readings have been provided in this section to assist your understanding of the information that supports and drives the models and to give examples of how the Overseer® Nutrient Budgets model can be used.

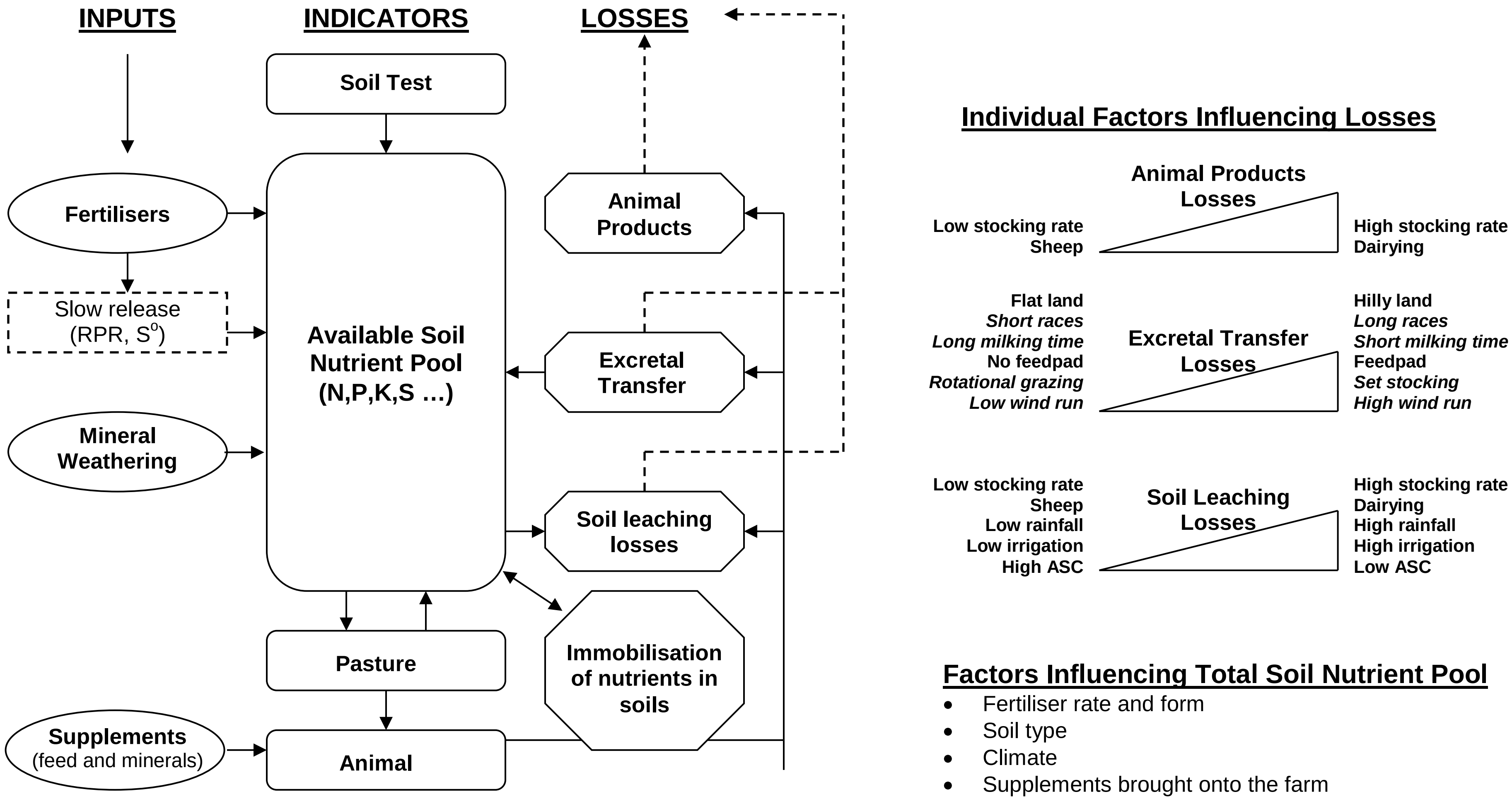

Figure 7.2.1 Conceptual diagram of the flow of nutrients in the Overseer® Nutrient Budgets model (Factor names in italics are not employed in Overseer®).

Recommended Readings

To become more familiar with the newest version of Overseer® and the recent changes which have been made to this program, it is suggested that students read the support information on the Overseer® website at: http://overseer.org.nz/OVERSEERModel/Information.aspx

In addition, four articles listed below have been provided as readings:

1. Ledgard, S.F., Williams, P.H., Broom, F.D., Thorrold, B.S., Wheeler D.M. and Willis, V.J., 1999. OVERSEER™ – A nutrient budgeting model for pastoral farming, wheat, potatoes, apples and kiwifruit. In: *Best soil management practices for production.* (Eds L.D. Currie and P. Loganathan). Occasional report No. 12. Fertilizer and Lime Research Centre, Massey University, Palmerston North. pp 143-152.

2. Ledgard, S.F., Steel, K., Roberts, A.H.C. and Journeaux, P.R., 2000. Use of OVERSEER™ to compare farm systems and countries for nutrient balances, losses and efficiency. In: *SOIL RESEARCH - A knowledge Industry for Land-based exporters.* (Eds L.D. Currie and P. Loganathan). Occasional report No. 13. Fertilizer and Lime Research Centre, Massey University, Palmerston North.

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5. Shepherd, M., Wheeler, D., Selbie, D., Buckthought, L., and Freeman, M., 2013. OVERSEER®: Accuracy, precision, error and uncertainty. In: Accurate and efficient use of nutrients on farms. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 26. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. pp 1-8.

6. Wheeler, D. M. and Bright, J., 2015. Irrigation in Overseer®. In: Moving farm systems to improved attenuation. (Eds L.D. Currie and L.L Burkitt). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 8 pages.

Reading 1

OVERSEER™ – A NUTRIENT BUDGETING MODEL FOR PASTORAL FARMING, WHEAT, POTATOES, APPLES AND KIWIFRUIT

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Abstract

Nutrient budgets represent a method for comparing the sustainability and potential nutrient losses from different farm, crop or orchard systems both within and between countries. This paper describes the nutrient budget model OVERSEER™. The model covers pastoral farming (dairy, sheep, beef and deer farming), wheat, potatoes, apples and kiwifruit. It is an annual time-step model which generally assumes a long-term equilibrium for soil organic matter under pastures and mature horticultural crops, whereas under arable crops mineralisation/immobilisation reactions are influenced by period under cultivation and the timing of management practices. The model can be run for a number of blocks, where the block may vary in size from a small uniform 'paddock' to a region, and the blocks can be integrated on an area basis e.g. for a catchment.

The user defines site, soil and production parameters for a specific block and specifies management variables. Inputs and outputs of nitrogen, phosphorus, potassium and sulphur are calculated in kg/ha/year. The management variables for pastoral systems include stocking rate and supplement use, for horticulture crops are vine/tree age, extent of pasture understorey and pruning management, and for wheat and potatoes constitute pre-planting management options.

External nutrient inputs are from fertiliser, supplements, clover N_2 fixation and rainfall. Internal nutrient transfers include release from slowly-available sources in soil, release from mineralisation due to cultivation, removal by immobilisation/absorption reactions, excreta transfer by grazing animals, and in perennial crops include removal into crop framework during development. Nutrient outputs in produce, atmospheric losses and leaching are calculated. Total nutrient balances are then determined from the inputs, transfers and outputs on either a site (external inputs - external outputs) or productivity (including internal transfers) basis.

Introduction

A nutrient budget is a valuable indicator of the long-term sustainability of a farm system. It indicates where fertiliser applications are inadequate and leading to a decline in the soil nutrient status. Conversely, it can indicate excessive inputs which result in a nutrient surplus and greater potential for losses to the environment. Nutrient budgets also provide a method for comparing nutrient flows in different farm, crop or orchard systems both within and between farms, regions and countries.

In The Netherlands, simple nutrient budgets for N and P are being used as a guide to the potential environmental impacts of different farm systems and to provide a basis for taxing farmers with excessive nutrient surpluses. The mineral nitrogen accounting system (MINAS) requires all farmers to keep a record of N and P inputs to the farm (in fertiliser, feed or manure brought onto the farm) and to record outputs via produce, feed, and manure sold off farm. Grassland farmers in The Netherlands are permitted the following levy-free N or P surpluses (i.e. N or P inputs - N or P outputs) (O. Oenema pers. comm.):

	1998	2000	2002	2005	2008
N (kg/ha/year)	300	275	250	200	180
P (kg/ha/year)	17	15	13	11	9

This simple approach merely gives the difference between the inputs and outputs of nutrients through the farm gate as an indication of the potential environmental effect. Ideally, a nutrient budgeting system also provides an estimate of all inputs (e.g. including N_2 fixation) and the fate of the nutrients including that of leaching to groundwater and atmospheric losses. One of the objectives in development of OVERSEER was to provide a quantitative estimate of the fate of nutrients in accounting for all nutrient input and loss processes.

In 1996, AgResearch produced a preliminary nutrient budget model for pastoral farming systems, for MAFPolicy. This model (OVERSEER™) has been upgraded and expanded, in collaboration with Crop & Food, HortResearch and New Zealand Landcare Trust, together with support from MAFPolicy and FertResearch, to include wheat, potatoes, apples and kiwifruit. This new version of OVERSEER™ is currently being produced as a Windows 95 software application and is expected to be completed by July 1999.

Basis of the model

OVERSEER is an empirical, annual time-step model. It provides average estimates of the fate of the nutrients N, P, K and S in kg/ha/year, ignoring year-to-year variability due to climate etc. The model contains a number of databases for nutrient concentrations of fertilisers, animals, products, crop framework, and crop residues. These are used for estimating the nutrient inputs or outputs on a per-hectare basis.

Two different nutrient balances are calculated. The **Productive-Balance** is an estimate of the net balance of plant-available nutrients that may impact on plant production. It includes external nutrient inputs and removals. It also includes nutrients that are released from soil into the "plant-available" pool (release of P and K from soil minerals; net mineralisation of N, P and S following cultivation of arable soils) and nutrients that are removed from the "plant-available" soil pool (net immobilisation of N, P and S; absorption of P; gain in framework of apples and kiwifruit). This balance relates to the level of nutrients available for productivity and therefore it will be of most interest to farmers and consultants.

The **Site-Balance** is the total balance for the site and is the difference between nutrient inputs from outside the site and nutrients that leave the site i.e. it excludes the nutrients that are released to or removed from the "plant-available" soil pool as noted above for the productive balance. Loss via transfer refers only to the excreta which leaves the whole paddock area. This balance is more commonly of interest for policy bodies wanting to assess nutrient changes over large areas (e.g. regions, countries).

A key objective for model development was accuracy with simplicity. Users require a small amount of input information, which is easily obtained.

USER INPUT REQUIREMENTS FOR THE MODEL

The model is site-specific and therefore requires the user to enter site-specific data (see Table 1). Data entry is usually by simple tab-based selections. The user can run the model for several sites or blocks and the results can be integrated on an area-weighted basis. Thus, a farmer could run the model for different productive blocks and integrate them on a farm basis. Similarly, a policy-maker could use it to integrate different areas within a catchment, region or country.

Table 1. Information required by user to obtain a nutrient budget from OVERSEER™

Site information
Area (ha)
Slope (steep, easy, rolling, flat, border-dyke)
Soil group (pumice, volcanic, sedimentary, podzol, sand or peat)
Soil drainage (free- or poor-draining)
Distance from coast (km)
Rainfall and irrigation (mm)
Soil test information
Olsen P
Quick-test K
Reserve K level (very low, low, medium or high) or K_c test
Organic S test - for pastoral farming only
Fertiliser
Sulphate-S applied last year
Rate of nutrients or fertilisers for current 12 months
System information
Product yield
Proportion of clover (low, medium, high or very high – for pastoral and horticultural)
Management information
Pastoral
Stocking rate
Feed brought-in or sold (t DM/ha, type)
Animals brought-in or sold (number, type)
Horticultural
Years in current system (i.e. crop age)
Understorey (bare soil, herbicide strip, full pasture)
Pruning disposal (mulched, removed)
Arable
Years in current system (i.e. years under cultivation)
Month of cultivation
Fate of residues (straw removed, burnt, cultivated-in – for wheat)
Pre-crop management (fallow, greenfeed grazed, stubble grazed, green manure, other crop)

CALCULATIONS AND ASSUMPTIONS

Equations used in the model were derived from summaries of New Zealand research relevant to the different farming systems. In some cases, such as for the leaching of nutrients from horticultural crops, there was very little data available and therefore equations were extrapolated from the pastoral model with some modification using long-term data (crop yields, fertiliser inputs and soil test values) from grower properties.

Nutrient inputs in rainfall are estimated from the distance from the coast and the amount of rainfall, based on past research (e.g. Ledgard and Upsdell 1991).

Simulation of soil processes for P, K and S have been derived from the model of Metherell (this Proceedings). Those for N have been derived from summaries of past research on N immobilisation (e.g. Ledgard et al. 1988, 1998) and ammonia volatilisation (e.g. Black et al. 1985). Denitrification and leaching losses are estimated from the surplus of N inputs over N outputs and are apportioned according to soil group using the same principle as in the model NCYCLE (Scholefield et al. 1991) but with factors based on New Zealand research. A key assumption for N in pastoral systems and mature horticultural crops is that the Site-Balance is zero i.e. ΣN inputs = ΣN outputs (e.g. Ledgard et al. 1998).

For pastoral systems, it is generally assumed that the soil organic matter is in long-term equilibrium i.e. no net change per year. In the case of S, some net mineralisation or immobilisation can occur if the user defines a low or high soil organic S level relative to the expected level.

In mature horticultural crops, it is also assumed that the soil organic matter is in long-term equilibrium. However, if the user selects an immature crop which had been cultivated prior to establishment, there is net mineralisation of nutrients from the soil organic matter. In immature crops, an important additional source of removal of nutrients from the "plant-available soil nutrient pool" occurs through nutrient accumulation in the developing tree/vine framework.

In arable crops, soil organic matter levels change over time due to cultivation and net mineralisation of nutrients occurs from the soil organic matter. Model estimates of nutrient release following cultivation were derived from data on changes in soil organic matter due to period under cultivation (e.g. Haynes and Tregurtha 1999) and are based on an exponential function with time.

There are a number of nutrient flows specific to the different farming systems. In pastoral and horticultural systems, inputs of N can occur from N_2 fixation by pasture legumes. This is calculated from pasture production (estimated from animal production, stocking rate or crop understorey management), legume percentage in pasture and factors for N_2 fixation per unit legume production based on past research (Ledgard et al. 1987, unpublished). N_2 fixation rate is adjusted for the effects of N fertiliser application (e.g. Ledgard et al. 1996).

In pastoral systems, nutrient outputs occur via animal transfer. Transfer of excreta to lanes, sheds or animal camp sites is calculated from pasture intake (derived from animal production or stocking rate), pasture nutrient concentration (estimated from soil test and fertiliser input data) and proportion of excreta transfer (Metherell, this proceedings).

In horticultural systems, nutrient removals occur through gain in tree/vine framework and by removal of prunings. These are calculated from databases which are a summary of research on plant tissue yields relative to fruit yields, amount of prunings relative to framework, and the nutrient concentrations in plant tissues (e.g. Smith et al. 1988).

Two aspects of the model specific to arable systems are the effect of timing (monthly time-step) of cultivation and fertilisation, and pre-crop management effects on the fate of the nutrients. Relationships between the timing of cultivation, timing of fertiliser application and pre-crop management (e.g. grazing residues or growing a green manure crop) on the potential for leaching were developed based on previous research (e.g. Francis et al. 1992, 1994).

The following sections include example outputs from the model in comparison with measured nutrient flows for specific farm systems for dairying, apples and wheat.

DAIRY FARMING

Nutrient flows predicted by the model were compared with measured data (Ledgard et al. 1998; Rajendram et al. 1998) obtained from a farmlet in a long-term DRC experiment which received a fertiliser N input of 215 kg N/ha/year (Penno et al. 1996). This comparison (Table 2) used site data of a flat, volcanic ash soil stocked at 3.3 cows/ha and producing 1220 kg milksolids/ha. Initial soil test levels were Olsen P 35, Organic S 15, soil K test 8, and very low K reserves. Data from the farmlet trial were not used in the model development, except for estimation of immobilisation of fertiliser N into soil organic matter, which was based on a summary of four field studies (including the DRC farmlet study) using ^{15}N.

The model estimates generally compared well with the measured values (Table 2). Possible exceptions were apparent underestimation of gaseous N loss and N leaching. However, the measured data in Table 2 refers to the first three years of the trial and in the subsequent two years the N losses were lower. Thus, average losses over five years were nearer that estimated by the model.

The model outputs show clear differences between the productivity and site nutrient balances for N, P and K. For N and P, this difference reflects the estimate of removal by immobilisation/absorption in soil, which is not included in the site balance since it does not represent a loss from the site (i.e. the soil/pasture). For K, the site balance shows greater loss because the production balance regards the slow release of K from soil minerals as a gain.

The negative K balances in Table 2 indicate that the fertiliser K inputs were insufficient to counter all losses and removals of K. However, soil K tests at the site have shown little change over time, indicating that the model may have underestimated input from slow-release K or overestimated output in transfer. Either of these effects would result in a more negative estimate of the K balances. Nevertheless, a productive balance of –13 kg K/ha would only represent a change in soil K test of approximately -0.2. With N, the productivity balance is of limited use for indicating the general N status since in many cases it will be zero due to one of the underlying assumptions of the model. Instead, the estimate of nitrate leaching gives an assessment of the potential environmental effect, which in the example in Table 2 is relatively high.

Table 2. Nutrient inputs, outputs and balances (kg/ha/year) for a DRC Number 2 dairy farmlet in Waikato estimated using the model OVERSEER and as measured (Ledgard et al. 1998; Rajendram et al. 1998). Model values for fertiliser inputs and surplus supplements were based on entered values, whereas other model values were estimated by the model.

	N		P		K		S	
	Model	***Meas.***	***Model***	***Meas.***	***Model***	***Meas.***	***Model***	***Meas.***
INPUTS								
Fertiliser	215	215	54	54	70	70	70	70
Atmospheric	128	119	0		3		6	
Slow-release			*0*		*23*			
OUTPUTS								
Milk + meat	96	89	17		21		5	
Surplus suppl.	11	11	1		10		1	
Transfer	77	78	9		74		10	
Immob./abs.	*43*		*27*		*0*		*0*	
Gaseous loss	44	58						
Leaching	73	81	0		14	10	58	64
BALANCE-prod[1]	0		1		-13		2	
BALANCE-site[1]	54		28		-25		4	

[1]BALANCE-production = Σ all Inputs - Σ all Outputs; whereas BALANCE-site excludes the inputs and outputs in italics (i.e. those derived from or which remain within the site)

APPLE ORCHARD

The study of Haynes and Goh (1980) is the only detailed research on the fate of nutrients in apple orchards in New Zealand and this was used to evaluate model outputs. This study ran for two years on a flat sedimentary soil in Canterbury with an 11-year-old orchard producing 40 t/ha of fruit. Soil test results were approximately Olsen P 30 and soil K test 12. It was assumed that the soil would have high K reserves. The only data from this study used in model development were the dry matter yields and nutrient concentrations of tree structural tissues.

Model outputs were generally close to the measured values. Exceptions were K output in fruit and K leaching. The former was due to a very high K concentration in fruit of 3 g/kg fresh-weight measured in the study of Haynes and Goh (1980). This is much higher than the average of 1 g/kg fresh-weight used in the model, which was based on measured values in studies by Haynes (1990, which covered a survey of growers), Broom (1995) and Wilton (unpublished data). Leaching of K may have been overestimated in the model. However, the specific soil in the study was found to have a high level of K-fixing clays (Haynes and Goh 1980) which would have reduced leaching losses. If the model had used K output in fruit of 120 kg/ha instead of 40 kg/ha, it would have resulted in a lower estimate of K leaching of 7 kg/ha/year.

The site K balance in Table 3 is close to zero indicating that the sum of the 'external' inputs was similar to the sum of the outputs from the site. However, the productivity balance for K includes slow release K and shows that K availability to plants in soil was relatively high. This may have been the reason for the high K off-take in fruit measured by Haynes and Goh (1980). The small positive productive balance for N is due to carry-over of inorganic N, which occurred because of the low rainfall+irrigation at the site. P inputs were close to P outputs resulting in a productive balance for P which was near zero, and indicating that fertiliser P inputs were sufficient for a maintenance situation. Similarly, the productivity balance for S was low but this occurred because sulphate leaching was high relative to the other outputs.

Table 3. Nutrient inputs, outputs and balances (kg/ha/year) for a mature apple orchard in Canterbury estimated using the model OVERSEER and as measured by Haynes and Goh (1980). Model values for fertiliser inputs were based on entered values, whereas the model estimated other model values.

	N		P		K		S	
	Model	*Meas.*	*Model*	*Meas.*	*Model*	*Meas.*	*Model*	*Meas.*
INPUTS								
Fertiliser	72	72	20	20	57	57	32	32
Atmospheric	36		0		3	5	6	3
Irrigation	5	10	0		2	2	5	7
Slow-release			*3*		*41*			
OUTPUTS								
Fruit	20	21	4	4	40	120	1	0.2
Prunings	3	4	1	0.5	1	2	1	0.4
Framework gain	*3*		*0*		*2*		*0*	
Immob./abs.	*29*		*17*		*0*		*1*	
Gaseous loss	20							
Leaching	36	33	0	0.1	9	2	35	27
BALANCE-prod[1]	2		1		51		5	
BALANCE-site[1]	33		15		12		6	

[1]BALANCE-production = Σ all Inputs - Σ all Outputs; whereas BALANCE-site excludes the inputs and outputs in italics (i.e. those derived from or which remain within the site)

WHEAT CROPPING

There are no published data in New Zealand on nutrient fluxes for arable crops that cover nutrients other than N. Thus, the comparisons used in this section were for measured and model results for nitrate leaching for an experiment by Francis et al. (1995). It included treatments with different times of cultivation followed by either a fallow or a green-manure crop prior to planting spring wheat. This two-year study was on a flat sedimentary soil in Canterbury and had previously been in a grass/clover pasture for 3 years. No N fertiliser was applied.

Model estimates show reasonable agreement with measured leaching values, bearing in mind the variation between years in the latter (Table 4). The October/fallow treatment shows that delaying the timing of cultivation to near sowing for wheat had a major effect on reducing nitrate leaching. Planting a green-manure crop was predicted to reduce nitrate leaching by about two-thirds. In the first year of the study there was no measured benefit from the green-manure because most nitrate leaching occurred in early winter before the crop was well established, whereas in the second year leaching occurred later and the green-manure reduced leaching losses. In a different study, Francis et al. (1994) measured nitrate leaching of 110 and 37 kg N/ha with March cultivation/fallow versus March cultivation/green-manure treatments.

Table 4. Nitrate leaching (kg N/ha/year) associated with a spring wheat cropping system in Canterbury. Data refers to modelled estimates using OVERSEER compared to values measured over two years by Francis et al. (1995), for different months of cultivation followed by a fallow or green-manure crop prior to planting wheat.

Month of cultivation	**Post-cultivation management**	**Nitrate leached (kg N/ha/year)**	
		Model	**Measured[1]**
March	Fallow	105	72,106
March	Green-manure	35	81, 45
May	Fallow	48	8, 52
October	Fallow	0	2, 15

[1]Data are measured means for two different years

Conclusions

This paper describes the model OVERSEER™ which can be used to estimate the inputs, outputs and balances (from productivity and total site perspectives) of N, P, K and S for pastoral systems, apples, kiwifruit, wheat and potatoes. The user defines a number of site, soil and production parameters for a specific paddock/farm situation and a number of management variables. It has a role for farmers to check the adequacy of nutrient inputs in their current farm system and for policy bodies as one index of farm sustainability and potential environmental effects. It also provides a method for comparing nutrient flows in different farm, crop or orchard systems both within and between countries.

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Reading 2

USE OF OVERSEER™ TO COMPARE FARM SYSTEMS AND COUNTRIES FOR NUTRIENT BALANCES, LOSSES AND EFFICIENCY

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Abstract

The model OVERSEER™ provides quantitative estimates of nutrient inputs, outputs and balances on farms. These are useful indicators of farm sustainability and of potential nutrient losses to the environment. They are also useful to compare New Zealand farms with those in overseas countries. This paper presents data from the application of OVERSEER™ to estimate variability in nutrient balances, efficiency and leaching losses within and between farm systems.

Variability in nutrient balances and losses were examined for a range of dairy farms and sheep and beef farms in the Waikato region. There was a wide variation in site nutrient balances (i.e. Σ nutrient inputs - Σ nutrient outputs from the soil/plant/animal system) between farms (e.g. 1-111 kg P/ha/year on dairy farms). On average, the site nutrient balances were positive for N (18-21 kg/ha/year) and P (29-38 kg/ha/year) due to immobilisation/sorption in soil, but were slightly negative for K (-4 to -11 kg/ha/year).

Average data for different pastoral, horticultural and arable farm systems in New Zealand were used to derive preliminary national estimates of N balances and losses. National estimates for site N balance and nitrate-N leaching for farmed land averaged 13 and 8 kg N/ha/year, respectively. These estimates were influenced mainly by results for sheep and beef farms since they constitute most of the total land area under farming in New Zealand. There was a wide range in estimates of nitrate leaching of between 3 and 103 kg N/ha/year for extensive sheep and beef farms through to vegetable farms, respectively. N balance data for average farm systems in New Zealand calculated using OVERSEER™ are compared to those estimated using the OECD soil surface N balance method and the different approaches are discussed.

Efficient conversion of nutrient into produce is important from economic and environmental perspectives. Data are presented comparing the N and P efficiency of dairy farms in New Zealand with several European countries. While conversion of P inputs into milk are generally similar between countries, there is a wide variation in N use efficiency. Conversion of N inputs into milk averaged 14-18% for conventional dairy farms in Europe, compared to 32% for the average New Zealand dairy farm. Estimates of N conversion efficiency ranged from 44% for a productive dairy farmlet reliant on clover N_2 fixation as its sole N input, to 28% for a dairy farmlet receiving 200 kg N/ha/year. A very high producing dairy farm incorporating a feed-pad with cows fed on fruit and vegetable residues high in energy and low in protein had a conversion efficiency of 49%. The latter farm also had the lowest estimated nitrate-N leaching loss per unit of milk production. Thus, some highly productive farms are also capable of high nutrient efficiency.

Introduction

Nutrient balances are useful indicators of farm sustainability and of potential environmental impacts. They can be used to compare the adequacy of fertiliser inputs or of potential environmental effects within different parts of a farming system, or between different farm types. Nutrient balances are also useful to compare farms in New Zealand with those in overseas countries, especially those we trade with.

In New Zealand, the nutrient balance model OVERSEER™ was developed to provide quantitative estimates of nutrient inputs, outputs and balances for a range of different farming systems (Ledgard et al. 1999c). OVERSEER™ was developed by AgResearch, in conjunction with Crop&Food Research and HortResearch, and is available from MAFPolicy.

Fertiliser nutrients represent an important resource input on farms. High efficiency of nutrient use through conversion into agricultural produce is beneficial for profitable production and to reduce the nutrient surplus or potential for loss into the environment. Nutrient output in produce as a proportion of total nutrient inputs is a useful index of nutrient use efficiency and can be calculated using OVERSEER™.

This paper reports on the use of OVERSEER™ to examine variability in nutrient balances and losses within farm systems and to integrate average farm data to produce preliminary national estimates. Nitrogen (N) balances are compared with estimates using the OECD soil surface N balance method (OECD 1997). Data are also presented which compare the N and P efficiency of dairy farms in New Zealand with several overseas countries.

VARIABILITY IN NUTRIENT BALANCES BETWEEN PASTORAL FARMS

Examples of the range in inputs and nutrient balances within dairy and sheep and beef farms are demonstrated in Table 1, using data from the MAFPolicy Monitor Farm Programme for the Waikato region. In general, the average, minimum and maximum nutrient inputs, balances and leaching losses were higher for dairy farms than for sheep and beef farms. However, there was a very wide range in nutrient inputs, balances and leaching losses within each farm type.

Table 1. Summary of farm inputs of N, P and K in fertiliser, and nutrient balances and leaching (all in kg/ha/year) estimated using OVERSEER™, for 43 dairy farms and 20 sheep and beef farms in the MAFPolicy Monitor Farm Programme in the Waikato region.

	Fertiliser inputs			Site nutrient balance			Nutrient leaching		
	N	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***
Dairy farms									
Average	36	53	60	18	38	-11	28	<1	22
Minimum	0	16	0	2	1	-86	15		8
Maximum	166	123	133	74	111	46	56		45
Sheep/beef farms									
Average	6	31	13	21	29	-4	11	<1	11
Minimum	0	14	0	-9	9	-22	0		5
Maximum	38	68	91	71	65	70	27		21

Site N and P balances (Σ inputs in fertiliser, supplements, rainfall, N_2 fixation - Σ outputs in produce, animal excreta transferred off site, leaching and atmospheric losses) were positive in most cases and reflect model estimates of immobilisation of N in soil organic matter and of P immobilisation and/or sorption (to very slowly-available forms) in soil. High P balances may reflect farmers using capital P fertiliser application to raise soil Olsen P tests to desired levels. In the Netherlands, the government has implemented a system to limit excessive inputs of nutrients whereby farmers must provide data for calculation of N and P surpluses (e.g. Breembroek et al. 1996). Dutch farmers are taxed when N and P surpluses exceed set levels, which are currently 275 and 15 kg/ha/year for N and P, respectively. For P, they can work towards a P surplus near zero (i.e. Σ P inputs ≈ P outputs in produce) because their pastoral soils have soil organic P levels at equilibrium and very high levels of adsorbed P in soil (Aarts, pers. comm.). However, this would be inappropriate for New Zealand because in many cases immobilisation and sorption will be a significant removal from the plant-available P pool.

Site K balances were slightly negative, on average, for both farm types. However, this does not mean that K was limiting production since calculation of site K balances does not account for K supply from non-exchangeable sources in the soil. Nevertheless, it does suggest that a slow decline in total soil K levels is occurring over time.

The estimates of K leaching were of a similar magnitude to those for N leaching. Estimates of nitrate-N leaching were higher for dairy farms than for sheep and beef farms, with average values similar to those for the national averages for dairy and intensive sheep and beef farms (compare Tables 1 and 2). Net drainage from most dairy farms is typically above 350 mm/year and therefore the average leaching loss of 28 kg N/ha would result in the average nitrate-N concentration in water draining to groundwater of < 8 g m^{-3}. This is below the recommended maximum for drinking water of 11.3 g m^{-3} (Ministry of Health 1995). However, farms near the maximum of 56 kg N/ha leached could exceed the drinking water standard.

Preliminary N balances for New Zealand

Preliminary N balances for the main pastoral, arable and horticultural practices in New Zealand are summarised in Table 2. Estimates were obtained using OVERSEER™ and were based on typical average data collected from the MAF Farm Monitoring Programme, from MAFPolicy for the cropping systems, or from Livestock Improvement (1998) statistics for dairy farming. Values for site N balance were calculated from the difference between estimated nutrient inputs (in fertiliser, supplements, clover N_2 fixation and rainfall) and nutrient outputs (via produce, prunings/residues or animal excreta transferred off-site, atmospheric losses and leaching). This represents an estimate of the complete net N flows into and out of the plant/soil/animal system. The site N balance increased with increased intensity of sheep and beef farming and reflected increased incorporation of N into the soil organic N pool. Similarly, the highest site N balance for orchards (based on averages for apples and kiwifruit) reflects relatively large immobilisation of N into soil organic matter. In contrast, the negative N balance for arable crops (based on a broad "average" cereal crop) occurred because of losses of N from net mineralisation of soil organic N due to cultivation (e.g. Francis et al. 1992). The N balance for vegetables (based on an average for potatoes) was close to zero and coincided with much lower net N mineralisation than for arable crops because of the longer average period that land has been continuously growing vegetables.

Nitrate leaching calculated using OVERSEER™ gives a more direct estimate of the potential environmental effect on groundwater quality. Table 2 shows that estimates of nitrate leaching were very low for extensive and moderate sheep and beef farming, and that they increased with increasing inputs and intensity of farming through to 103 kg N/ha/year for vegetables. Data on the approximate relative area occupied by the different farming practices were used to aggregate the N balances and nitrate leaching losses into a national figure. Sheep and beef farming occupies the main area of farmed land in New Zealand and therefore it had a dominant effect on the weighted estimates.

This approach of assessing nutrient balances and losses within and between different farm systems using OVERSEER™ is valuable for assessing the impacts of different farm systems and key farm management practices. It warrants extending beyond the preliminary approach used in Table 2 to use of more accurate data, inclusion of other nutrients and application of OVERSEER™ using overseas data.

Table 2. Preliminary estimates of site N balance and nitrate leaching using OVERSEER™ for different farm systems in New Zealand.

Farm system	New Zealand area	Site N balance (kg N/ha/year)	Nitrate leaching (kg N/ha/year)
Sheep / beef			
- *extensive*	29 %	3	3
- *moderate*	41 %	17	1
- *intensive*	12 %	30	13
Deer	2 %	36	19
Dairy	13 %	13	27
Orchard	0.5 %	50	27
Arable	1.5 %	-43	36
Vegetable	1 %	-3	103
New Zealand average		***13***	***8***

OECD SOIL SURFACE N BALANCES COMPARED WITH NEW ZEALAND N SURPLUSES

The OECD has a number of agri-environmental indicators, which include a simple soil surface N balance (OECD 1997). This is similar to the "N surplus" or farm gate N balance concepts, which do not account for N output in transfer, atmospheric loss or leaching. Data for the different New Zealand farm systems was used to calculate a soil surface N balance using the OECD methodology, and this is compared to the N surplus (Σ N inputs – N in produce) calculated using results from OVERSEER™ (Table 3). These estimates were the same for the different cropping or horticultural systems, but the OECD soil surface N balance estimates for the pastoral systems were all negative. This was due to the OECD methodology for pastoral systems which considers livestock manure as an input and pasture N uptake as an output. It uses a constant coefficient per animal for manure, which is relatively high for New Zealand animals grazed outdoors on pasture. Clearly, this indirect approach is not well suited for grazed pasture systems.

Table 3. Preliminary estimates of N surpluses for different farm systems in New Zealand using OVERSEER™ compared to estimates calculated using the OECD soil surface N balance equation.

Farm system	New Zealand area	OVERSEER N surplus[1] (kg N/ha/year)	OECD soil surface N balance[2] (kg N/ha/year)
Sheep / beef			
- extensive	29 %	9	-1
- moderate	41 %	34	-35
- intensive	12 %	72	-34
Deer	2 %	94	-56
Dairy	13 %	100	-63
Orchard	0.5 %	100	100
Arable	1.5 %	8	8
Vegetable	1 %	172	172
New Zealand average		***42***	***-26***

[1] Σ N inputs – N outputs in produce

[2] Σ N inputs (including animal excreta) – N outputs in plants. For pastoral systems, the latter refers to total N uptake by pastures.

SOIL SURFACE N BALANCES FOR A RANGE OF OECD COUNTRIES

Estimates of soil surface N balances for agricultural land in a range of countries in the OECD are given in Table 4. The estimate for New Zealand is different from that in Table 3 because it was not calculated separately for the different farm systems but was based on national animal and crop data and average estimates for the whole country e.g. pasture production of 9 t DM/ha/year.

Table 4 highlights that some countries have intensive agriculture over much of the country and have high national N balances. New Zealand is at the middle-lower end of the range, although there has been concern expressed by MAFPolicy about the accuracy of the estimate for New Zealand (e.g. see comment above about pastoral system methodology) and this is being revised. Some countries are known to have areas of intensive agriculture with significant N losses to the environment (e.g. France and USA) but have very low N balances on a national basis. Thus, in their report on data in Table 4 the OECD (1997) noted that it is desirable to improve N balance calculations and to examine the spatial variation and results for different farming systems. OVERSEER™ has been presented to the OECD as an alternative for calculating N balances.

Table 4. Soil surface N balances estimated using OECD methodology for a range of OECD countries for 1993-1995 (OECD 1997).

Country	N input to agricultural land ('000 tonnes)	N input to agricultural land (% as fertiliser)	Soil surface N balance (kg N/ha/year for agric. land)
Australia	8174	7	2
Austria	411	30	57
Belgium	434	39	177
Canada	3151	44	9
Denmark	647	52	138
France	4155	55	4
Germany	3411	50	66
Greece	713	47	45
Ireland	854	47	55
Japan	1253	52	136
Korea	773	61	215
Netherlands	1005	?	272
New Zealand	1285	8	27
Poland	1822	44	51
Switzerland	286	?	86
Turkey	3312	40	17
UK	3041	45	76
USA	29380	37	21
OECD	75159	37	17

NUTRIENT USE EFFICIENCY IN DAIRY FARM SYSTEMS

In all farming systems, efficient conversion of nutrient inputs into product is important from economic and environmental perspectives. Dairy farming is relatively intensive and consequently is sometimes considered to be 'leaky' and inefficient with respect to nutrient use. Table 5 shows a comparison of the efficiency of conversion of the total inputs of N (from fertiliser, N_2 fixation and rainfall) and P (from fertiliser and slow-release soil P) into milk for the average New Zealand dairy farm, two farmlets at DRC Number 2 dairy near Hamilton and a commercial farm called Hawkes Bay Dairies Ltd. The latter farm achieves a very high milk production due to use of a feed-pad system whereby fruit and vegetable residues are fed to cows for about 3 hours per day and constitute almost half the dietary dry matter intake (for details, see Ledgard et al. 1999a).

The lowest conversion of total N inputs into milk-N occurred in the average New Zealand farm and the DRC farmlet receiving fertiliser N at 200 kg N/ha/year (Table 5). This N conversion efficiency was about 1.5 x higher in the DRC 0 N farmlet and Hawkes Bay Dairies farm. The high N efficiency in the 0 N farmlet occurred because of low N inputs (almost all from clover N_2 fixation) and relatively high milk production due to high pasture utilisation. High N efficiency on the Hawkes Bay Dairies farm was due to very high milk production at modest total N inputs. The main reason for this was that the fruit and vegetable residues were high in energy but very low in protein and gave a good balance to pasture which has more protein than cows need. Therefore, more dietary N was converted into milk and much less was excreted. These feed residues had about one-third the protein level of N-fertilised pasture. In highly N-fertilised pasture, <15% of the N consumed by cows is converted into milk. The rest is excreted, mostly in urine which is the main source of leached nitrate (e.g. Ledgard et al. 1996). Another measure of farm N efficiency is the amount of N leached per unit of milk production. Table 4 shows that this was least for the nil N farmlet and Hawkes Bay Dairies. Thus, highly productive farms are capable of high nutrient efficiency and low nutrient leaching per unit of milk production.

The highest conversion of total P inputs into milk-P occurred on the Hawkes Bay Dairies farm. Again, this can be attributed to greater conversion of dietary P into milk. One-half of the total P input at Hawkes Bay Dairies was in the fruit and vegetable residues. It is uncertain if the relatively low P fertiliser input in conjunction with the residue-P input is sufficient to maintain optimum soil P levels. One of the reasons for the greater P efficiency on Hawkes Bay Dairies is that it is on a sedimentary soil, which has a slightly lower net P loss than the volcanic ash soils of the DRC farmlets, and therefore has a lower maintenance P fertiliser requirement (Metherell et al. 1995).

Table 5. Comparison of milk production and N and P efficiency on different dairy farms in New Zealand.

	New Zealand average[1]	**DRC Number 2 dairy**		**Hawkes Bay Dairies**[3]
		0 N[2]	**+200 N**[2]	
kg milksolids/ha/year	750	1040	1210	2200
Total N input (kg/ha/year)	161	165	315	314
Total P input (kg/ha/year)	c.40	54	54	47
N efficiency:				
milk N/total input N	32%	44%	28%	49%
kg leached N per '000 kg milksolids	36	29	52	30
P efficiency:				
milk P/total input P	c.22%	22%	26%	54%

[1]N and P data estimated using OVERSEER from Livestock Improvement (1998) statistics; [2]Ledgard et al. (1999b and unpublished data); [3]Ledgard et al. (1999a)

A lower conversion efficiency of N inputs into milk and higher nitrate leaching loss are evident in dairy farms in Europe compared to New Zealand (Table 6). In The Netherlands the low N efficiency is due to the very high total N inputs in fertiliser and concentrates. Nitrogen inputs are lower on French and Danish farms but the efficiency of conversion of N inputs into milk is not much higher than in The Netherlands. However, the N efficiency is higher on organic dairy farms than on conventional farms due mainly to much lower N inputs (Table 6). In Denmark and to a lesser extent in France, the whole farm N efficiency is higher than indicated from conversion into milk since a significant amount of N is exported from the farms in crop and manure. The latter increases N efficiency to up to 38% on Danish organic dairy farms.

Table 6. Comparison of N and P inputs, surpluses and efficiency on 'average' dairy farms in Europe and New Zealand. Data includes comparison of conventional and organic farms.

	Netherlands[1]	Brittany, France[2]		Denmark[3]		New Zealand[4]
	Conv.	**Conv.**	**Organic**	**Conv.**	**Organic**	**Conv.**
Total N input (kg/ha/year)	479	267	115[5]	274	150	161
N surplus	405	206	77	173	112	100
Total P input (kg/ha/year)	51	*nd*[6]	*nd*	37	14	c.40
P surplus	37	*nd*	*nd*	19	7	c.31
N efficiency:						
milk N/total input N	13%	18% (20%)[7]	21% (23%)	14% (30%)	19% (38%)	32%
kg leached N per						
'000 kg milksolids	c.100	c.80	c.50	-	-	36
P efficiency:						
milk P/total input P	26%	*nd*	*nd*	19%	36%	22%

[1]Van Bruchem et al. (1999) national summary; [2]Simon et al. (1997) for 133 farms; [3]Halberg (1999) for 20 farms; [4]Livestock Improvement (1998) national summary; [5]N_2 fixation was probably underestimated by up to 40% and therefore this will be an underestimate; [6]not determined; [7]includes output from farm in crop and 'sold' manure.

These comparisons indicate that the New Zealand farm system dependent on clover N_2 fixation for most of the N input is generally more efficient at conversion of N input into milk than their European counterparts. However, there is much less variation in the efficiency of conversion of P inputs into milk between average farms in New Zealand and the conventional EU farms. The P efficiency was higher on the Danish organic farms than the conventional farms. This was due to negligible inputs of P on several of the organic farms, which is unlikely to be sustainable in the long term.

FUTURE ADDITIONS TO OVERSEER™

Further additions to OVERSEER™ proposed for 2000/2001 include incorporation of forestry, options for dairy farm effluent management, and greater environmental N information. The current version of OVERSEER™ can be used to examine the detail of many agricultural systems but when it comes to producing a national nutrient budget it is currently not possible to extend this to cover the large area of New Zealand under forestry.

The current model provides estimates of the per-hectare loss of N into the atmosphere and by nitrate leaching. An additional environmental N output page will be generated which separates atmospheric N losses into ammonia, total denitrification and N_2O emissions. Nitrate leaching information will be extended to include an estimate of the potential nitrate-N concentration in groundwater. Thus, it will give more direct estimates of N impacts on the environment.

In future, OVERSEER™ could also be extended to include nutrient balances for a wider range of crops, nutrients (e.g. C, Ca, Mg) and possibly to cover eco-efficiency in allied industries (e.g. product processing plants). Before the end of the year 2000, the nutrient balance model will be linked with the pastoral nutrient and lime requirement models in a single framework, which will be called OVERSEER™.

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Reading 3

USE OF OVERSEER® AS A TOOL TO IDENTIFY MANAGEMENT STRATEGIES FOR REDUCING NITRATE LEACHING FROM FARMS AROUND LAKE TAUPO

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Abstract

Environment Waikato intend introducing a Variation to their Regional Plan by September 2001 to protect water quality in Lake Taupo. Current slight deterioration in water quality has been linked to increased inputs of N to the lake and agricultural intensification can significantly influence this.

OVERSEER® has a potential role as an easily used tool for benchmarking farms and for farmers to examine the effects of a range of alternative farm management options on nitrate leaching. In this paper, nitrate leaching is estimated using OVERSEER® at 49 kg N/ha/year for a typical dairy farms in the district and at 14 kg N/ha/year for a typical sheep and beef farm. Data is presented on the effects of a range of different management practices to reduce nitrate leaching including reducing intensity (stocking rate, N inputs), changing feed source (e.g. maize silage instead of N-boosted pasture), changing stock type (e.g. from beef cattle to sheep or deer), and strategic winter management. The latter includes grazing animals off outside the lake catchment or on feed-pads during autumn/winter and showed potential for decreased nitrate leaching by up to 60%. Strategic winter management options are not in the current version of OVERSEER® but will be incorporated in the upgrade due out December 2001.

Introduction

Lake Taupo is New Zealand's largest lake and is a prominent feature for tourists. It currently has very high water quality but summaries of data by Environment Waikato have shown that water clarity has decreased during the past two decades (Vant and Huser 2000). Environment Waikato are planning to introduce a Variation to the Regional Plan in September 2001 to protect water quality. Prior to introducing this Variation, they have been actively involved in providing people in the Lake Taupo catchment with information on the water quality issue and discussion about the various factors affecting it. Nitrogen (N) is the major limiting factor to growth of phytoplankton in lake water and in turn the abundance of phytoplankton is the main determinant of water clarity (Vant and Huser 2000). The main inputs of N into Lake Taupo occur via nitrate leaching from land within the lake catchment. Apart from point-source inputs of N from sewage from communities around Lake Taupo, the highest leaching losses per hectare are from pastoral farming. Intensification of pastoral farming also represents the largest potential for increased inputs of N from nitrate leaching.

A series of community meetings have been held to outline 4 possible options for managing water quality in Lake Taupo. These range from doing nothing (option 4) and allowing continued deterioration through to returning water quality back to that prior to land development in the lake catchment (option 1). In practice, options 2 or 3 are preferred, which are retaining water quality at its current level or allowing some deterioration but freezing N inputs at their current levels. These options recognise that there is a lag of perhaps 10-20+ years between N leaching at the land surface and the associated effects on water quality. This is due to time lags associated with land management changes on nitrate leaching, movement of leached nitrate to groundwater, groundwater flows to streams or lake, and transit time in the lake.

FARMER CONCERNS

Uncertainty about the final content of the Variation to the Regional Plan means that farmers are unsure of the likely impacts on their farming operations. Examples of questions raised by farmers include:

1. Can sheep and beef farms be converted to dairy farming?
2. Is dairy farming possible with low nitrate leaching?
3. What is the effect of intensification of sheep and beef farming on nitrate leaching?
4. What management practices can be used to reduce nitrate leaching?

In order to answer such questions, an objective method for estimating nitrate leaching is required. One such method is the OVERSEER® nutrient balance model (Ledgard et al. 1999b).

OVERSEER®

OVERSEER® is an empirical, annual time-step model that provides average estimates of the fate of the nutrients N, P, K and S. Model details were given by Ledgard et al. (1999b). In brief, the model is site-specific and therefore requires the user to enter site-specific data. For N, this includes site (soil group, land slope, drainage and annual rainfall) and farm (product yield, stocking rate and stock type, N fertiliser applied, supplementary feed purchased or sold off the farm, and animals brought in or sold off the farm) information. All N inputs and outputs are calculated, with leaching and gaseous N losses being estimated from the surplus of N inputs over N outputs.

Farm input information can be altered by the user to enable "what if" scenarios to be examined. For example, the user can examine the effects of different inputs of N fertiliser or stocking rate.

OVERSEER® was used to provide estimates of the amount of nitrate leached from different farming systems within the Lake Taupo catchment, and the output from some of the evaluations was presented to farmers in the Environment Waikato (2000) discussion paper entitled "Issues and options for managing water quality in Lake Taupo". Results from these farm evaluations are presented in the following two sections.

DAIRY FARM MANAGEMENT EFFECTS ON NITRATE LEACHING

Dairy farm data was obtained for a "typical current dairy farm" in the Taupo district. Features of this farm used in the modelling exercise are:

1. Traditional seasonal supply dairy farm system stocked at 2.7 cows/ha and producing 800 kg milksolids/ha, with young stock grazed off-farm outside the lake catchment.
2. Flat land on pumice soil growing perennial ryegrass/white clover pasture.
3. Farm dairy effluent sprayed back on to pasture using best management practices.
4. Average use of N fertiliser at 100 kg N/ha/year.

The dairy cow stocking rate and milksolids production were based on information for the Waikato average (Livestock Improvement, 1998). The rate of N fertiliser application was based on a rate approximately 20% above the current Waikato average (T. Johnston pers. comm.) but on a similar level to the average for farms where N fertiliser is used. It was assumed that all farm systems contained pastures with typical average clover contents and that soil organic N was at an equilibrium level.

Application of OVERSEER® using the typical farm data resulted in estimated nitrate leaching of 49 kg N/ha/year (Figure 1). This was calculated to decrease by nearly 40% by substituting maize silage for fertiliser N-boosted pasture. These calculations were based on maize silage as an alternative feed source to supply the 1000 kg DM/ha estimated to be produced from the 100 kg N/ha/year applied as N fertiliser. The benefit from maize silage is due to its low N concentration (c. one-third that of N-boosted pasture) and greater conversion into milk (Ledgard et al. 2000). However, it was assumed that the maize silage was brought in from outside the lake catchment since cropping practices associated with growing maize may lead to significant nitrate leaching.

Alternatively, lower nitrate leaching could be achieved by reducing farming intensity. A stocking rate of 2 cows/ha producing 600 kg milksolids/ha with no N fertiliser use was estimated to reduce nitrate leaching to 25 kg N/ha/year (Figure 1). This leaching loss was similar to that for maintaining farm intensity on half the farm area and planting the other half in pine trees. Estimates for the effect of conversion into pine forest were based on the assumption that nitrate leaching would reduce to 2.5 kg N ha/year (Vant and Huser 2000) in the forested area.

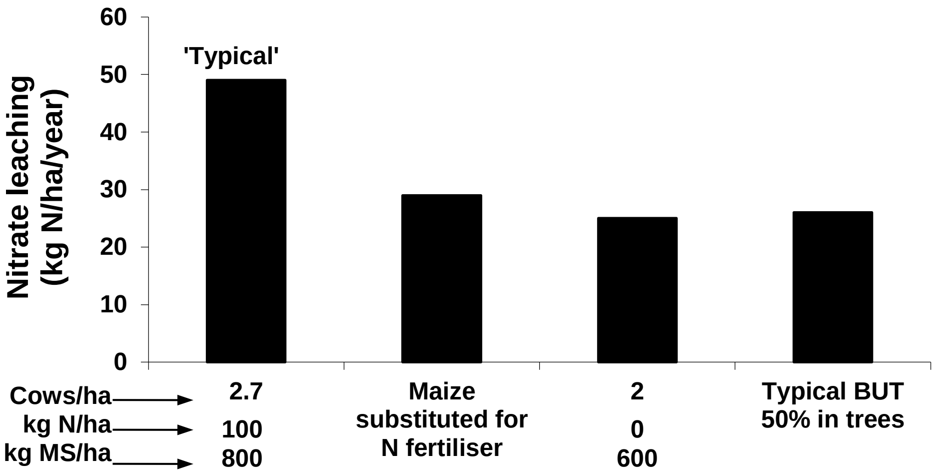

Figure 1: ***Nitrate leaching from a 'typical' dairy farm in the Taupo district and as affected by changes in feed source, farming intensity and conversion of half the land area into pine trees. Losses were estimated using OVERSEER®.***

Previous research in New Zealand (e.g. Ledgard et al. 1999a) has shown that most nitrate leaching is from urinary-N excreted by grazing animals. Leaching is associated with net drainage, which is largely confined to May-September. Thus, urine returned in autumn and winter, resulting in surplus inorganic N in soil when drainage occurs, is most susceptible to leaching. This was shown in two UK studies (Cuttle and Bourne 1993; Sherwood 1986) where little inorganic N was present in soil from urine deposited in late-summer, whereas high levels existed from depositions in mid- to late-autumn. Data from these studies was used to estimate effects of removing grazing animals at different times of the year on N cycling and nitrate leaching in model calculations of N flows by De Klein and Ledgard (2001). These model calculations were also applied to the Taupo farm data to assess potential effects of grazing cows out of the lake catchment from June-August or April-August (Figure 2). In the latter, it was assumed that a silage cut was also made and was not fed out during winter. The modelling approach of De Klein and Ledgard (2001) included an assessment of the effects of retaining the cows on-farm on a feed-pad and cutting and carrying pasture to them, with effluent collected and returned to pasture in spring and summer. Results from applying these winter management strategies (Figure 2) indicate that there is a large potential to reduce nitrate leaching. This was confirmed in a recent field experiment in Southland where strategic de-stocking in autumn-winter decreased the average nitrate-N concentration in drainage by about 60% (De Klein et al. 2000).

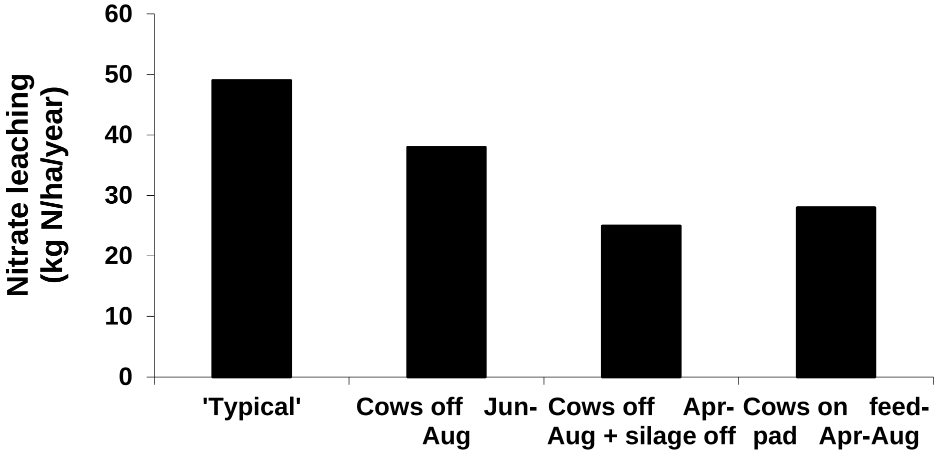

Figure 2: ***Nitrate leaching from a 'typical' dairy farm in the Taupo district and as affected by grazing dairy cows off the farm at different times or by putting cows on a feed-pad with effluent collected and applied to land in spring and summer. Losses were estimated using OVERSEER® in combination with model calculations (see text).***

Various combinations of farming practices were examined to determine the largest reduction in nitrate leaching from dairy farms in the Lake Taupo catchment, using "practical" methods. Two contrasting systems were identified (Figure 3). Low nitrate leaching could be achieved on the typical dairy farm producing 800 kg milksolids/ha by modifying management to include no N fertiliser use and substituting the extra feed source for maize silage (brought in from outside the lake catchment) and by 'housing' the dairy cows all year round. This would utilise a continuous cut and carry system for pasture and effluent would be collected and applied to land in spring and summer using best management practices. Alternatively a low intensity farm system could be used with 2 cows/ha producing 600 kg milksolids/ha, no N fertiliser applied, and cows on a feed-pad during April-August with effluent collected and applied to land in spring and summer. Both of these systems were calculated to decrease nitrate leaching to between 15 and 20 kg N/ha/year.

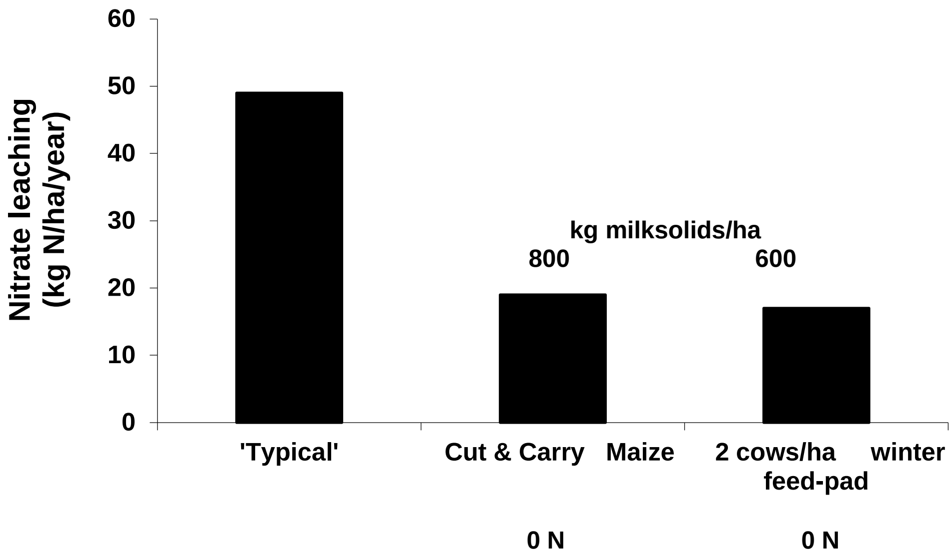

Figure 3: Nitrate leaching from a 'typical' dairy farm in the Taupo district in comparison with two alternative combinations of farm management practices to achieve low losses. Losses were estimated using OVERSEER® in combination with model calculations (see text).

SHEEP AND BEEF FARM MANAGEMENT EFFECTS ON NITRATE LEACHING

Sheep and beef farm data was obtained for a "typical current farm" in the Taupo district. Features of this farm used in the modelling exercise are:

1. Conventional sheep and beef breeding system at an equivalent of 12 stock units/ha, with 65% sheep and 35% beef cattle (breeding cows).
2. Rolling land on pumice soil growing predominantly perennial ryegrass/white clover pasture.
3. Average use of N fertiliser at 8 kg N/ha/year.

The stocking rate and farm management practices were based on information from MAFPolicy (1997) and from discussions with key local consultants in the lake catchment.

Application of OVERSEER® using the typical farm data resulted in estimated nitrate leaching of 14 kg N/ha/year (Figure 4). Cessation of N fertiliser use was calculated to have little reduction in nitrate leaching because of the low average rate currently being used on farms. Change in stock type from mixed sheep and beef to all sheep and/or deer, while maintaining the stocking rate, was estimated to decrease nitrate leaching to 10 kg N/ha/year. Alternatively, a similar decrease in nitrate leaching was calculated from a reduction in stocking rate to 8 stock units/ha. The model includes a difference in efficiency of N cycling from sheep and deer due to lower rates of N in excreta compared to that for cattle, which is supported by research studies (e.g. reviewed by Painter et al. 1997).

Winter management options were examined, as for the dairy farm example. Grazing the beef cattle out of the lake catchment from April-August was estimated to decrease nitrate leaching to 10 kg N/ha/year (Figure 5). A slightly lower reduction was calculated where cattle were kept on a feed-pad during the same period because of the increased N cycling associated with the return of excreta from the feed-pad. Grazing all animals (sheep + beef cattle) out of the lake catchment from April-August was estimated to give the largest decrease in nitrate leaching down to 6 kg N/ha/year.

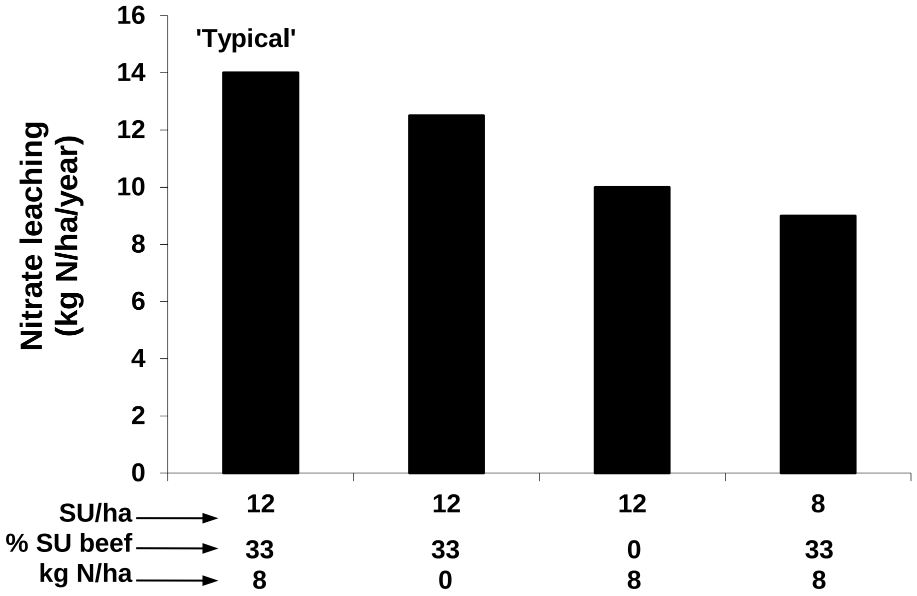

Figure 4: *Nitrate leaching from a 'typical' sheep and beef farm in the Taupo district and the effect of changes in N fertiliser, stock type or stocking rate, as estimated using OVERSEER®.*

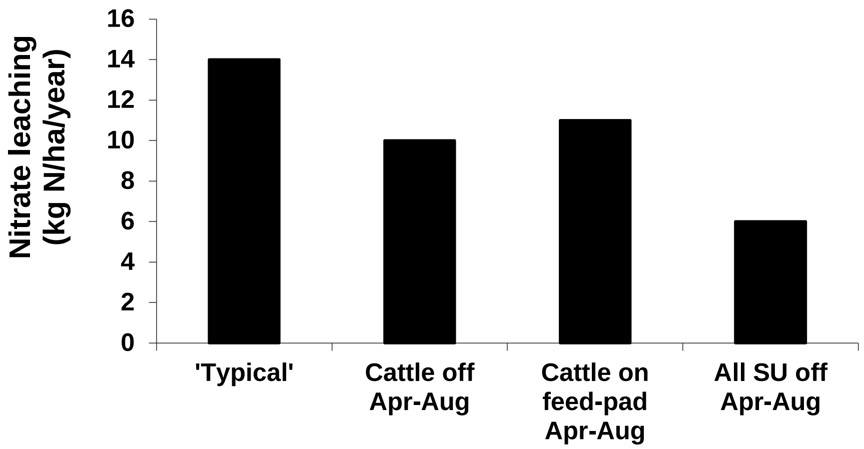

Figure 5: *Nitrate leaching from a 'typical' sheep and beef farm in the Taupo district and the effect of grazing animals off farm or on a feed-pad with effluent collected and applied to land in spring and summer. Losses were estimated using OVERSEER® in combination with model calculations (see text).*

LOCAL RESEARCH

In order to validate results from the above model estimates for the reduction in nitrate leaching from strategic grazing off in autumn and/or winter, field experiments have commenced in the lake catchment on medium and high rainfall sites. The experiments are examining the effect of timing of urine deposition on nitrate leaching from cattle and sheep urine. This is part of an AgResearch research programme in the Lake Taupo catchment. Other key aspects of the research programme are the study of economic and social consequences of the proposed Variation to the Regional Plan and of a range of management strategies to reduce nitrate leaching (examples of which are given in the two previous sections). In addition, the crown research institutes IGNS and NIWA are researching aspects of groundwater flows, N inputs via groundwater and streams, and N flows within Lake Taupo to better understand time-lags associated with N impacts on the lake.

Summary and planned additions to OVERSEER®

Environment Waikato intend introducing a Variation to their Regional Plan by September 2001 to protect water quality in Lake Taupo. Current slight deterioration in water quality has been linked to increased inputs of N to the lake and agricultural intensification has significant potential to influence this.

OVERSEER® has a potential role as an easily used tool for benchmarking farms. Farmers can use OVERSEER® to examine the effects of a range of alternative farm management options on nitrate leaching. Examples of farm management options to reduce nitrate leaching include reduced farming intensity, less N inputs, forage manipulation, and autumn/winter management to reduce deposition of animal excreta. Economic analysis of these options will allow optimal farm and catchment management plans to be developed.

The autumn/winter management options are not currently in OVERSEER® but will be incorporated in an updated version due for completion by December 2001.

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Reading 4

OVERSEER® NUTRIENT BUDGET MODEL – WHAT IT IS, WHAT IT DOES

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WHAT THE MODEL IS?

The OVERSEER® nutrient budget model is an on-farm decision support model to help users develop nutrient budgets for nitrogen (N), phosphorus (P), potassium (K) and sulphur (S), calcium (Ca), magnesium (Mg), sodium (Na) and hydrogen (potential acidity) on a block and farm scale. It also provides a greenhouse gas emission and energy inventories for each farm.

The model uses farm and block specific data to prepare nutrient budgets, which are tables showing nutrient inputs and output from a blocks within a farm, or on a whole farm basis. From this information reports are prepared so that maintenance nutrient and lime recommendations, nutrient use efficiency and potential environmental effects can be assessed. These reports include environmental and productivity indices, with comments to assist in interpretation of the information. Additional information such as the 'Use of fertiliser' booklets and 'Fertiliser Code of Practice 'is also supplied in electronic form, with direct links from the model at appropriate places. The model also has features the ability to select mitigation options to reduce environmental effects, and these can be shown in comparative tables.

The model was primarily designed as decision support software to aid with maintenance nutrients and lime recommendations, nutrient use efficiency and environmental effect reports. The model has expanded in capacity over time in response to additional drivers, and this process will continue with new management and mitigation options planned.

Ground rules for model development

An initial set of ground rules were established to guide development of the model, and these were:

- farmer-friendly input requirements
- farm scale
- based on New Zealand data (model, validation, defaults)
- quasi-equilibrium model (long term average)
- annual estimates
- assumed good management practice was followed
- actual and reasonable inputs
- mitigation options

Farmer-friendly inputs are inputs that farmers know, can be readily obtain, or where reasonable default values can be supplied. These were established by a mix of model requirements along with farmers and consultant comments, end user surveys and feedback from users.

The model operates at a farm scale, but also includes blocks (groups of paddocks with similar site, soil, and management parameters). The model tracks nutrient movement within a block (from zones of depletion to zones of accumulation such as stock camps), and within a farm. Within-farm nutrient movements include nutrients deposited on raceways, supplements brought in and fed on paddocks or feed pads, and effluent-nutrient movements from the farm dairy or feed pad out to the effluent paddocks or through a pond system.

The underlying algorithms are based on research done in New Zealand, and are linked to current science programs so that the model can be updated as new science results are obtained.

A quasi-equilibrium model means that the model makes predictions for a given management practice remaining 'relatively constant' over a medium time-period. The model was not developed as a day-to-day management tool, nor was it developed to make fertiliser recommendations (nutrient recommendations combined with local information to decide fertiliser type, rate, and application times).

The model was developed assuming that actual inputs would be provided. However, this has a constraint in that if an input parameter is changed, then all associated input parameters, particularly those associated with productivity, should also be changed. Two mitigation option examples may illustrate this:

- reducing N fertiliser is also expected to decrease pasture production, and thus animal production.
- adding a winter feed pad frequently requires a number of other farm management changes. For example, the farmer may hard-graze the farm in autumn before using a feed pad. There may also be increased milk production as supplements are brought in over winter to feed animals, yet the same amount of grass is grown over winter and fed in spring leading to higher production.

A range of mitigation scenarios have been added to the model that take account of these changes.

MODEL CONSTRUCTION

The model is constructed from a series of submodels developed by individual research teams (Table 1). For each submodel, the procedure was to identify processes that are important for the submodel, and then to identify a means of estimating that process using farmer friendly inputs or defaults based on other parameters e.g. rainfall, soil type. These submodels were developed from New Zealand field trial data, and were then developed further by extending them to cover the whole farm, and to cover all New Zealand pastoral sites.

A key focus has been the incorporation of a wide range of possible on-farm management practices, including those that can lead to mitigation of environmental impacts.

Block nutrient budgets are weighted average budgets for camp and non-camp sites within a paddock. The farm nutrient budgets are weighted averages of the individual block nutrient budgets, and nutrient flows not included in paddocks such as farm dairies, feed pads, laneways, oxidation ponds, etc. This structure has two implications. First, maintenance nutrient recommendations should not be derived from a block nutrient budget as block nutrient budgets include camp nutrient flows. Secondly, for farms with only one block, the nutrient budget for the block and the farm will differ due to transfers from the block to the race, ponds, etc.

Detailed estimation of nutrient inputs, flows, output, and changes in soil organic pools have been used to calculate maintenance nutrient and lime requirements i.e. amount of nutrient and lime required to maintain current soil test values.

Table 1. Overseer® nutrient budget submodels and references

Submodel	Reference
Pasture intake by animals	Clark (2001)
P soil and plant model	Metherell (1994), Metherell et al. (1995)
Paddock transfer coefficients	Metherell (1994)
	Ledgard & Brier (2004)
P runoff/leaching model	McDowell et al. (2005)
Ca, Mg and Na	Carey and Metherell (2002)
Acidity (maintenance lime)	de Klein et al. (1997)
Greenhouse / energy inventory	Wells (2001)
	New Zealand's greenhouse gas inventory (2005)
Nitrous oxide emissions	de Klein et al. (2001)
Methane	Clark (2001)

EXAMPLE MODEL: THE NITROGEN LOSS MODEL

Reviews of research trials show that the major driver of nitrogen (N) leaching in pasture is urine N deposited on the paddock, with rainfall, soil group and animal types modifying the amounts leached or lost in a gaseous form. The amount of N deposited by animals as urine was dependent on animal N intake, and the proportion of animal excreta N that was deposited as urine, which was estimated from N concentration in the diet (Fig 1).

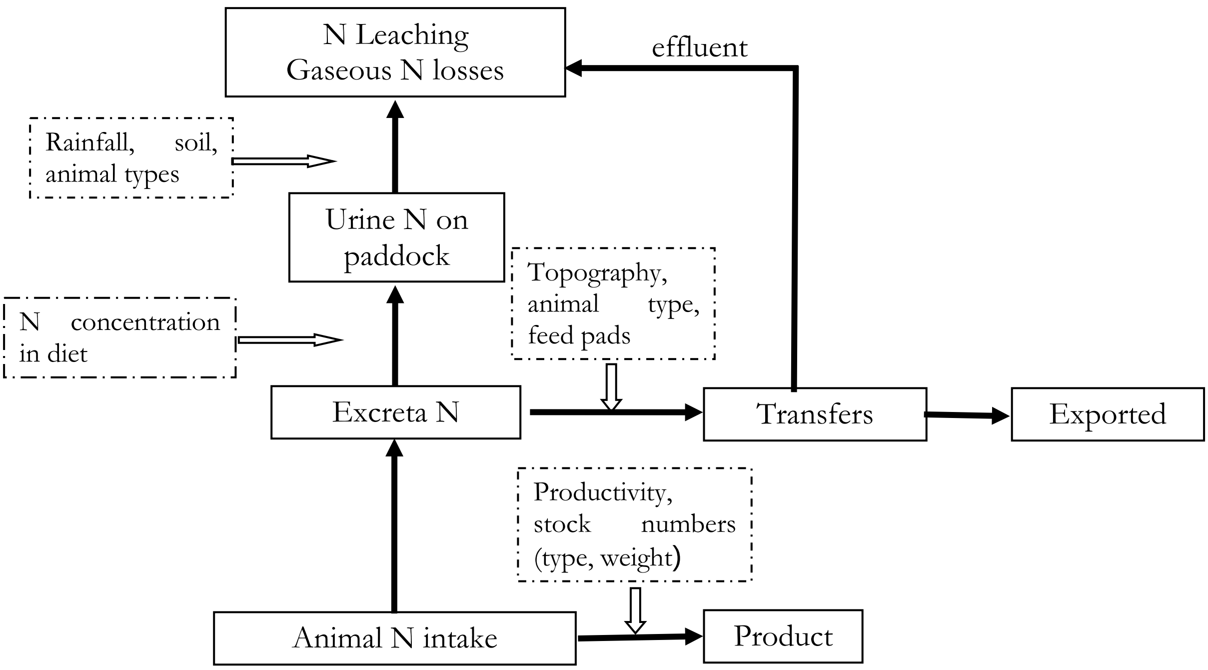

Figure 1. Schematic diagram of key components of the nitrogen loss submodel

This submodel was then expanded to a full farm model of nitrogen leaching and gaseous losses by including transfers and losses from other sources such as dung, fertiliser, lanes, farm dairy, ponds, feed pads, etc (Fig. 1). Losses include ammonia volatilisation from fertiliser, which is dependent on fertiliser rate, form of N and rainfall. Direct leaching of fertiliser was also included, being highest if high rates are applied in high-risk periods. It should be noted that the main effect of fertiliser is from increased plant N concentration, increased animal N intake and thus increased excreta N, and an increase proportion of excreta N lost as urine as average pasture N concentrations were higher.

Estimation of pasture production and utilisation, or pasture intake by animals directly, is difficult, particularly for general users. We circumvented this by estimating pasture intake by animals from productivity using a metabolic animal intake model (Fig. 2). This submodel provides values for animal N intake and N concentration in the diet that are used in the nitrogen loss submodel. All of the nutrient submodels use animal nutrient intake as a driver of some processes.

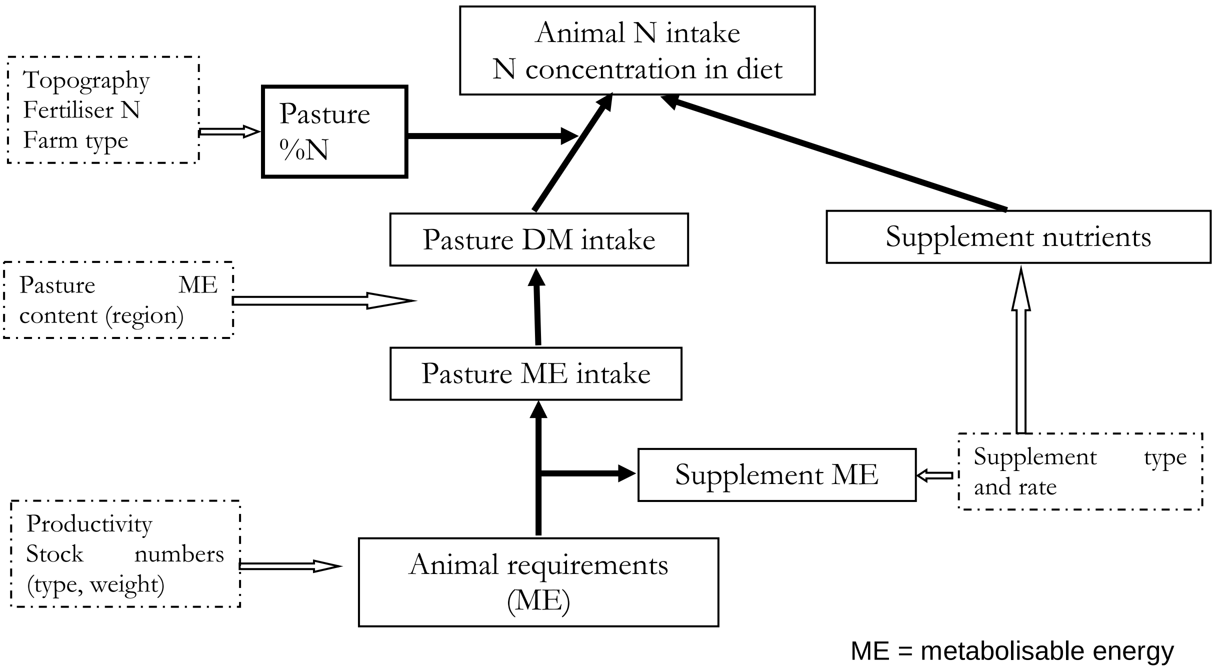

Figure 2. Schematic diagram of animal intake submodel

For dairy animals, sufficient information can be obtained from milk production, cow numbers, breed, and region, along with model defaults, to give a reasonable estimate of pasture intake by animals. The model does provide facilities to override the default with known user information. Supplement inputs may be important, particularly if their N concentrations differ from that in pasture.

For sheep/beef/deer systems, stock units are, in effect, a measure of pasture intake by animals. SUs are relatively easy to estimate for breeding stock, and published tables can be used provided they have taken into account increases in lambing percent, ewe weights and lamb weaning weights that have occurred over time. For trading stock, this estimate is more difficult as account needs to be taken for the time animals are on the property. A stock unit calculator has been added to the model, based on metabolic intake models, as a method to estimate SUs.

Conclusions

The Overseer® nutrient budget model is a decision support tool that helps users develop nutrient budgets, examine nutrient efficiency, assess potential environmental impacts, and evaluate the effects of mitigation practices.

The Overseer® nutrient budget model was developed as an on-farm decision support tool. However it has been selected as a possible tool to help meet regulatory requirements because the is based on best science, has a large research backing, has been checked against New Zealand field trial results, uses verifiable farmer friendly inputs, and is freely available for use.

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OVERSEER®: ACCURACY, PRECISION, ERROR AND UNCERTAINTY

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Summary

When debating the performance of models such as *Overseer's* ability to estimate whole-farm nutrient losses, four terms are often used almost interchangeably: accuracy, precision, error and uncertainty. However, the terms are not interchangeable and it is important to consider the implications of the commonly used terminology, in the context of this farm-scale nutrient budgeting model. Given that it is not usually practicable to directly measure whole-farm nutrient losses, use of the terms accuracy or error are not directly applicable, because there is no true value to compare an estimate with. Model uncertainty is the most relevant applicable term for annual whole-farm nutrient loss estimates. Model uncertainty will be greatest for conditions where there are no, or few, data for calibration and validation. Precision in the context of *Overseer* is about precision of input information.

Introduction

Agricultural nutrient models designed for practical application aim to provide decision support tools for farm advisors, farmers and consultants. They are especially useful for complex systems or when there is limited capability for actual measurements. For example, actual quantification of nitrogen (N) leaching from soil is difficult, particularly so at a paddock scale; all measurement techniques have advantages and disadvantages (Lilburne et al., 2012). Consequently, it is impractical to routinely monitor nutrient losses at an individual farm scale. However, farmers need to know the consequences of their farm management decisions if nutrient use efficiency is to be improved and catchment nutrient management goals met. For this reason, farm-scale models or decision support systems/tools are developed to model nutrient flows around the farm system.

There are a number of models in use in New Zealand, or are being developed, which aim to estimate N and phosphorus (P) losses from farm systems, and cover a broad range of scale and purposes (Cichota & Snow, 2009). This range of diverse models reflects both the different level of detail and scale at which N (and P) losses can be estimated.
Models such as OVERSEER® Nutrient Budgets ('*Overseer*') (Wheeler et al., 2008) must involve simplifications of complex processes, and the predictions that such models make will always involve uncertainties. In discussions relating to models, their applicability and use, a number of terms are often used: accuracy, precision, error and uncertainty. The aim of this paper is to set these terms in the context of models developed for estimating farm-scale nutrient losses, with particular reference to *Overseer*.

BACKGROUND TO NUTRIENT BUDGET MODELLING

Model approaches

Cichota & Snow (2009) observed that the differences in model complexity relate mainly to the numbers of pools and processes used to calculate the nutrient balance and they categorised models as 'complex' or 'simple'. For the purpose of this paper we have equated these terms with mechanistic and empirical modelling approaches, respectively. They can also be equated with 'research' and 'application' models. Research type models tend to be more complex; application models tend to be simpler in their approaches, by necessity.

Empirical models can be effective in summarising data and relationships and can provide practical tools for decision making. Empirical models are statistical descriptions of observed data. The relationships underpinning the overall model are typically based on experimental data. The main approach is to gather the data, design a single equation or set of equations, and fit these to the data. Consequently, the model describes the observed data. Because of this, empirical models do not give any indication of the factors and mechanisms that produce a given response, nor the possible reasons behind a response (Thornley and Johnson, 2000). Hence, extrapolation beyond the dataset used to develop the model might be problematic.

In contrast, mechanistic modelling aims to construct mathematical representations of the behaviour of a system based on the description of processes, thereby creating a deeper level of understanding. In mechanistic modelling, the system of interest is analytically broken down into components, to which processes and properties are assigned. There are a number of ways that a system can be separated into its components. Ultimately, the set of equations that characterise the system are integrated, and the responses of the system are constructed (Thornley and Johnson, 2000). Mechanistic models typically do not fit the observed data as well as empirical models, because there are many more assumptions built into them; or the models need 'training' to achieve this. However, the content of mechanistic models can be more comprehensive and applies to a greater range of systems and processes with the ability to interrelate them (Thornley and Johnson, 2000). If the underpinning science is sound, then there is more scope for extrapolating beyond datasets used to validate the model.

Model scale

Scale is an important consideration in model development. Many models are designed at the plot or field/paddock scale, while policy-makers usually need models that can be used at catchment, regional and/or national scales (Addiscott, 2003). Up-scaling and down-scaling models can cause problems. For example, up-scaling reduces the accuracy of inputs by ignoring a part of natural heterogeneity. Conversely, down-scaling requires increased accuracy (Addiscott, 2003). Validation and error propagation are also potential problems that need to be considered in up or down scaling models. This then raises the question of whether validation of a model at one hierarchical level is relevant to another, as well as parameterisation of a model and the ability of parameters to be transferred across scales (Addiscott, 2003); this is perhaps more of a challenge for simpler models.

Overseer

Overseer is a whole-farm nutrient budget model that provides users with a tool to examine the impact of nutrient use and flows within a farm (product, fertiliser, effluent, supplements or transfer by animals) on nutrient use efficiency and possible environmental losses. The model also provides a means to investigate mitigation options to reduce the environmental impact of nutrients within a land use. Users range from farmers and their consultants through to policy makers and policy implementers. The main assumptions underpinning the model are that: it uses long-term annual averages, i.e. the model assumes a 'steady state'; the system is in quasi-equilibrium (inputs commensurate with production levels on the farm); users supply actual and reasonable inputs; and management practice implemented on the farm follows good practice. Version 6 was released in 2013 and marked a major upgrade (software and science) of the model as summarised by Shepherd & Wheeler (2012).

The challenge with farm systems models (and often their purpose) is to model nutrient losses at a scale that cannot be practically measured, such as farm scale N leaching. Thus, *Overseer* is building up from specific component processes, such as those involved in urine patches, to the farm level, using accepted (and often published) relationships at the paddock or sub-paddock scale to model a representation of nutrient flows at the farm level.

Where does *Overseer* fit in the classification of Cichota & Snow (2009) of 'simple' and 'complex', as described earlier? We suggest: somewhere in between, i.e. a mixture of empirical and mechanistic. *Overseer* models nutrient transfers around a farm system to initially determine, for a given nutrient, when and how much is deposited on different parts of the farm (e.g., paddock, raceway, feedpad). Sub-models, varying in complexity and approach, then model the fate of these nutrients for each of the farm locations. For example, the N leaching model uses urine patch and 'background' sub-models to determine the fate of N sources (Shepherd & Wheeler, 2013).

ASSESSING MODEL PERFORMANCE

The following terms are often used in reference to model performance: accuracy, precision, error and uncertainty. There are international definitions for these terms (Anon., 1993).

Accuracy

The accuracy of a measurement system is defined as the degree of closeness of measurements of a quantity to that quantity's actual (true) or accepted value (where actual measurement is impractical). The concept of accuracy has limited application to the estimation of whole-farm nutrient loss because of the great technical difficulty of quantitatively measuring these losses, such as N leaching.

Error

In a modelling context, error generally refers to the difference between the modelled representation of a system, and the reality of the system (Heuvelink, 1998). The primary types of error include input, model, and output error; and models could contain combinations of these:

- *Input error* - Model parameters such as soil properties and weather and/or climatic data always contain errors. Some of these may be 'human error' or mistakes, and it is important to minimise this type of error.
- *Model error* - A fault in the model itself can arise from 'concept error', i.e. an error in understanding, or deliberate simplification of the system being modelled; or errors in measured data from experiments used to calibrate and validate the model. There is no specific test for these kinds of errors, but they can be exposed by sensitivity analysis and review critique. Another possibility is 'error in translation', where error occurs when converting the concept or theory into a set of mathematical equations and computer code. Translation errors are revealed during model verification (Addiscott, 2003).
- *Output error* - Output error can be a result of input error, model error or both. However, the concept of an output error clearly has limited application where actual measurement is not practicable and there is no 'accepted' value.

Precision
This is also called reproducibility or repeatability, and is the degree to which repeated measurements under unchanged conditions show the same results. This concept has some applicability to *Overseer* nutrient loss estimates.

Uncertainty
Uncertainty (in the context of modelling) can be defined as a potential limitation in some part of the modelling process that is a result of incomplete knowledge. The sources of uncertainty in environmental modelling can be divided into five categories (Table 1).

The concept of uncertainty is the most applicable term relating to the use of *Overseer*, i.e., given the number of assumptions and errors involved in the model, there will be a level of uncertainty attached to estimates of nutrient losses.

Table 1. Sources of modelling uncertainty (based on Walker et al., 2003).

Sources of modelling uncertainty	**Brief description and comment**
Context and framing	This can include choices about the physical boundaries of the system being modelled, the range of factors to incorporate into a model, and specific prediction choices.
Inputs	Uncertainties about inputs that drive the model, e.g. fertiliser, production, supplements, soil type, climate, etc.
Model structure	Models simplify reality and may be based on an incomplete understanding of the processes and structure(s) being modelled, e.g., the *Overseer* engine and our understanding of the underpinning science.
Parameters	Parameters used in the model need to be estimated or inferred from sometimes very limited data, e.g. parameters that drive the urine N leaching, crop N leaching, etc.
Model implementation	This can include technical modelling choices and potential software bugs.

DISCUSSION

A mathematical model such as *Overseer* can be a useful conduit for making recent research available to farmers and advisors, particularly if executed in a user-friendly computer interface. *Overseer* aims to be such a model. However, users need information on performance and clarity of required inputs, particularly as its use is widening, from farm management to support catchment nutrient management policy implementation. In any model, there is always a proportion of observed data, currently accepted theory and conjecture based on the best available information). Research models generally have a reasonable level of explicit conjecture; however, application models must give predictions based on the limited data and information available - if the uncertainty associated with an application of the model is not considered when using that model, there could be serious consequences (Thornley and Johnson, 2000).

The current dilemma for modellers is that in general, although application models for agricultural systems are related to observational data, are user friendly, and mathematically simple, they have a strong element of empiricism (Thornley and Johnson, 2000) which tends to ignore the more detailed levels of physiological and biological theory. This can results in less sensitivity of the model to changes in the environment and farm management; it also limits extrapolations. As a result, there is increasing demand for greater scope and applicability of agricultural models, requiring a more mechanistic approach; this approach requires more inputs, so is also more likely to produce predictions with larger uncertainties, however. There will therefore be an on-going tension between simplicity and complexity in approaches for modelling complex farm systems. The level of simplification chosen by the modeller will always be criticised by colleagues and other scientists who consider the model to be either too complex or not complex enough or that their particular discipline is under-represented by the model (Thornley and Johnson, 2000).

The above comments are general to all models. Questions specific to *Overseer* typically concern error, accuracy, uncertainty and precision.

Error/accuracy/uncertainty

When interpreting a model's predictive abilities, it is important to know whether the model has been calibrated. This is the process of adjusting model parameter values to maximise the agreement between a given set of data and the model outputs (Refsgaard, 2000; Trucano et al., 2006). The next step in the application of a model like *Overseer* is to validate the model to provide a method of assessing the confidence in the modelled outputs (i.e., testing to see how well the model outputs fit a set of independent data: Jorgensen, 2003). *Overseers*' pastoral N leaching model has had a significant amount of validation (Shepherd & Wheeler, 2013), whereas the P loss model is based on a calibration process (McDowell et al., 2005).

There are two major challenges in assessing the performance of *Overseer*:

- Farm-level nutrient losses are practically difficult, if not impossible, to measure accurately, so benchmarks against which to compared modelled values are rare and also carry large uncertainty.
- *Overseer* can be used for a very wide range of farm systems in many different geographical settings; validation or calibration data for all circumstances are not possible.

These challenges are additional to accounting for the complexity of farm systems and any issues around accuracy of input data (discussed later) and immediately illustrates that estimating error or accuracy of outputs is not practicably possible, given that the determination of actual values is extremely difficult (and has a large error associated with these measurements: Lilburne et al., 2012). We therefore contend that it is more appropriate to consider the uncertainty attached to the model's outputs. The issue then becomes that the uncertainty associated with whole-farm nutrient loss estimates will increase for situations that are well outside the calibration/validation range (Figure 1).

More data for calibration/validation data will be required to decrease this uncertainty, most notably for: cropping and beef & sheep enterprises; clay and shallow and light textured soil types; and locations with high (>1200 mm) rainfall.

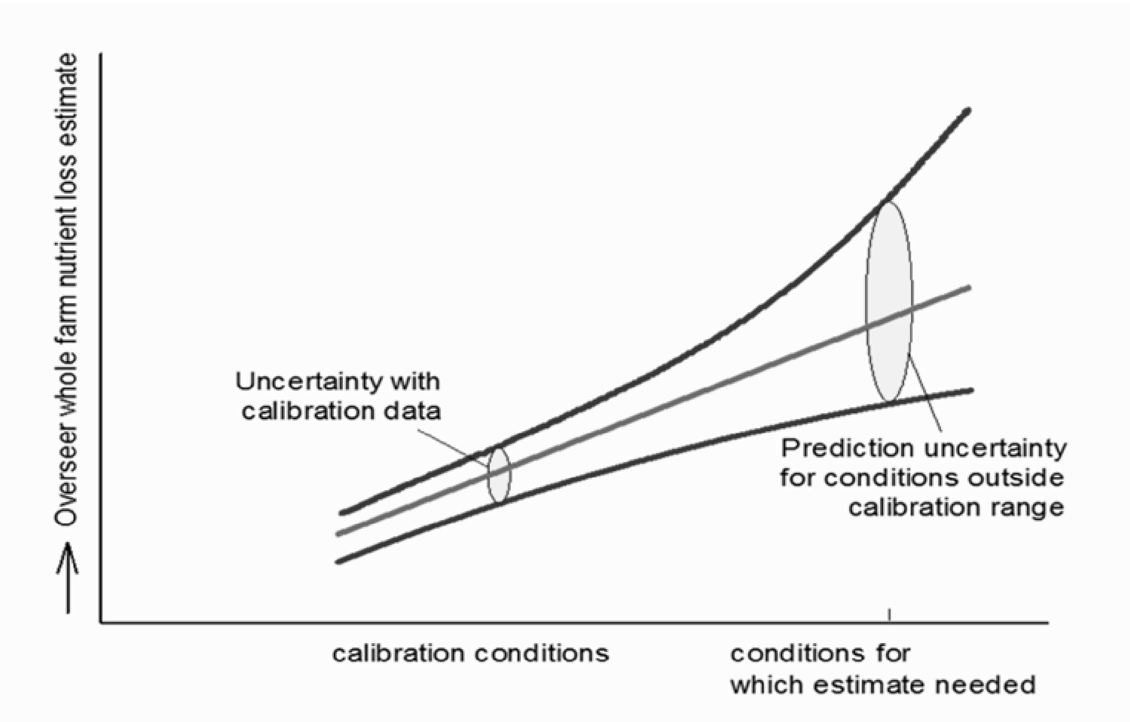

Figure 1. Representation of Overseer uncertainty (based on Loucks et al., 2005).

PRECISION

Given that precision is the measure of reproducibility or repeatability, for *Overseer*, this translates to the ability of multiple users to produce the same result. This relates to 'errors' around inputs, as discussed earlier. These 'errors' may well arise from differences in interpretation when the user is trying to translate a complex farm system into a moderate/manageable number of inputs. Improved precision of outputs will require users modelling the same (or similar) farm(s) to: (a) set up the *Overseer* file to represent the farm system in the same way, and (b) use the same input data (types and values of data). Model development has tried to address issues of data input by:

- Developing the model in such a way as to provide consistency of inputs between sectors and also between data entry methods if there is more than one way for entering data (e.g. entry of animal numbers).
- Developing the model using data, information and support structures (e.g. labels) that the farmer or consultant knows and understands.

However, setting up a farm system in *Overseer* requires a reasonable amount of interpretation and judgement by the user. The major limitation to improving precision can be potential differences in inputs entered by users. There is hence a need for guidelines for data entry and farm set-up.

The development of industry-agreed 'protocols' or input guidelines will be critical for improving confidence in all applications of Overseer. With that, the way the farms are modelled will be consistent and hence will provide confidence in the model outputs, both in absolute and relative terms. This high level of sensitivity of whole-farm nutrient loss outputs to many input choices means that if meaningful whole-farm nutrient loss estimates are to be achieved, agreed protocols are essential.

Conclusions

Models like Overseer must involve simplifications of complex processes and the predictions that such models make will therefore always involve uncertainty. Given that it is not usually practicable to directly measure whole-farm nutrient losses, use of the terms accuracy or error are not directly applicable. Model uncertainty is the most relevant term for annual whole-farm nutrient loss estimates. Model uncertainty will be greatest in conditions where there are no, or few, data for calibration/validation. Precision in the context of *Overseer* is about precision of inputs. Better precision and reduction of uncertainty could be attained by developing comprehensive guidelines for entering input data into the model.

Acknowledgements

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Reading 6

IRRIGATION IN OVERSEER®

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Introduction

In New Zealand, there were approximately 620,000 ha of irrigated land in 2013, with 38% on dairy farms and 26% on sheep/beef farms. About 84% of the total irrigated area was in the South Island (Irrigation New Zealand, 2014). The irrigation sub-model within OVERSEER® Nutrient Budgets (hereafter referred to as *Overseer*) has come under increasing scrutiny, particular in the Canterbury and Hawkes Bay regions. Although there have been no formal surveys, concerns about the Overseer irrigation model have centred on:

- The 'method only' option maintains soil moisture in a narrow range and thus does not reflect irrigation as it is commonly practised. Hence the 'method only' option, typically results in under-estimation of the applied irrigation;

- The 'method only' option does not have sufficient range in management options to reflect changes in nutrient losses when irrigation management practices are changed;

- Confusion over whether the 'method plus depth' or 'method only' option should be used to enter irrigation;

- Difficulty in determining the correct irrigation depths to align with climate inputs if the 'method plus depth' option is used;

In pastoral systems, irrigation increases pasture production and hence animal production. The resulted increase in pasture production results in higher nitrogen (N) intake by stock and hence higher amounts of N excreta as urine, the major source of N leached from pastoral systems. The amount of N leached is determined from the amount of N deposited and drainage (Wheeler *et al.*, 2011). Within *Overseer*, there is a daily single layer water balance model (Wheeler and Rutherford, 2014) which has the generalised form:

$$SM_t = SM_{t-1} + DailyRain + DailyIrrigation - AET - ROsurface - ROdrain$$

where SM_t is the soil water content (mm) to 600 mm on day t, DailyRain is the daily rainfall, DailyIrrigation is estimated daily irrigation (mm/day), AET is the actual evapotransipation (mm/day), ROsurface is the surface runoff (mm/day) and ROdrain is the drainage from root zone (mm/day). Daily rainfall and potential evapotranspiration, used in the estimation of AET, are derived from climate data (Wheeler, 2014). Drainage occurs when soil water content (SM) exceeds field capacity (Wheeler and Rutherford, 2014). Daily irrigation is estimated within the model using irrigation management rules.

The above equation shows that the addition of irrigation can increase soil water contents, and if this is larger enough results in drainage. For a given irrigation event, the likelihood of drainage occurring increases as the amount of storage available decreases, that is the difference between soil water content and field capacity. Thus, the amount and timing of irrigation can affect the amount of drainage. Irrigation also increases AET due to increased soil water availability.

Therefore, a project to improve the irrigation sub-model was instigated so that irrigation management rules within the model reflected the range used within New Zealand, and allowed a fair reflection of the impact of irrigation management practices on drainage and resultant estimates of N leaching.

PROCESS

The upgrade was initiated by implementing irrigation management rules into *Overseer* that are in IrriCalc (Bright, 2009), a standard model used for irrigation planning. The irrigation management rules in IrriCalc are based on a matrix of whether depth per application and return period is fixed, or determined by soil water content. This gives four basic systems, FF, VF, FV, and VV as shown in Table 1.

Table 1. Matrix of irrigation management rules used in IrriCalc.

		Return period	
		Fixed	Variable
Depth of application	Fixed	FF	VF
	Variable	FV	VV

The irrigation management rules in Table 1 where implemented in a development version of *Overseer*. A comparison between IrriCalc and *Overseer* outputs of annual actual evapotranspiration, irrigation and depths was undertaken based on four climate regimes, seven soil types and nine irrigation scenarios. Site-specific monthly climate data was used, which consisted. IrriCalc used 30 year daily data set (IrriCalc), and the outputs where average annual outputs. *Overseer* used average monthly climate data using the IrricClac climate data set, and the outputs where annual. This comparison indicated that:

- In the absence of irrigation, IrriCalc and *Overseer* estimates of drainage were similar,
- *Overseer* predicted similar irrigation and drainage depths to IrriCalc. There were small differences between the models in estimated irrigation depths for the variable management options,
- *Overseer* predicted AET was 100 mm higher than IrriCalc for the non-irrigated scenarios, and about 45 mm higher for the irrigation scenarios.

Hence, it was concluded that the irrigation management rules used in IrriCalc could be used within Overseer as the approaches were compatible with Overseer and the results were similar, and it provided the increase in range of management options required.

Two workshops where then conducted with an Industry group, facilitated by Irrigation New Zealand, to provide feedback on the model design. The development version of the model with the updated irrigation sub-model was upgraded for testing. The development model has now then been integrated into the main *Overseer* model in preparation for an April 2015 release.

IRRIGATION SYSTEM TYPES

Overseer now aligns with commonly accepted irrigation systems types used in New Zealand, as described by Irrigation New Zealand (Irrigation New Zealand, 2014). The irrigation system type options are:

- Linear and centre pivot
- Travelling irrigator
- Spraylines
- Micro-irrigation (drip and sprinkler)
- Solid set
- Controlled flood
- Border dyke

Irrigation system types are primarily used to set default data for management options and to estimate additional drainage associated with the delivery system and spay drift. Management rules were required that covered the range of irrigation system types typically used in New Zealand.

MANAGEMENT RULES

The management rules in IrriCalc (Table 1) where translated into four management options:

- Fixed depth and return period (FF)
- Trigger point; fixed depth applied (FV)
- Depth applied to achieve target; fixed return period (VF)
- Trigger point and depth applied to achieve target (VV)

with the input parameters that the user can enter for each option shown in Table 2. The first letter in the code in parenthesises is whether depth is fixed or variable, and the second whether return period is fixed of variable. Trigger point is the soil water content that triggers an irrigation event. Target is the soil water content that irrigation is applied to achieve. Both are dependent on profile available water (PAW) to 600 mm.

Table 2. Parameters for management options that use soil moisture data

Management option	Parameters
Fixed depth; fixed return period (FF)	Depth per application (mm/application) Return period (days)
Trigger point; fixed depth applied (FV)	Depth per application (mm/application) Minimum return period (days)* Trigger point[1]
Depth applied to achieve target; fixed return period (VF)	Minimum application depth (mm/application)* Maximum application depth (mm/application)* Return period (days) Target[1]
Trigger point and depth applied to achieve target (VV)	Trigger point[1] Target[1]

*optional input.
[1]units of % of PAW or mm deficit.

Border dyke and controlled flood irrigation only have the fixed depth and return period option. For border dyke, an option for management of border dyke outwash is included, with options of 'Outwash occurs' (the default) and 'No outwash'. Outwash results in loss of water and nutrients from the block, but these can be recycled within the farm.

The depth of application and return period vary with the irrigation system type (Irrigation New Zealand, 2014). For example, border dyke usually has higher depths per application and longer return periods than centre pivots.

The management rules define the depth per application and frequency of application, and whether these are fixed or vary with soil water content. The rules for determining when irrigation is applied and for determining the depth of applications are common to all systems. These are summarised as:

- For controlled flood and border dyke systems the fixed depth and return period' option is only available. Therefore, if time since irrigation equals the return period then the irrigation depth applied to the crop or pasture (mm/day) is estimated as the entered depth per application (mm/application).

- If the 'Trigger point; fixed depth applied', option is selected then an irrigation event is triggered when the soil water deficit reaches the trigger point, and if a minimum return period is entered or default option is selected, then the time since irrigation is equal to or greater than the minimum return period. If an irrigation event is triggered, then the entered application per depth is added as irrigation.

- For the 'Depth applied to achieve target; fixed return period' an irrigation event is triggered when the time since irrigation is equal to the return period. The application depth is estimated as the amount of water to bring the soil up to the target soil water content. The application depth is constrained by minimum application depth (if entered or if default option is selected) and the maximum application depth (if entered or if default option is selected).

- If the option 'Depth applied to achieve target; fixed return period', then an irrigation event is triggered as in point 2, and the application depth is estimated as in point 3. There are no constraints on the application depth or the return periods.

DATA REQUIREMENTS

The minimum data requirement is for the user to select the irrigation system type, the management options, and whether default values are used or the user enters parameter shown in Table 2. Most systems have only one set of default parameters. The exception is for Travelling irrigator and Sprayline irrigation system types which have two options, '1 shift per day' and '2 shifts per day'. The default values are available from the *Overseer* website.

A schematic representation of data decision tree is shown in Figure 1.

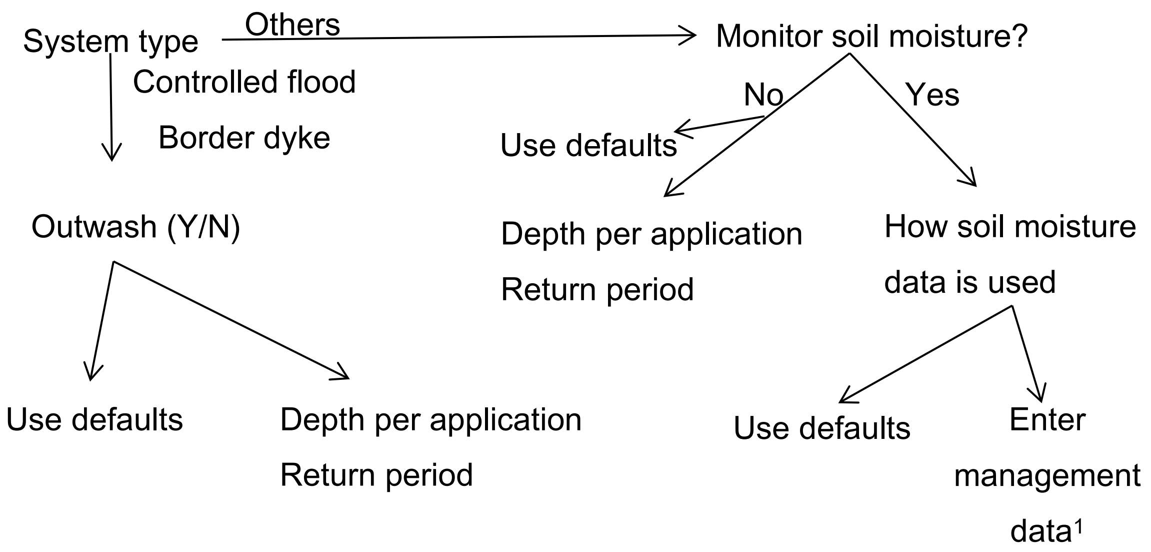

Figure 1. Schematic representation of decision tree for modelling irrigation using management options. [1]The data management options are shown in Table 2.

EXAMPLE OUTPUTS

Estimated irrigation rate, drainage rate and N leached for a range of management options are shown in Table 3 for a block receiving 600 mm rainfall, irrigated between October and March, on a light soil (PAW = 49 mm to 600 mm) or a heavy soil (PAW = 103 mm to 600 mm), using the default options. This analysis was undertaken using the development (pre-release) version of the model and hence values may change by the time of release. It is also important to note that these examples have been set for illustrative purposes only. The effects of management rules will depend on climate and soil characteristics, and only a small subset of possible options is shown in Table 3. However, Table 3 does illustrate several points:

1. Different management options give a large range of annual irrigation depths; for example, for light soils 350-1465 mm irrigation with a resultant drainage 197-1288 mm and N leaching of 40 to 147 kg N/ha/year.

2. High irrigation inputs lead to high drainage and hence high N leaching.

3. Irrigation management practices can be changed to reduce the effect on drainage and N leaching. In this example, adjusting the frequency of application so that water was only applied when a trigger point soil water content was reached (FV, VV options) resulted in lower N leaching.

4. For the travelling irrigator, even though a fixed depth and return period where used, the different annual depths are due to the default values being dependent on PAW for this system.

These examples also indicate that lower irrigation depth, drainage, and N leaching occur when applications are controlled by soil moisture monitoring (FV, VF, and VV options).

Table 3. Estimated irrigation rate, drainage rate and N leached for a range of default management options for a block receiving 600 mm rainfall, irrigated between October to March on a light soil (PAW = 49) and heavy soil (PAW = 103 mm).

	Light soil			**Heavy soil**		
	Irrigation (mm/yr)	**Drainage (mm/yr)**	**N leached (kg N/ha/yr)**	**Irrigation (mm/yr)**	**Drainage (mm/yr)**	**N leached (kg N/ha/yr)**
Border dyke	1337	852	147	1337	834	108
FF – centre pivot	970	777	107	971	794	87
FF – travelling irrigation	1465	1288	106	1097	1045	97
FV – centre pivot	350	197	40	315	157	16
VF – centre pivot	965	788	105	956	779	82
VV – centre pivot	365	227	40	328	170	16
FF – 25 mm 5 day return	981	804	106	971	794	87
FF – 50 mm 10 day return	1007	829	111	998	820	90

In pastoral systems, urine leaching losses are dependent on the amount of urine N added, which is a function of stock numbers, their diet and their location (whether they are on pasture), and the proportion of that N that leaches (Wheeler *et al.*, 2011). The proportion of that urine N that leaches is dependent on soil properties, drainage, and the rate at which N is removed from the urine patch, for example, by pasture uptake, volatilisation, and denitrification. The process that determined the proportion of N that is leached has been encapsulated in a unitless urine risk indicator, which is based on the current urine patch model. An example of urine risk indicators for non-irrigated and irrigated FF centre pivot option is shown in Figure 2.

In this example, irrigation is increasing the risk of N leaching in spring and summer, partly due to extra drainage in October (not shown) due to excess irrigation allowing urine N deposited in June to September to be susceptible to leaching losses. The susceptible is enhanced by low temperatures reducing N removal from the urine patch. Using a VV management system in October decreases drainage and thus reduces this impact. In the January to April period, the increased drainage due to the March irrigation has been offset by higher N removal by the pasture as the soils are moist and temperatures encourage the removal of N. This suggests that the shoulder periods (spring and autumn) are an important time to manage irrigation systems. In the examples in Table 3, no attempt was made to do this. Figure 2 also indicates that there are complex interactions between timing of drainage and urine deposition and N removal from the urine patch. Further work on N cycling in irrigated pasture systems is required to understand these interactions.

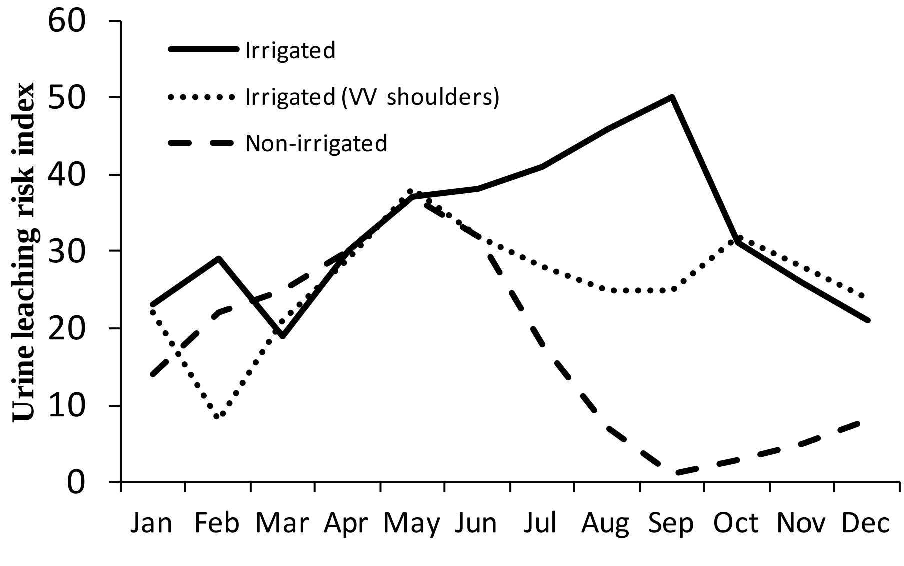

Figure 2. Urine leaching risk indicator for unirrigated, irrigated using centre pivot and default depth per application and return period, and the irrigation option except a VV option is applied in October and March (Irrigated VV shoulders).

COMPARISON WITH OVERSEER 6.1.3

Results from the earlier version of the model when the 'Method only' is used are similar to those for the new VV system for non-border dyke systems, and about 10% higher than VV for border dyke systems. The VV system is currently not widespread in New Zealand.

Hence, N leaching rates are likely to be higher than the previous model when actual management systems are added, and in some cases considerable higher. The technology to monitor soil water contents and the results to adjust the irrigation applications depths or frequency are available.

As in the previous version, when adding irrigation to a farm file that was previously unirrigated, it is still important that stock production be also increased. The block relativity input option within the model can be used to indicate production differences between dryland and irrigated blocks.

Conclusions

The implemented sub-model reflects a wider range of irrigation management practices than the current *Overseer* version. This will be reflected in a wider range of drainage and N leaching estimates and is better able to capture the effects of improved irrigation management. From the test runs undertake, the impact on drainage and N leaching is less when soil water contents are monitored and used to adjust irrigation management practice.

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