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

S F Ledgard[1], P H Williams[2], F D Broom[3], B S Thorrold[1], D M Wheeler[1] and V J Willis[3]
[1]AgResearch Ruakura Research Centre, Private Bag 3123, Hamilton
[2]Crop & Food Research, Private Bag 4704, Christchurch
[3]HortResearch Ruakura Research Centre, Private Bag 3123, Hamilton

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/yr)	300	275	250	200	180
P (kg/ha/yr)	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 NZ 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.

Acknowledgements

We thank A Metherell for supplying P and K model information; S Miller and B Stowell for supplying kiwifruit information; S Scarrow and R Underwood for data and comment on kiwifruit model; R Wilson for comment on apple model; K Muscroft Taylor, J Reid and G Francis for comment on apple model; D Ross for project coordination; MAFPolicy and FertResearch for funding model development.

References

Black, A.S., Sherlock, R.R., Smith, N.P., Cameron, K.C. and Goh, K.M. (1985) Effects of form of nitrogen, season, and urea application rate on ammonia volatilisation from pastures. *New Zealand Journal of Agricultural Research* 28: 469-474.

Broom, F.D. (1995) Spatial variation, Bitter pit and the quality of individual 'Braeburn' apple fruits. D Phil. thesis, Waikato University 159p.

Francis, G.S., Haynes, R.J. and Williams, P.H. (1994). Nitrogen mineralization, nitrate leaching and crop growth after ploughing-in leguminous and non-leguminous grain crop residues. *Journal of Agricultural Science, Cambridge* 123: 81-87.

Francis, G.S., Haynes, R.J. and Williams, P.H. (1995). Effects of timing of ploughing-in temporary leguminous pastures and two winter cover crops on nitrogen mineralization, nitrate leaching and spring wheat growth. *Journal of Agricultural Science, Cambridge* 124: 1-9.

Francis, G.S., Haynes, R.J., Sparling, G.P., Ross, D.J. and Williams, P.H. (1992). Nitrogen mineralization, nitrate leaching and crop growth following cultivation of a temporary leguminous pastures in autumn and winter. *Fertilizer Research* 33: 59-70.

Haynes, R.J. (1980). Nutrient status of apple orchards in Canterbury, New Zealand. 1. Levels in soil, leaves and fruit and the prevalence of storage disorders. *Communications in Soil Science and Plant Analysis* 21: 903-920.

Haynes, R.J. and Goh, K.M. (1980). Distribution and budget of nutrients in a commercial apple orchard. *Plant and Soil* 56: 445-457.

Haynes, R.J. and Tregurtha, R. (1999). Effects of increasing periods under intensive arable vegetable production on biological, chemical and physical indices of soil quality. *Biology and Fertility of Soils* 28: 259-266.

Ledgard, S.F., Brier, G.J. and Littler, R.A. (1987). Legume production and nitrogen fixation in hill pasture communities. *New Zealand Journal of Agricultural Research* 30: 413-421.

Ledgard, S.F., Penno, J.W. and Sprosen, M.S. (1998). Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. *Journal of Agricultural Science, Cambridge* (in press).

Ledgard, S.F., Sprosen, M.S. and Steele, K.W. (1996). Nitrogen fixation by nine white clover cultivars in grazed pasture, as affected by nitrogen fertilization.*Plant and Soil* 178: 193-203.

Ledgard, S.F. and Upsdell, M.P. (1991). Sulphur inputs from rainfall throughout New Zealand. *New Zealand Journal of Agricultural Research* 34:105-111.

Penno, J.W., Macdonald, K.A. and Bryant, A.M. (1996). The economics of No 2 dairy systems. *Proceedings of the Ruakura Farmers' Conference* 48: 11-19.

Rajendram, G.S., Ledgard, S.F., Monaghan, R.M., Sprosen, M.S. and Ouyang, L. (1998). Effect of rate of nitrogen fertilizer on cation and anion leaching under intensively grazed dairy pasture. In: *Long-term nutrient needs for New Zealand's primary industries: global supply, production requirements and environmental constraints.* (Eds. L D Currie and P Loganathan). Occasional report No. 11. FLRC, Massey University, Palmerston North. pp. 67-73.

Scholefield, D., Lockyer, D.R., Whitehead, D.C. and Tyson, K.C. (1991). A model to predict transformations and losses of nitrogen in UK pastures grazed by beef cattle. *Plant and Soil* 132: 165-177.

Smith, G.S., Buwalda, J.G. and Clark, C.J. (1988). Nutrient dynamics of a kiwifruit ecosystem. *Scientia Horticulturae* 37: 87-109.