OVERSEER® Technical Manual

Technical Manual for the description of the OVERSEER® Nutrient Budgets engine

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Crop based nitrogen sub-model

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Preface

OVERSEER® Nutrient Budgets

OVERSEER® Nutrient Budgets (OVERSEER) is a strategic management tool that supports optimal nutrient use on farm for increased profitability and managing within environmental limits.

OVERSEER provides users with information to examine the impact of nutrient use and flows within a farm and off-farm losses of nutrients and greenhouse gases. An OVERSEER nutrient budget takes into account inputs and outputs and the key internal recycling of nutrients around the farm.

See the OVERSEER website for more detailed information: http://www.overseer.org.nz

This technical manual

OVERSEER is made up of a user interface and an engine. These two components work together to enable users to generate nutrient budget reports. The Technical Manual provides details of the calculation methods used in the OVERSEER engine.

The OVERSEER engine is based on extensive published scientific research. Technical information about the model's development and use can be found in a growing number of conference proceedings and peer-reviewed papers. Given the ongoing upgrades many of the earlier papers no longer reflect the current version.

The Technical Manual chapters provide detailed descriptions of the methods used in the OVERSEER engine's main sub-models. The Technical Manual sets out the underlying principles and sources of data used to build the model engine. It is a description of the model as implemented, and hence references may not now be the most appropriate or cover the range of data of information currently available, or may not necessarily be the most up to date. If the source of some information and/or assumptions is not known or could not be found, this is acknowledged.

The chapters will continually be updated to reflect the current version.

If readers have feedback or further technical information that they consider could contribute to the future development of the model, please provide feedback via the website http://www.overseer.org.nz.

Scientific contribution to model development:

OVERSEER is a farm systems model covering a wide range of science disciplines. Since the model's inception, a large number of researchers from many disciplines and organisations have contributed to its development.

Researchers contributing significantly to the crop nitrogen component of the model described in this chapter include:

Hamish Brown, Plant and Food Research

Val Snow, AgResearch Ltd

Rogerio Cichota, AgResearch Ltd

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Crop based nitrogen sub-model

1. Introduction

1.1. Crop based models

OVERSEER incorporates multiple block types, and cropping and fodder crop blocks are an integral component of OVERSEER. The crop nitrogen (N) sub-model (henceforth referred to as the crop N sub-model) was developed under a Sustainable Farming Fund project (MPI 2008) and the resultant model published by Cichota *et al*. (2010). The outputs of this model are used to populate the nutrient budget and reports.

A cut and carry model has been developed using the same principles as the crop model (Wheeler *et al*. 2010). The underlying assumption was that the principles for N cycling in a cropping and in a cut and carry block are the essentially the same, and just the input parameters vary between the different blocks. Hence the same model has been used for both block types.

In the pastoral block, the N model is split between the urine patch model, and the background (inter-urine) N models. The background model is assumed to be the same as for the cut and carry model, and the crop model.

Fruit crop blocks are split into the main crop area and intercrop area. The main crop area is where the crop canopy is present, and may include some pasture, depending on the crop type, crop age and whether a sward is present. The intercrop area is outside the crop area, and pasture may be present depending on whether a sward is present or absent. The crop N model is used for both the main crop and intercrop area.

The leaching loss from urine deposited by animals that graze a block is estimated using the urine patch N model, which is detailed in a separate chapter. On pastoral blocks, in most cases, leaching from the background model is less than that from the urine patch. The exception is usually associated with high inputs of N such as fertiliser or effluent. On grazed cropping blocks, the biggest source of N leaching (urine patch or as estimated from the crop N sub-model) is dependent on the timing of grazing, and amount of N intake and hence urine deposition, and animal enterprises grazing, time of cultivation, fertiliser N applications and harvesting of the crops.

1.2. Basis of crop N model

The crop N model is based on estimating inputs and outputs from the soil N pool, a conceptual pool, each month. A 24 month cycle (2 year) is used, with the first year used to initialise the reporting year.

The model has the general form:

Equation 1: $N\_Min_t = N\_Min_{t-1} + Sum(N\ inputs) – Sum(N\ outputs)$

where N inputs included N added in rainfall and irrigation water, N added through N fixation, N added as fertiliser or effluent, and N from the decomposition of resident organic matter and residues. N outputs include N lost through volatilisation, denitrification, leaching, and N uptake from the soil. The model is depth independent except for leaching, which is based on soil properties and drainage at 600 mm depth.

Although a 2-year cycle is used, only information from the second 12 months of the cycle is reported (the reporting year) (Figure 1). This way, the effect of residues from the previous year on the reporting year's N cycling is included.

The source of data for the first and reporting year also varies with the block type.

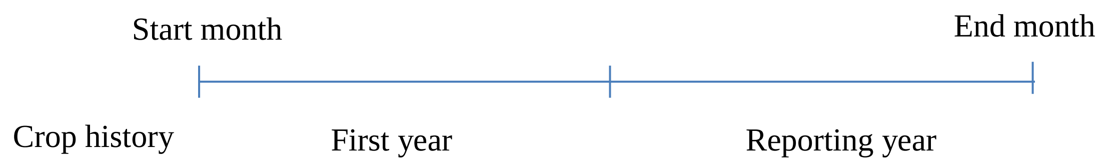

Figure 1. Schematic layout of the crop model.

On crop blocks, the crop rotation is entered using a 24 month grid. The input grid captures the crop management, hence growth patterns, and user-defined irrigation and fertiliser inputs over the 24 month cycle. Thus the inputs for the first and second year can be different. The user enters the final month of the grid. The model also takes account of crop activity prior to the 2 year cycle as the effects of N release from residue decomposition can continue over more than a 12 month period.

In pastoral, cut and carry, and fruit crop blocks, the cycle is based on internal pasture or crop growth patterns, monthly effluent inputs based on the user-defined effluent management system, and user entered monthly fertiliser and irrigation inputs. The first year is assumed to be the same as the reporting year.

In fodder crop blocks, the crop rotation is captured over a 12-month period (the reporting year). The user enters the end month (the month that the fodder crop area is sown back into pasture), and the crop rotation, irrigation and fertiliser inputs over the 12 months. As the fodder crop rotates through pasture blocks, the first year is based on an area weighted average of inputs into the pastoral block.

This chapter describes the inputs used to drive the crop N sub-model (section 2); the key mineralisation models for soil organic matter and crop residues used within the model (section 3); model and the other methodologies used within the sub-model (section 4), and the outputs from the sub-model (section 5).

1.3. Workings of the technical manual

The aim of the technical manual is to provide a level of detail so that users of OVERSEER can clearly see the underlying principles and sources of data used to build the components of the model. This technical chapter is part of a series of technical manuals currently under development to explain the inner working of the OVERSEER engine.

In the equations in this manual, units are shown using ( ) and cross-references other equations and sections within this manual or to other chapters of the technical manual are shown using [ ]. Equations with multiple '=' options are cascading alternatives in the order they are considered. The condition is shown on the right hand side. The variable and parameter names used are generally shortened names of the property, and this naming convention is similar to the convention used in the OVERSEER engine model.

1.4. Subscripts, abbreviations and chemical symbols

Subscripts

mon month of year

Chemical symbols

N Nitrogen

2. Inputs

This sections lists the inputs into the model. These inputs are estimated within the block models. The following sections provide more details about the inputs, and in some cases details of the methodology are provided where there is no other interactions with other block processes.

2.1. List of inputs

The list of inputs used in the crop N sub-model are shown in Table 1. Unless indicated otherwise, monthly inputs:

- for crop blocks are derived from the description of the crop rotation.
- for the first 12 months in fodder crop blocks is based on estimating pasture production, and the second are derived from the definitions of the 12-month crop rotation.
- for pastoral, cut and carry and fruit crop blocks, the first and second years have the same inputs.

Table 1. Inputs for the crop N sub-model.

Variable	Description	Units	Section or chapter
IsPasture	Is a pasture block (true/false).		Section 2.2
FinalMonth	Final month of the 2 year cycle.		Section 2.3
initialN_min	Initial soil mineral N value.	kg N/ha	Section 2.4
YIP	Years in pasture.		Section 2.5
Cult_Pract	Monthly[1] method of cultivation.		Section 2.6
MAC	Monthly[1] value of number of months after the last cultivation event.		Section 2.7
fyieldSOM	Low mineralisation rate		Section 3.2.2.2
LowNMinPasture	Low N mineralisation occurs (true/false).		Section 3.2.2.2
Immrate	Immobilisation rate		Section 4.3
WSoilMoistMon600	Soil water content to 600 for each month (mm).	mm	Hydrology
WDrainageMon600	Estimated amount of drainage at 600 mm depth each month.	mm/month	Hydrology
TotalDrainage	Total annual drainage at 600 mm depth.	mm/year	Hydrology
FC600	Field capacity to 600 mm depth.	mm	Characteristics of soils
AvailWater600	Plant available water to 600 mm depth.	mm	Characteristics of soils
MonthTemp	Monthly[1] average air temperature.	°C	Climate
Nrain	Annual N added in rainfall.	kg N/ha/year	
Nirrig	Monthly[1] N added in irrigation water.	kg N/ha/month	Section 2.8
NDung	Monthly[1] N added as dung deposited by animals grazing	kg N/ha/month	Section 2.9
NEffluentInorg	Monthly[1] Inorganic fraction of effluent N (all types) added.	kg N/ha/month	Section 2.10
NEffluentSolid	Monthly[1] organic fraction of effluent N added as a solid.	kg N/ha/month	Section 2.10
NEffluent	Monthly[1] organic N added as slurry effluent.	kg N/ha/month	Section 2.10
NEffluentWP	Monthly[1] organic N added as slurry effluent from the wintering pad.	kg N/ha/month	Section 2.10
NImportSolid	Monthly[1] organic N added as imported solid effluent.	kg N/ha/month	Section 2.10
NImportDairy	Monthly[1] organic N added as slurry imported dairy effluent.	kg N/ha/month	Section 2.10
NImportPig	Monthly[1] organic N added as slurry imported piggery effluent.	kg N/ha/month	Section 2.10
NVolatil	Monthly[1] volatilisation of N from fertiliser (kg N/ha).	kg N/ha/month	Section 2.11
NSolubleFert	Monthly[1] N added as soluble fertiliser	kg N/ha/month	Section 2.11

Variable	Description	Units	Section or chapter
NFertOtherInorg	Monthly[1] N added as organic fertiliser that is in the inorganic form	kg N/ha/month	Section 2.11
NFertOtherOrg	Monthly[1] N added as organic fertiliser (organic and inorganic fractions)	kg N/ha/month	Section 2.11
NFixed	Monthly[1] N fixed by the crop or pasture.	kg N/ha/month	Section 2.12
ResidualStoverNut	Monthly[2] nutrients added as stover residues.	kg nut/ha/month	Section 2.13
ResidualRootNut	Monthly[2] nutrients added as root residues.	kg nut/ha/month	Section 2.13
NPrunings	Monthly[1] N added as prunings.	kg N/ha/month	Section 2.14
NUntilSupplements	Monthly[1] N added as unutilised supplements fed on a block	kg N/ha/month	Section 2.15
Nuptake	Monthly[1] N uptake by the crop or pasture.	kg N/ha/month	Section 2.16
ko_Stover	Monthly[2] release rate for stover N ($ResidualStoverNut_N$).		Section 3.3
ko_Roots	Monthly[2] release rate for roots N ($ResidualRootsNut_N$).		Section 3.3
ko_other	Monthly[1] release rate for organic fraction of fertiliser additions.		Section 3.3
ko_supplement	Release rate for unutilised supplements.		Section 3.3
ko_liq	Release rate for the organic fraction of liquid (slurry) effluents (NEffluent and NEffluentWP).		Section 3.3
ko_solid	Release rate for the organic fraction of solid effluent (NEffluentSolid).		Section 3.3
ko_liqImport	Release rate for the organic fraction of imported liquid (Slurry) effluents (NimportDairy and NimportPig).		Section 3.3
ko_solidImport	Release rate for the organic fraction of imported solid effluents (NImportSolid).		Section 3.3
DCDFert	Monthly[3] DCD fertiliser factor.		

[1] 24 months of data in order of the crop rotation

[2] 25 months of data in order of the crop rotation, with the first month (month = 0) used to initialise the model.

[3] 12 months of data – currently only applies to the pastoral block

2.2. Pasture blocks

A pasture block is a block with continuous pasture and for which 'pasture' effects on mineralisation are required. Thus the input IsPasture is true for pastoral and cut and carry blocks, and fruit crop inter-row areas when a sward is present.

2.3. Start month

The start month for the 24 month cycle (Figure 1) is the start month of the input grid for describing the crop rotation for cropping and fodder crop blocks (determined from the final month users select), and January for other block types (final month is December). It is used to align month based data such as DCD effect, which is based on a January to December cycle, with the data from the crop description, which is based on the final month of the input grid.

2.4. Initial soil mineral N

The value of the initial soil mineral N varies with block type. In most cases, the initial soil mineral N level has little effect on model outputs in the reporting year. Soil mineral N is nominally to 600 mm as that is the depth drainage is estimated at, otherwise it is depth independent.

Pastoral blocks

An initial value for soil mineral N of 50 kg N/ha was used. However, in some pastoral blocks, the soil inorganic N pool was not reaching equilibrium, resulting in high N leaching. This was typically occuring in sites with low N uptake (low pasture yields) and dry sites, that is site were uptake, leaching or dentirification were not sufficient to reduce the initial value of soil inorganic N to one that was near equilibrium in the first 12 months. Hence the initial value of soil mineral N was estimated as:

Equation 2: $N\_Min_0 = 50 * DMpasture/15000$
DMpasture is the estimated block DM production (kg DM/ha/year).

Cut and carry and fruit crop blocks

It is assumed that these systems use N efficiently and hence initial soil N levels would be low. Thus:

Equation 3: $N\_Min_0 = 10$

Crop blocks

The initial soil N levels was arbitrarily set to 10 kg N/ha for fodder crop blocks. The initial soil N levels for crop blocks were estimated from a subjective assessment of mineral soil N levels (section 4.1) under typical crop rotations replicated each year. Thus, initial soil mineral N was based on the previous history, a user selected option, and had the values of:

Equation 4: N_Min_0 = 10 Pasture, Regrowth Seed White Clover, Regrowth Seed Ryegrass
= 30 Crop
= 20 Grain crop

= 15 Otherwise

2.5. Years in pasture

Years in pasture is the number of years the block is in pasture 10 years prior to the current and previous year for the period, that is for years 3 to 12, given current (reporting) year is year 1, and year 2 is the previous year. The timing of cropping phase is ignored. Thus if over the 10-year period, 5 years in crop and 5 years in pasture, or 5 years in pasture and 5 years in crop, or 3 years in pasture, 2 years in crop, 2 years in pasture and 3 years in crop are counted as 5 years in pasture. A year in pasture is defined as at least 8 months of the year in continuous pasture.

For cropping blocks, years in pasture is an entered value, with a maximum of 10.

For pastoral and cut and carry blocks, years in pasture is assumed to be 10.

For fodder crop blocks, which are assumed to rotate through pastoral blocks, years in pasture (YIP) is set to the integer value of:

Equation 5: YIP = 10 * (1 - areaFodderCrops / areaPastoralFodder)
areaFodderCrops is the area of fodder crops (ha)
areaPastoralFodder is the area of pastoral blocks that have fodder crops rotating through them (ha).

For fruit crop blocks, Years in pasture is set to 6 if the block is cultivated at establishment, and 2 otherwise.

2.6. Method of cultivation

The options for method of cultivation are conventional, direct drill or minimum till. The different method of cultivation only affects the decomposition of organic matter (section 3.2.2.3), whereas the months since cultivation affect both decomposition and soil organic matter mineralisation. Hence conventional cultivation should be selected when the stover is mixed in with the soil. If this does not happen then either of the other two options (minimum till or direct drill) can be selected. Note that the method of cultivation has no effect on outputs for the last month of the grid.

In the crop block, the method of cultivation is determined by the crop rotation. In all blocks, the method of cultivation at time zero (the month before the start of the 24 month cycle) is set to minimum till. This value is transferred to the next month, unless a sown or cultivation event is entered, in which case the method of cultivation is used.

For all other blocks, the method of cultivation is set to ‘Minimum till or spray first’ for all months.

2.7. Month after cultivation

The months after the last cultivations (MAC) is dependent on the crop rotation on crop and fodder crop blocks. It is reset to 1 each time a cultivation or sowing event is selected.

For pastoral and cut and carry blocks, MAC is set to 120 for all months.

For fruit crop blocks, if the block is cultivated at establishment then months after cultivation for the first month is set to:

Equation 6: MAC = (Age * 12) + 6
Age is the entered age of the crop (years).

This is increased by 1 for each month, with a maximum of 120 months. If the block is not cultivated at establishment, months after cultivation is set to 120 for all months.

2.8. Irrigation

The amount of N added in irrigation water is based on the calculated amount of irrigation water applied, and the irrigation concentration entered by the user or the default for that block. Thus the amount of N added in irrigation water (N_irrig, kg N/ha) in a given month is estimated as:

Equation 7: $N\_irrig = WIrrigAppMon_{mon} * Nconc$
WIrrigAppMon is the amount of irrigation water applied in a given month (mm) [Hydrology chapter].
Nconc is the N concentration in the applied irrigation water (mg/l).

Irrigation N inputs are required for a 24 month cycle. For pastoral, cut and carry and fruit crop blocks, the calculated amount in the first year is the same as the calculated amount in the reporting year.

For cropping blocks, the calculated amount is based on the amount of water applied as specified by the user using the 24 month input grid. The model assumes that the N content of the irrigation water is constant during the year.

2.9. Dung

The amount of N added in dung (N_dung, kg N/ha/month) is totalled across all animal enterprises each month, that is, the model assumes that there is no difference between dung from different animal enterprises.

Dung inputs are required for a 24 month cycle. For pastoral and fruit crop blocks, the amount added in the first year is assumed to be the same as that added in the reporting year.

For cropping blocks, the amount added is dependent on the crop rotation and when animals are grazing the block. For fodder crops, the amount added during the first year is based on an estimated pasture production for that period.

By definition, a cut and carry block has no dung inputs.

2.10. Effluent inputs

Similar to above, all effluent inputs are required for a 24 month cycle. For pastoral, cut and carry and fruit crop blocks, the amount added in the first year is assumed to be the same as that added in the reporting year.

For cropping blocks, the amount added is specified by the user using the 24 month input grid.

2.11. Fertiliser

The crop N sub-model requires three fertiliser inputs, which are the amount of N from conventional fertilisers (soluble N), and the organic and inorganic amounts of N from organic material (effluents, composts and other organic material). For organic material, a mineralisation rate for the organic fraction is also required. For soluble fertilisers, the amount of N volatilisation is also required.

All fertiliser inputs are required for a 24 month cycle. For pastoral, cut and carry and fruit crop blocks, the amount added in the first year is assumed to be the same as that added in the reporting year, which is estimated from the amount entered by the user for that block.

For cropping blocks, the amount added is specified by the user using the 24 month input grid.

2.11.1. Soluble fertiliser

Fertiliser additions are split between inorganic and organic forms. Conventional or soluble fertiliser N is assumed to be added to the soil N pool in the month of application. Slow release N forms, except those that are organic, are not catered for.

The amount of soluble fertiliser N added is estimated as:

Equation 8: SolubleFertN = Sum(FertNtypeMon)
FertNtypeMon is the amount of N added for each fertiliser type (kg N/ha) [Fertiliser chapter].

2.11.2. Organic material

The inorganic portion (NFertOtherInorg) is assumed to behave as soluble fertilisers and enters the soil mineral N pool in the month of application. The organic portion (NFertOtherOrg less NFertOtherInorg) is assumed to be released over time using the same model in the same manner as organic additions (section 3.3).

2.11.3. Volatilisation

The estimation of the amount of N lost as volatilisation from fertiliser (N_Volatil, kg N/ha/month) is described in the Fertiliser chapter. For crop blocks, the estimation of volatilisation uses the amount of crop cover in a given month (Fertiliser chapter).

For fruit crop blocks, the user can select whether fertiliser is applied as bands, or broadcast over the crop area. When broadcast, it is assumed that the fertiliser application rate on the inter-row area is lower than closer to the crop. Hence, if fertiliser is applied by broadcast and an inter-row area exists, then the fertiliser application rate for the crop is increased by 30%, and for the inter-row area decreased by 30%. For the inter-row area, if N fertiliser is applied as bands, then fertiliser inputs are set to zero. The estimation of fertiliser volatilisation uses sward presence as an indicator of cover.

2.12. N fixed

N fixed is the amount of biological N fixation (kg N/ha/month). It is estimated for pasture based on annual growth, clover content and an N fixation rate, and then distributed monthly.

In cropping blocks, the leguminous crops (beans, lentils, peas, seed clover) fix nitrogen, with the rate dependent on crop type.

2.13. Residues

For pasture, the amount of N added as stover residue is the amount of N not eaten by animals, or the amount of N not harvested if the block isn't grazed. Thus:

Equation 9: $ResidualStoverNut_{mon, N} = NUptake_{mon} * 0.77 * (1 - removed)$

NUptake is the N uptake from pasture (kg N/ha).

0.77 is proportion of uptake from tops.

removed is the proportion of N in the tops that is removed.

The proportion of N in the tops that is removed from grazed pasture in pastoral, fodder crop and cut and carry blocks is the estimated annual pasture utilisation rate, or an utilisation rate of 80% for pasture grazed by animals in fruit crop blocks. In cut and carry blocks, the proportion of N in the tops that is removed it is assumed that 90%, and in mown fruit crop blocks, it is assumed that all grown pasture is returned as stover residues.

Root residue is estimated as:

Equation 10: $ResidualRootNut_{mon, N} = NUptake_{mon} * 0.23 * RootTurnover * 0.3$

NUptake is the N uptake from pasture (kg N/ha).

0.23 is proportion of uptake from roots.

RootTurnover is the root turnover rate, and is 0.3 for non-lucerne pastures and 0.15 for lucerne.

0.3 is an adjustement for lower N content in dead roots.

The root turnover rate was assumed to be lower for lucerne due to the presence of taproots. The N concentration in dead roots was assumed to be closer to 1% as used in the model development [section 3.1], and hence a factor of 0.3 was used.

In crop blocks, the amount of N added as residue stover and roots is dependent on the cropping rotation.

2.14. Prunings

The amount of N released from prunings from fruit crops was estimated (MPI 2008), and the amount released is included as an input into the crop N sub-model. Hence:

Equation 11: $Nprunings_{mon} = NpruningAdd * PropNrelease_{crop, mon}$

NpruningAdd is the amount of N added as prunings each year (kg N/ha/year).

PropNrelease is the proportion of annual prunings released each year [Table 2].

For other blocks, Nprunings is zero.

Table 2. The proportion of the N in prunings that is released each month into the soil mineral N pool.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Kiwifruit	0.09	0.07	0.06	0.05	0.04	0.03	0.07	0.10	0.12	0.13	0.12	0.10
Apples	0.08	0.06	0.05	0.04	0.06	0.08	0.10	0.11	0.11	0.11	0.11	0.09
Grapes	0.08	0.06	0.05	0.04	0.05	0.08	0.10	0.11	0.11	0.12	0.11	0.10
Avocados	0.10	0.07	0.07	0.05	0.04	0.03	0.06	0.10	0.11	0.13	0.13	0.11
Peaches	0.09	0.06	0.06	0.04	0.04	0.07	0.09	0.11	0.11	0.12	0.12	0.10

2.15. Unutilised supplements

Unutilised supplements fed on a block (Supplement chapter) are estimated from the utilisation rate. They are assumed to decompose in a similar manner to organic material.

2.16. Uptake

The method of estimating the amount of N uptake by tops and roots (kg N/ha/month) varies with the block type.

In cropping or fodder crop blocks, the N uptake each month is dependent on the crop rotation. This is covered in the Crop model chapter (unpublished).

2.16.1. Pastoral blocks

In pastoral blocks, N uptake in a given month is estimated as:

Equation 12: $N\_Uptake = DMpasture * BackgroundFactor * MonthlyNConc_{mon} / 100 * 1.3 * PastureProp_{mon}$

DMpasture is the block pasture DM yield (kg DM/ha/year).

BackgroundFactor adjusts yield from whole paddock to background yield [2.16.1.1].

MonthlyNConc is the monthly N concentration (%) [Characteristics of pasture chapter].

1.3 accounts for uptake by roots.

PastureProp is the proportion of annual yield grown each month [Characteristics of pasture chapter].

2.16.1.1. *Background factor*

The model estimates DM yield for the block (kg DM/ha/year) from animal intake and utilisation for the whole block. Thus:

Equation 13: $DMyield = (DMIu * pu + DMInu + pnu) / utilisation$

DMIu and DMInu is the dry matter intake from urine and non urine areas of the paddock.

pu and pnu are the proportions of the paddock covered by urine and non-urine areas.

utilisation is the annual proportion of feed utilised by animals grazing the block

If utilisation is assumed to be constant then the background factor is the ratio:

Equation 14: $BackgroundFactor = DMInu / DMyield$

During calibration, a value of 0.9 gave good results.

2.16.1.2. *Hard grazing*

A management option is to hard graze the farm prior to animals going on the wintering pad/animal shelter, or being grazed off. This results in pastures with lower residues across the whole farm than under normal grazing pattern. Hence net N uptake by pasture is expected to be lower than that normally estimated closer to the time of removal as all the farm is hard grazed to low residues, and higher in subsequent months as all the farm has pasture growing near maximum rates. If hard grazing occurs, pasture N intake is adjusted in April and May as:

Equation 15: N_Uptake = N_Uptake - (0.1 * ReductNUptake / totSUWinMonths)

and in June and July

Equation 16: N_Uptake = N_Uptake + (0.1 * ReductNUptake / totSUWinMonths)

ReductNUptake is the sum across animal enterprises for the months April to July inclusive of BlockSU (relative yearly intake of each animal enterprise on a block, Animals chapter) if the animal enterprise is using a wintering pad, hard grazing is checked, and is grazing the block. TotSUWinMonths is the sum across animal enterprises for animal enterprises grazing the block.

2.16.2. Cut and carry blocks

In cut and carry blocks, N uptake in a given month is estimated as:

Equation 17: N_Uptake = DMpasture * 1.1 * $\text{MonthlyNConc}_{mon}$ / 100 * 1.3 * PastureProp_{mon}

DMpasture is the block pasture DM yield (kg DM/ha/year).
1.1 accounts for the untilised pasture that is grown but not removed.
MonthlyNConc is the monthly N concentration (%) [Characteristics of pasture chapter].
1.3 accounts for uptake by roots.
PastureProp is the proportion of annual yield grown each month [Characteristics of pasture chapter].

The pasture yield is based on supplements removed. The model assumes that about 10% of the grown pasture is left in the block at harvest, hence yield is increased by multiplying by 1.1.

2.16.3. Fruit crop blocks

The crop component consists of uptake by the crop, and pasture if present. Thus total uptake each month is estimated as:

Equation 18: NUptake_{mon} = NuptakeTrees + MonNUptake

NuptakeTrees is the uptake by the tree crop (kg N/ha) [Equation 19].

MonNUptake is the uptake from pasture (kg N/ha) [Equation 22].

The monthly N uptake by trees (kg N/ha/month) is estimated as:

Equation 19: $NuptakeTrees = AnnualNuptake * PropNUptake_{crop,\ mon} - sprayN$

AnnualNuptake is the annual uptake by trees (kg N/ha/year) [Equation 20 or Equation 21].

PropNUptake is the proportion of N uptake that occurs in a given

sprayN is the amount of N added as sprays (kg N/ha) [Table 3].

The annual N uptake by trees (kg N/ha/year) is the greater of:

Equation 20: $AnnualNuptake = Productout_{N} + PruningLoss_{N} + FrameGain_{N}$

Productout is the N removed as product (kg N/ha).

PruningLoss is the N removed in prunings (kg N/ha).

FrameGain is the N that accumulates in the frame (kg N/ha).

or

Equation 21: $AnnualNuptake = ProductYld * NuptakeProduct_{crop}$

ProductYld is the yield of product (kg DM/ha).

NuptakeProduct is the N concentration product is multplied by to represent total N uptake by the crop (kg/kg) [Table 4].

The contribution from spray is based on the user-entered sprays. These are assumed to be applied equally each month between October and March inclusive.

Table 3. The proportion of N uptake by the crop that occurs in a given month.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Kiwifruit	0.14	0.08	0.07	0.06	0.06	0.04	0.00	0.00	0.00	0.23	0.18	0.13
Apples	0.19	0.11	0.09	0.06	0.00	0.00	0.00	0.00	0.00	0.21	0.17	0.16
Grapes	0.14	0.10	0.09	0.08	0.00	0.00	0.00	0.00	0.00	0.14	0.26	0.18
Avocados	0.15	0.14	0.11	0.07	0.03	0.01	0.01	0.02	0.06	0.14	0.21	0.20
Peaches	0.15	0.10	0.09	0.07	0.03	0.00	0.00	0.00	0.00	0.18	0.23	0.15

Table 4. N concentration product is multiplied by to represent total N uptake by the crop (kg/kg).

Species	NuptakeProduct
Kiwifruit	0.043
Apples	0.035
Grapes	0.066
Avocados	0.075
Peaches	0.034

Table 5. The proportion of the crop area covered by the crop in a given month.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Kiwifruit	1.00	1.00	1.00	1.00	1.00	0.51	0.20	0.20	0.22	0.50	0.87	1.00
Apples	1.00	1.00	0.97	0.80	0.40	0.30	0.15	0.24	0.45	0.80	1.00	1.00
Grapes	0.77	0.76	0.71	0.60	0.09	0.06	0.05	0.06	0.09	0.18	0.52	0.71
Avocados	0.96	0.96	0.94	0.91	0.86	0.65	0.60	0.61	0.64	0.74	0.85	0.93
Peaches	1.00	1.00	1.00	0.96	0.44	0.17	0.16	0.18	0.28	0.67	0.98	1.00

The presence of pasture in the crop is dependent on the user inputs of crop type, crop age, and the present or absence of a sward. If pasture is present within the crop, N uptake per month (kg N/ha/month) from the pasture component is estimated as:

Equation 22: $MonNUptake = DMYield_{mon} * MonthlyNConc_{mon} / 100 *$

DMyield is the estimated pasture annual DM yield (kg DM/ha/month) [Equation 23].

MonthlyNConc is the pasture N content (%) [Characteristics of pasture].

The estimated yearly pasture annual yield (kg DM/ha/year) is estimated as:

Equation 23: $DMYield_{mon} = EstPastYield * PastureProp_{mon} * PastureGrowthRate * (1 – HortCover_{crop, mon}) * pastureInCrop$

EstPastYield is the estimated pasture annual DM yield with no crop (kg DM/ha/month)

PastureProp is the estimated proportion of annual yield occurring in a given month [Characteristics of pasture].

PastureGrowthRate is the proportion of pasture crop expected in a crop block [Table 5].

pastureInCrop is the proportion of the crop area that has pasture growing on it.

The proportion of the crop area covered by the crop (HortCover) is a reflection of the area covered by the framework of the crop, and the amount of leaf cover. For the deciduous crops in particular, there is a seasonal pattern (Table 5).

If an inter-row region growing pasture exists, then uptake is estimated using Equation 22 except that monthly DM yield is estimated as:

Equation 24: $DMYield_{mon} = EstPastYield * PastureProp_{mon} * PastureGrowthRate$

EstPastYield is the estimated pasture annual DM yield with no crop (kg DM/ha/month).

PastureGrowthRate is the proportion of pasture crop expected in a crop block.

pastureInCrop is the proportion of the crop area that has pasture growing it it.

3. Mineralisation models

The soil organic mineralisation was based on data from year 5 of the millennium tillage trial (FAR, 2008). Derivation of parameters used in the mineralisation models are discussed in section 3.1, and the implemented model for soil organic N mineralisation and mineralisation of organic material are given in sections 3.2 and 3.3.

3.1. Determining constants for soil organic matter decomposition

The soil organic mineralisation was based on data from year 5 of the millennium tillage trial (FAR, 2008). The area had been in long term pasture before the trial was established. One treatment was maintained in pasture during the trial. Another treatment was cultivated out of pasture and maintained as a bare land fallow by application of herbicide. Three other treatments were cultivated each spring by either intensive tillage (Plough, 2x grubbing, harrow, roll), minimum tillage (disc, harrow and roll) or no tillage (direct drilled) with spring crops sown after each cultivation.

Table 6. Years in pasture, soil organic nitrogen and root biomass of treatments.

Treatment	Years in pasture	Soil organic N (t/ha)	Root biomass (t/ha)	Nitrogen content of roots
Pasture	10	4.65	6.5	0.01
Fallow	5	3.88	-	-
Intensive tillage	5	3.42	2.0	0.018
Minimum tillage	5	4.00	2.0	0.018
No tillage	5	3.78	2.0	0.018

Soil organic nitrogen (Norg) was measured to 15 cm depth. There was a small decline in Norg over 5 years of cultivation relative to pasture treatments (Table 6) which can be accounted for in using the rule: Norg = 5 t/ha – (10 - YearsInPasture) * 0.1.

Samples were collected as undisturbed cores following the harvest (25/02/05) of a pea crop and incubated as either undisturbed cores or passed through a 5 mm sieve (to remove stones and large bits of crop residue) and then incubated. Each sample was incubated for 100 days at field capacity and 20 °C and N mineralised was measured on 4 occasions during the incubation.

Samples contained soil organic matter and crop root residue so it was necessary to differentiate between N mineralised from the two sources to isolate parameters for prediction soil organic matter mineralisation.

SOM mineralisation (Nsom) was predicted from the following three equations:

Equation 25: Nsom = Norg * *f*(SOMmin) * *f*(temp) * *f*(SWC)
Equation 26: *f*(SOMmin) = Ko * (1 * exp(a*MAS) + b)
Equation 27: Ko = (YearsInPasture * YearsInPasture_factor)/100000

f(SWC) was 1 because samples were incubated at field capacity, *f*(Temp) is 2.33 at 20 °C, and MAS the months after sowing. Nsom and Nroot predictions were then added together and compared to the observed N mineralisation measured in the incubation treatments. The values of Root_decay_factor, a, b and YearsInPasture_factor were then altered to give simultaneous best fit of predicted to observed mineralisation in all treatments (Figure 2).

Mineralisation from root residue (Nroot) was predicted from the following three equations:

Equation 28: Nroot = RootN * RootCoeff * *f*(SWC) * *f*(Temp)

Equation 29: RootCoeff = [N]root * Root_decay_constant
Equation 30: RootN = Root_biomass * [N]root

The concentration of N in the roots, [N]root, was assumed to be 0.01 for pasture (predominantly ryegrass) and 0.018 for crop treatments following peas (Table 6), and the values of *f*(temp) and *f*(SWC) were as described for calculating soil N mineralisation. Root_biomass was assumed to be 6.5 t/ha for the pasture treatment (based on measurements taken from an established pasture in the rain-shelter) and 2 t/ha for crop treatments based on crop yields (5 t grain/ha) and an assumed root proportion (0.2 of total biomass). The root_decay_constant was optimised in the same procedure as the SOM mineralisation parameters.

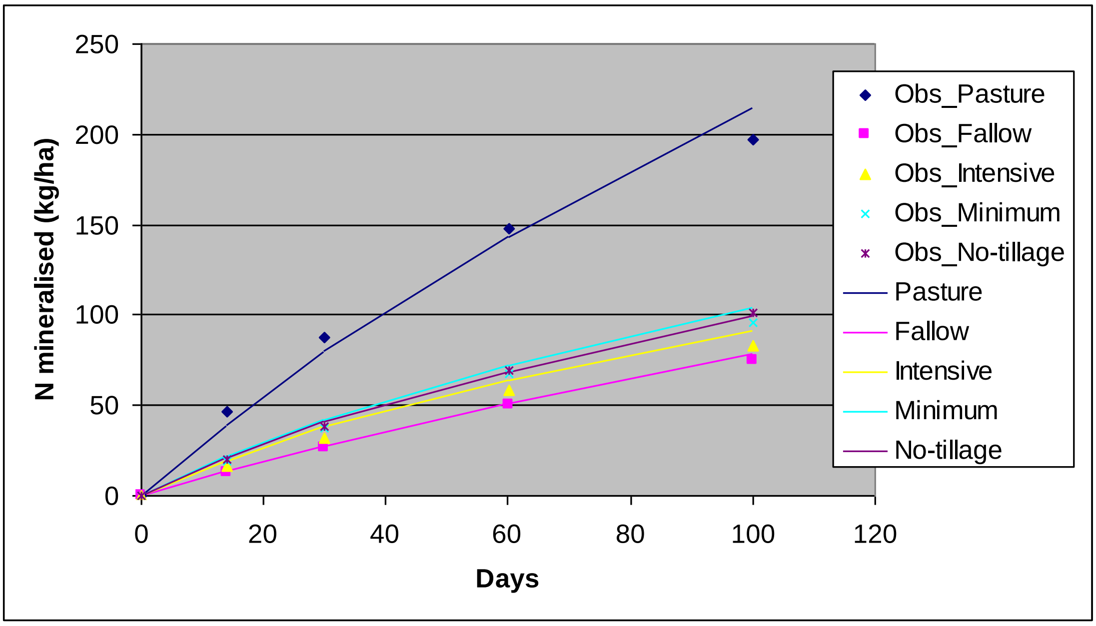

Figure 2. Observed and predicted N mineralisation rates from different cultivation treatments incubated at field capacity and 20 °C (from Release doc SOM_mineralisation.doc supplied by Plant and Food as part of the release documents from the NMEA project).

This exercise yielded values of 5, -0.2, 0.5 and 45 for root_decay_factor, a, b and YearsInPasture_factor, respectively. The resulting predictions of mineralisation showed good agreement with the observed pattern of N mineralisation (Figure 2).

The method of sample preparation (sieved samples vs intact cores) did not affect mineralisation results suggesting that the method of cultivation and subsequent soil disturbance does not need to be accounted for in the prediction of N mineralisation.

These calculations predicted the crop treatments would mineralise 21 kg of N over the 100 day incubation period, equivalent to the difference in mineralisation between the fallow and crop treatments, which suggests the model proposed is appropriate. Using a root_decay_factor higher than 5 gave over-predictions of mineralisation rate early in the incubation and a lower value gave under-predictions of mineralisation.

The calculations also gave a good prediction of the difference between pasture and crop treatments suggesting the mechanism or relating mineralisation rate to the variable (YearsInPasture) is appropriate.

The “a” parameter was less than zero suggesting that cultivation events cause an increase in mineralisation that decreases as time passes and the model proposed accounts for this. There was no evidence that differing cultivation techniques influence the rate of mineralisation.

The only major difference in observed mineralisation rates between cultivated treatments was a lower total mineralisation for the intensively cultivated treatment. This difference was accounted for by the differences in Norg between the treatments (Table 6) showing it is not necessary to use different procedures to predict mineralisation from different cultivation techniques. The difference in Norg came about because the intensively cultivated treatment was ploughed to 20 cm but only sampled to 15 cm. The soil below 15 cm has a lower organic matter content so the deeper cultivation would have diluted the Norg in the 15 cm sample. If the soils had been sampled to 30 cm there would have been no difference in Norg and the mineralisation rates would have been similar also.

3.2. Mineralisation from soil organic matter

The estimated amount of N mineralised from soil organic matter (N_SOM, kg N/ha/month) is based on the model Cichota *et al*. (2010) in a given month, and is estimated as:

Equation 31: N_SOM = Norg* f_SOM * f_SWC * f_Temp * f_LowMin
Norg is the organic N pool (kg/ha) [section 3.2.1].
f_SOM is the mineralisation rate at 20°C and field capacity [section 3.2.2].
f_SWC is a factor to account for soil water content [section 3.2.3].
f_Temp is a factor to account for temperature [section 3.2.4].
f_LowMin is a factor to reduce mineralisation rates in certain situations [section 3.2.2.2].

3.2.1. Organic N pool

The amount of soil organic N (kg N/ha) mineralised each month is a linear function of the proportion of time in the past 10 years the field was under pasture. Thus:

Equation 32: Norg = 5000 - (10 - YIP) * 100
5000 is a derived constant (kg N/ha) [section 3.1].
10 is a derived constant [section 3.1].
YIP is years in pasture [section 2.5].
100 is the rate of change per year (kg N/ha/year) [section 3.1].

3.2.2. Mineralisation rate

The mineralisation rate at field capacity and approximately 10°C (when f_SWC and f_temp are both 1) is required. The mineralisation rate also captures the slower rate of resident organic matter degradation for fields that have been under cultivation for an extended period (years in pasture, section 2.5). It is also a function of the time since the last cultivation event, thus representing the flush of mineralization that occurs following cultivation.

On pastoral and cut and carry blocks, the underlying assumption is that soil mineral N levels are in equilibrium, that is, the start and end values in the reporting year are similar.

3.2.2.1. *Rate*

The mineralisation rate at field capacity and 10°C (when f_SWC and f_temp are both 1), including the flush of mineralization that occurs following cultivation, is estimated as:

Equation 33: $f\_SOM = ko\_SOM * f\_cultivation_{mon}$

ko_SOM is the release rate of a recently cultivated soil at 20 °C and field capacity [Equation 34].

f_cultivation is a factor to include the flush of mineralization that occurs following cultivation [3.2.2.3].

where the mineralisation rate (kg N per kg Norg) when f_SWC and f_temp are both 1 (at field capacity and approximately 10 °C), including the slower rate of resident organic matter degradation for fields that have been under cultivation for an extended period, is estimated as:

Equation 34: $ko\_SOM = YIP * 45 / 100000$

YIP is years in pasture [section 2.5].

45 is a fitted constant [YearsInPasture_factor, section 3.1].

100000 is a conversion factor.

On pastoral and cut and carry blocks where the option for low N pasture mineralisation has been selected, the mineralisation rate reduction factor (f_SOM) is halved.

3.2.2.2. *Low mineralisation blocks*

The mineralisation rate reduction factor is 1 by default (i.e. no reduction), and is 1 for crop blocks.

On permanent pasture, soil mineral N levels are usually low due to multiple feedback mechanisms. These are complicated to model, and hence an empirical approach was taken to reduce mineralisation rates and N fixation rates when soil mineral N was high. In addition, the mineralisation rates is based on a trail (MPI, 2008) where there is good pasture growth if water is supplied. In areas where pasture growth is low due to factors other than temperature or water supply, the soil has a lower ability to supply mineral N if low soil mineral N levels occur. Hence on pastoral, cut and carry and fruit crop blocks, it is assumed that as pasture production decreases, the rate of mineralisation probably also decreases. This has been modelled using an empirical approach for pastoral, cut and carry, and pasture phase of fruit crop blocks such that:

Equation 35: f_LowMin = f_MinN * fyieldSOM

f_MinN is a reduction factor for high soil mineral N levels [*Equation 36*].

fyieldSOM is a reduction factor for low pasture production [*Equation 37*].

If N soil mineral N levels are greater than 10 kg N, mineralisation rates are decreased. Thus:

Equation 36: $f\_MinN = 1.18 + (-0.018 * N\_min_{mon-1})$

N_min is the soil mineral N at the end of the previous month (kg N/ha).

The reduction factor for low pasture production on pastoral and cut and carry blocks is estimated as:

Equation 37: fyieldSOM = DMpasture/15000
DMpasture is the pasture DM production (kg DM/ha/year).

fyieldSOM has a minimum value of 0.1. On fruit crop blocks, fyieldSOM for the pasture sward is assumed to be 0.5.

3.2.2.3. *Cultivation effect*

The effect of cultivation on mineralisation rate of resident soil organic matter is estimated as:

Equation 38: f_cultivation = (a_SOM * Exp(-b_SOM * MAC)) + Xo_SOM
a_SOM, b_SOM, and Xo_SOM were determined in incubation studies [section 3.1] and have values of 1, 0.2, and 0.5 respectively.
MAC is the number of months after a cultivation event.

The relationship between f_cultivation and the number of months after cultivation is shown in Figure 3 and Figure 4.

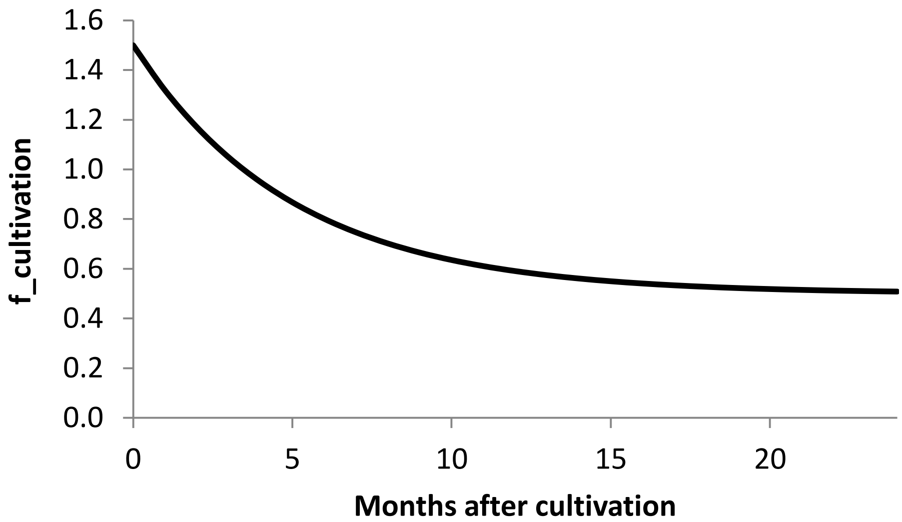

Figure 3. Relationship between months after cultivation and f_cultivation.

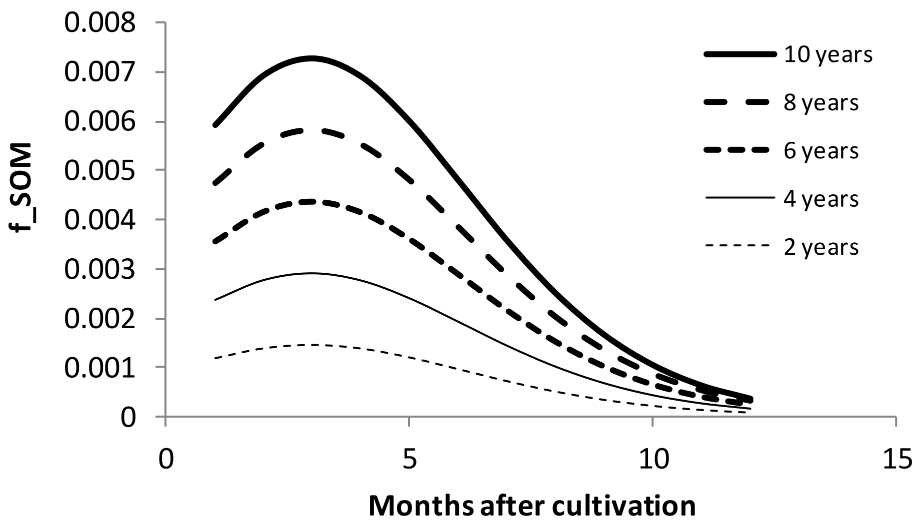

Figure 4. Relationship between months after cultivation and f_SOM for a range of years in pasture.

3.2.2.4. *Months after cultivation*

The month after cultivation is not dependent on the type of cultivation.

In pastoral and cut and carry blocks, months after cultivation is set at 120 to align with years in pasture.

3.2.3. Soil water content factor

The effect of soil water content on mineralisation rates is based on the ratio between the soil water content in the current month and the potential water storage at field capacity at 600 mm depth. Thus the soil water content factor is estimated as:

Equation 39: $f\_SWC = W\_Soil600_{Mon} / FC600$

W_Soil600 is the soil water content to 600 mm for a given month (mm).

FC600 is the field capacity to 600 mm depth (mm).

and has maximum value of 1. Hence, mineralisation rates on saturated soils are assumed to the same as soils at field capacity.

3.2.4. Temperature factor

The mineralisation factor used for estimating organic matter mineralisation within soil is based on Cichota *et al*. (2010) which uses 'Mean monthly temperature', but the temperature used is not specified. The factor was applied to results from incubation studies (section 3.1), and hence it was assumed that soil temperature is a better estimate than mean air temperature. The Climate sub-model uses mean air temperature at 9 am as an input and a method to convert this to mean soil temperature at 5 cm or 10 cm depth at 9 am is provided. As most mineralisation occurs close to the soil surface, the soil temperature at 5 cm was adopted.

The temperature factor was estimated as:

Equation 40: $$f\_temp = Exp(coeff_1 + (coeff_2 * temp5) + (coeff_3 * temp5^2)) - Exp(coeff_4 + (coeff_5 * temp5) + (coeff_6 * temp5^2))$$

coeff are coefficients [Table 7].

temp5 is the soil temperature at 9 am at 5 cm (°C) [Climate chapter].

The resulting relationship is shown in Figure 5, and gives f_temp of 2.336 at 20 °C.

Table 7. Coefficients for estimating f_temp.

Co-efficient	Value
$coeff_1$	0.57
$coeff_2$	-0.024
$coeff_3$	0.002
$coeff_4$	0.57
$coeff_5$	-0.042
$coeff_6$	-0.0051

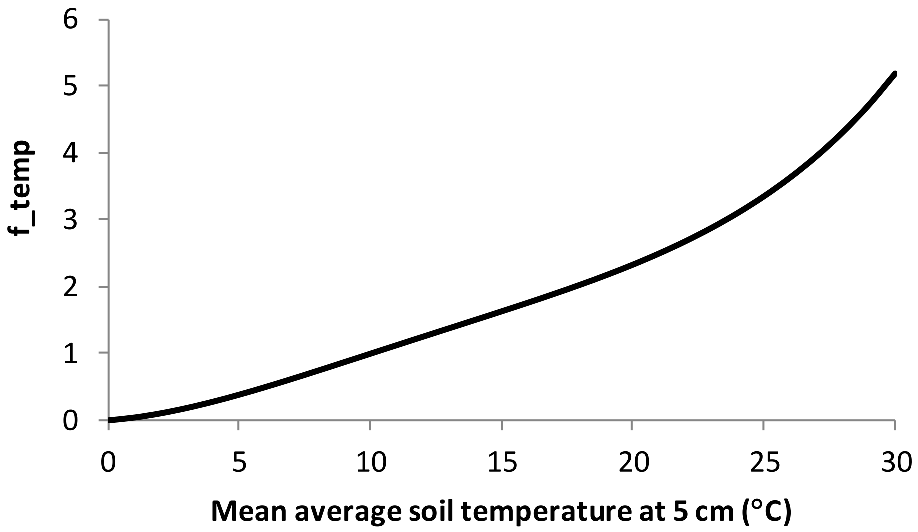

Figure 5. Relationship between mean average soil temperature at 5 cm (°C) and f_temp.

3.3. Decomposition of organic material

The method used to estimate release of N from organic material via decomposition is based on the root and stover model in Cichota *et al*. (2010), using parameters as estimated in section 3.1. This approach is applied to residues (stover and roots), dung, the organic fractions of effluent, fertiliser (composts, added effluents etc.), and unutilised supplements.

Residues, fertiliser, effluents and supplements are assumed to be evenly distributed over the block. Dung and supplements are typically added to a block in spatially discrete patches (dung patch, and supplement feeding lines), similar to urine patches, and could be modelled separately. Given the small amount of N added to the soil N pool across the block from dung compared to urine, dung has been incorporated into the crop N sub model.

3.3.1. Standard decomposition

All organic material is assigned to a monthly cohort. Nutrients are released (mineralised) from each cohort up to the current month. It is assumed that once a cohort is less than 0.1 kg N/ha, then it no longer continues to exist, and any remaining nutrient is released that month. Hence N release is estimated as:

Equation 41: $Nutrel = \sum_{mon\ =\ 0\ to\ mon2} (Xnut_{mon} * ko_{mon} * f\_SWC_{mon2} * f\_temp_{mon2} * f\_cult_{mon2})$

mon2 is the current month.

Xnut is the amount of nutrient in a cohort for a given month (kg N/ha).

ko is the proportion of a cohort that is mineralised in a given month.

f_SWC is the soil water content factor for organic matter mineralisation [section 3.2.3].

f_Temp is the temperature factor for organic matter mineralisation [section 3.2.4].

f_cult is a factor for cultivation practice [section 3.3.2].

The amount of root and stover residues at the beginning and end of the reporting year is used to estimate change in residue nutrients reported in the nutrient budget. This is estimated for all nutrients as part of the N decomposition model. For stover and root residues, the above equation also applied to P and S. For the cations, it is assumed that 50% is released each month.

Equation 42: $\text{Nutrel} = \sum_{\text{mon} = 0 \text{ to mon2}} (\text{Xnut}_{\text{mon}} * 0.5)$

3.3.2. Cultivation practice factor

The cultivation practice factor is a measure of the effect of incorporating stover residues into the soil on mineralisation rates. If a cultivation event occurs, the cultivation practice is used to determine a value of k_Incorp using the values shown in Table 8.

Table 8. The value of k_Incorp for each cultivation technique.

Cultivation technique	k_Incorp
Minimum till or spray first	0.5
Direct drill	0.5
Conventional	1.0

The initial value of f_cult is the default value of 0.5.

When estimating decomposition, if k_Incorp for the previous months is less than k_Incorp for the current month, then f_cult is assigned the current month's value. Once a previous month's value is assigned a higher value, it does not revert back to a lower value. Hence, the decomposition rate for stover increases once a conventional cultivation event occurs as it is assumed to be mixed into the soil.

3.3.3. Maximum portion mineralised (ko)

The model assumes that decomposition rates are proportional to the amount of N in the organic fraction. Hence, for a given amount of N added, fresh leaves (with high N content) will decompose faster than straw (with a lower N content). The timing of addition, the potential rate of decomposition, and the factors related to soil water content or temperature, can affect the timing of N release to the soil mineral N pool, and hence the amount of N that can be leached or be denitrified. Thus, for example, an organic material added in late summer when conditions are dry may decompose rapidly in autumn, resulting in high mineral soil N in late autumn/winter that could result in higher leaching losses. In contrast, an organic material added in winter may have little effect on leaching as cool temperatures slow decomposition rates, whereas an inorganic material (e.g. N fertiliser) may be susceptible to leaching.

3.3.3.1. *Derivation of ko*

Generically, the values of ko are estimated as:

Equation 43: ko = a_organic * Cmaterial a_organic is a release rate.

Cmaterial is the N content (kg/kg) of the organic fraction of the material.

As the cutivation practice factor, k_incorp, is 0.5 by default (section 3.3.2), and the mineralisation study estimated a value of 5 for a_organic (section 3.1), a_organic was set to 10.

3.3.3.2. *Specific ko rates*

For pasture based systems, stover also includes unutilised pasture, which may have a higher N contents than dead material. Thus it is assumed stovers have 2% N, and hence ko_stover is estimated as:

Equation 44: ko_Stover = a_organic * 0.02

The value for roots from pastoral blocks was also based on 1% N, as used for estimating parameter values (section 3.1). A lower value than stover was used as it is assumed that the roots had died, and dead material has a lower N content than live material. Thus ko_Roots was estimated as:

Equation 45: ko_Roots = a_organic * 0.01

For crops, if the crop had stopped growing at harvest (grain) or was pasture, then a root N concentration of 0.01 was used. Otherwise a crop specific N concentration was used.

For dung, the release rate is based on the recalcitrant N content reported by Barrow and Lambourne (1962). Hence ko_Dug was estimated as:

Equation 46: ko_Dung = a_organic * 0.00835

For organic fertilisers, the proportion N that is inorganic fraction, and the concentration of N in the organic fraction depends on the material applied (Fertiliser chapter). The value used to estimate ko for a given month is a weighted average across all organic materials applied to the block in a given month.

Effluent concentrations in the organic fraction depend on the effluent management system. An average annual concentration is used as the effluent management system is assumed to be constant throughout the year, and it was assumed that N content of the organic fraction was the same for slurries and solids (2.1%). This implies that the addition of unutilised supplements is not affecting the decomposition rate of effluents from wintering pads.

For unutilised supplements, the average concentration of N of unutilised supplements is estimated as the unutilised N divided by the unutilised DM.

This approach means that an important determinant of the release of N from organic fertiliser effluent is the ratio of inorganic to organic N.

4. Implemented model

The crop N sub-model estimates soil mineral N each month for 24 months. The first year is used to initialise the model for the reporting year, which provides the output data (section 5).

This way, the effect of residues from the previous year on the current year's N cycling is included.

For crop blocks, the end month is selected by the user. Due to crop rotation, all inputs are calculated for a two year period based on the crop rotation described by the user.

For pastoral and cut and carry blocks, the model uses a cycle starting in January and ending in December. The model still uses a two year cycle, however the inputs are the same for year 1 as year 2.

4.1. Soil Mineral N

The soil mineral N pool is a conceptual pool or inorganic plant available N in the soil. In concept, it is similar to soil nitrate and ammonium levels, though the absolute levels are not necessarily the same.

Each month, starting from the month following the final month, the soil mineral N pool (N_Min, kg N/ha) is estimated as:

Equation 47: $$\begin{aligned} N\_Min_{mon} = N\_Min_{mon-1} & + N\_Shortage \\ & + N\_Fixed + N\_Rain + N\_Irrig \\ & + N\_SOM \\ & + N\_Residue + N\_Effluent + N\_MinResid \\ & + N\_Fert + N\_OrganicFert \\ & - N\_Volatil - N\_Denit - N\_Leach - N\_Uptake \end{aligned}$$

N_Shortage is the difference between required and available N (kg N/ha [section 4.8].

N_Fixed is N fixed by the crop (kg N/ha) [section 2.12].

N_Rain is N added in rainfall (kg N/ha) [section 4.2].

N_Irrig is N added in irrigation (kg N/ha) [section 2.8].

N_SOM is N released from soil organic matter [section 3.1].

N_Fert is is inorganic N (soluble and inorganic portion or organic material) added in a given month plus N released from the organic component within a given month (kg N/ha) [section 4.3].

N_OrganicFert is the N released from organic fraction of organic fertilisers within a given month (kg N/ha) [section 4.5].

N_Residue is the N released from residues (roots and stovers) within a give month (kg N/ha) [section 4.5.3].

N_Effluent is inorganic N added in a given month plus N released from the organic component within a given month (kg N/ha) [section 4.5].

N_Volatil is N volatilised from fertiliser (kg N/ha) [section 2.11.3].

N_Denit is N denitrified (kg N/ha) [section 4.6].

N_Leach is N leached (kg N/ha) [section 4.7].

N_Uptake is N uptake by the crop (kg N/ha) [section 2.15].

If the soil mineral N pool is less than zero in a given month, then the difference is added to N_Shortage and soil mineral N pool is set to zero.

Initial soil mineral value (section 2.3) is the value in month 0.

4.2. Rainfall

The monthly input from rainfall (N_Rain, kg N/ha) is estimated as:

Equation 48: $N\_Rain = RainNut_{nitrogen} / 12$

RainNut is the annual amount of N added in rainfall (kg N/ha/year) [section 2.1].

As the amount of rainfall N is low, the seasonal distribution of rain in most location is low, and if the seasonal distribution of N content in rain was unknown, a monthly average N loading was used.

4.3. Immobilisation

On crop blocks, it is assumed that the incubation study provides mineralisation rates. Under continuous cropping there is no net accumulation in organic matter except via the input from residues, and this is already accounted for. The crop N sub-model was validated against field trial data (MPI, 2008) which indicated that this model was adequate. Hence it is assumed that an immobilisation term was not required for cropping blocks.

In pastures, accumulation of organic matter can occur over time.

For dairy farms, typical immobilisation rate of N fertiliser is 15% for rates < 200 kg N/ha/year and 10% for rates > 400 kg N/ha/year (Ledgard, AgResearch, pers. comm. 2010). This immobilisation rate is less than that from relatively short-term studies (e.g., 1 year) but is similar to that where ^{15}N recovery of applied N was measured over several years and where it was tending to plateau (e.g., Ledgard and Sprosen 1997). A higher average value of 35% immobilisation of fertiliser N is typical for non-dairy pastures in recognition of higher rates measured or estimated (Ruz Jerez *et al*. 1995; Sprosen *et al*. unpublished).

Thus, in pastoral and cut and carry blocks, immobilisation is estimated as:

Equation 49:
$$N\_Immob = Dung_{Mon} * 0.3 + N\_fert * (0.25 + (1 - ImmRate) * 0.10) + N\_Effluent * (0.35 + (1 - ImmRate) * 0.15) + N\_Uptake * 0.102 * Immrate$$

By assuming that the difference in immobilisation rates between dairy and non-dairy pastures is reflected in pasture production, then on pastoral and cut and carry blocks, the factor ImmRate is estimated as:

Equation 50: $ImmRate = 1 – (DMpasture_{block} – 10000)/ 25000$

On pastoral blocks, if the N immobilisation potential is none then Immrate is set to zero, and if N immobilisation potential is higher than standard, then 0.2 is added given that ImmRate has a maximum value of 1.

Immobilisation from effluent was considered to be higher due to the organic material, and hence recalcitrant N, likely to be in this fraction. Similarly, dung was considered to have a high immobilisation potential due to high amounts of recalcitrant N. The immobilisation for N uptake was related to the recalcitrant N returned to the soil as senesced material.

The immobilisation term in effect is a method of removing N from the soil mineral N pool, and hence reduce the amount of N that can be leached or denitrified. Although this is labelled immobilisation, many processes may be involved. It also encompasses any errors in estimating other inputs and outputs to the soil mineral N pool. Immobilisation is further adjusted as part of the balancing routines (unpublished).

4.4. Fertiliser

The amount of N from fertiliser inputs added to the soil pool each month is estimated as:

Equation 51: $N\_Fert = SolubleFertN_{mon} + NFertOtherInorg_{mon}$

SolubleFertN is the amount of fertiliser N added in a given month (kg N/ha/year) [section 2.11.1].

NFertOtherInorg is the amount of inorganic N in organic fertiliser added in a given month (kg N/ha) [section 2.11.2]

4.5. Organic additions

These are split between inorganic and organic forms. The inorganic portions are assumed to behave as soluble fertilisers and enters the soil mineral N pool in the month of application.

Organic fractions are assumed to be released over time using the standard decomposition (section 3.3) method. The ko and output of N released for a given month for a given source of organic material is shown in Table 9.

Table 9. Organic materials where slow release of N by decomposition is estimated. The initial variable, mineralisation rate and output used when estimating mineral soil N levels each month.

Source	Input [1]	ko [2]	Output
Roots	$ResidualStoverNut_N$	ko_roots	N_Residue
Stover	$ResidualRootNut_N$	ko_stover	N_Residue
Dung	Ndung	ko_dung	N_Dung
Organic fertiliser	NFertOtherInorg		N_OrganicFert
Effluent (slurry) from farm dairy	NEffluent	ko_liq	N_Effluent
Effluent (slurry) from wintering pad	NEffluentWP	ko_liq	N_Effluent
Solid effluent (all sources)	NEffluentSolid	ko_solid	N_Effluent
Imported dairy slurry	NImportDairy	ko_liqImport	N_Effluent
Imported pig slurry	NImportPig	ko_liqImport	N_Effluent
Imported solid effluent	NImportSolid	ko_solidImport	N_Effluent
Unutilised supplements	NUntilSupplements	Ko_supplement	N_Residue

[1] Inputs are defined in section 2.1.
[2] Inputs are defined in section 2.1 and the derivation of ko is described in section 3.3.3.

4.5.1. Fertiliser

The difference between the amount of organic N added and that as inorganic N is used to estimate decomposition rates. The inorganic fraction is added as in section 4.4.

4.5.2. Effluent

The amount of N added to the mineral soil N pool from effluent each month (kg N/ha/month) is estimated as:

Equation 52: N_Effluent = EffluentInorgN + Nreleasespray + Nreleasesolid

EffluentInorgN is the inorganic fraction of effluent N (all types) added

Nreleasespray is the amount of N released fromslurry effluents (kg N/ha/month) based on standard decompostion method [section 3.3].

Nreleasesolid is the amount of N released from solid effluents (kg N/ha/month) based on standard decompostion method [section 3.3].

4.5.3. Residues

The amount of residue N released each month (kg N/ha/ month) is estimated as:

Equation 53: N_Residue = NreleaseStover + NreleaseRoots + Nreleasedung + NreleaseUnutilSup + Nprunings

NreleaseStover is the amount of N released from stover (kg N/ha/month) based on standard decompostion method [section 3.3].

NreleaseRoots is the amount of N released from roots (kg N/ha/ month) based on standard decompostion method [section 3.3].

NreleaseRoots is the amount of N released from dung (kg N/ha/ month) based on standard decompostion method [section 3.3].

NreleaseUnutilSup s is the amount of N released from unutilised supplements (kg N/ha/ month) based on standard decompostion method [section 3.3].

Nprunings is the amount of N released from prunings of fruit crops (kg N/ha/ month) [section 2.14].

4.6. Denitrification

Denitrification is estimated using the model described by Cichota *et al*. (2010). Thus the amount denitrified (kg N/ha) in a given month is estimated as:

Equation 54: N_Denit = N_Min_{mon-1} * a_Denit * f_Denit * (f_Temp * 0.5)

a_Denit is 0.05, that is a maximum of 5% of soil mineral N is lost to denitrification per month when the soil is at field capacity and 20°C.

f_Denit is a soil moisture factor for denitrification [Equation 55].

f_Temp is the temperature factor for organic matter mineralisation [section 3.2.4].

0.5 is a scalar to scale f_Temp to close to 1 at 20°C.

The effect of soil water content on denitrification is described by the factor f_Denit, assuming it decreases linearly as soil dries out, reaching zero when the soil water content is less than or equal to 80% of the field capacity. Hence f_Denit is estimated as:

Equation 55: f_Denit = (f_SWC - b_Denit) / (1 - b_Denit)

f_SWC is the soil water content factor for organic matter mineralisation [section 3.2.3].

b_Denit is the constant 0.8.

If DCD is applied, the reduction in the amount of N denitrified (NSaved) is estimated as:

Equation 56: $NSaveDenit = N\_Denit * (1 - DCDfert_{block, mon}/ 100) * 1.1$

DCDFert is the relative amount of N leached in the presence of DCD [DCD Model].

1.1 adjusts DCDFert to total dentirification saved.

The amount saved is deducted from the estimated N denitrified.

4.7. N leaching

A proportion of the soil mineral N pool is assumed to leach each month. Thus the amount leached in a given month (kg N/ha) is estimated as:

Equation 57: N_Leach = f_leach * BaseSoilN

fleach is the proportion of Navailable that can be leached [section 4.7.1].

BaseSoilN is the soil mineral N pool that is available to be leached (kg N/ha) [Equation 58].

where the amount of N available to be leached (kg N/ha) is estimated as:

Equation 58: $BaseSoilN = N\_Min_{mon-1} + N\_Fert_{mon} + N\_Irrig_{mon} + N\_Rain_{mon} + N\_Residue_{mon} + N\_SOM_{mon} + N\_MinResid_{mon} + N\_OrganicFert_{mon} + N\_effluent_{mon} - N\_Volatil_{mon} - N\_Denit_{mon} - N\_Uptake_{mon}$

If N_leach is less than or equal to zero and f_leach is greater than zero, then a minimum amount of N leaching is estimated as:

Equation 59: $N\_Leach = f\_leach * (N\_min_{mon-1} + N\_Fert_{mon} + N\_Residue_{mon} + N\_Effluent_{mon} – N\_Volatil_{mon}) * 0.1$

If DCD is applied, the reduction in the amount of N leached (NSaved) is estimated as:

Equation 60: $NSaveLeach = N\_leach * (1 - DCDfert_{block, mon}/ 100)$

DCDFert is the relative amount of N leached in the presence of DCD [DCD Model].

The amount saved is deducted from the estimated N leached.

4.7.1. Proportion of N that leaches

The proportion of soil mineral N that can be leached (fleach) is estimated as:

Equation 61: $f\_leach = a\_leach * (drainage / PAW)^{b\_leach}$

a_leach is the maximum proportion of soil mineral N that leaches [section 4.7.2].

drainage is the monthly drainage at 600 mm depth (mm) [Hydrology chapter].

b_leach is a drainage parameter [section 4.7.3].

PAW is the profile available water to 600 mm depth (mm) [Characteristics of soils chapter]

f_leach has a maximum value of 0.7. The rationale for dividing the drainage by the available water in the leaching equation was to eliminate any soil effect. This was accomplished only partly as texture*depth still need to be considered when estimating the maximum proportion of soil mineral N that leaches.

4.7.2. Maximum proportion that leaches

The difference between N leaching estimated by the nitrogen management for environmental accountability (NMEA) tool whether using a complex set of parameters or a simplified set to estimate the maximum proportion that leaches did not exhibit significant differences. After accounting for the amount of N available for leaching and the variations in water storage capacity in the soils, about 89% of variance in leaching was explained by variance in drainage (D. Hedderley, personal communication).

On heavy textured soils, the maximum proportion of soil mineral N that leaches decreased with depth to the non-standard layer (Figure 6). Heavy textured soils are described as those with a soil textural group of ‘heavy’ or those with a subsoil clay content of greater than 30%.

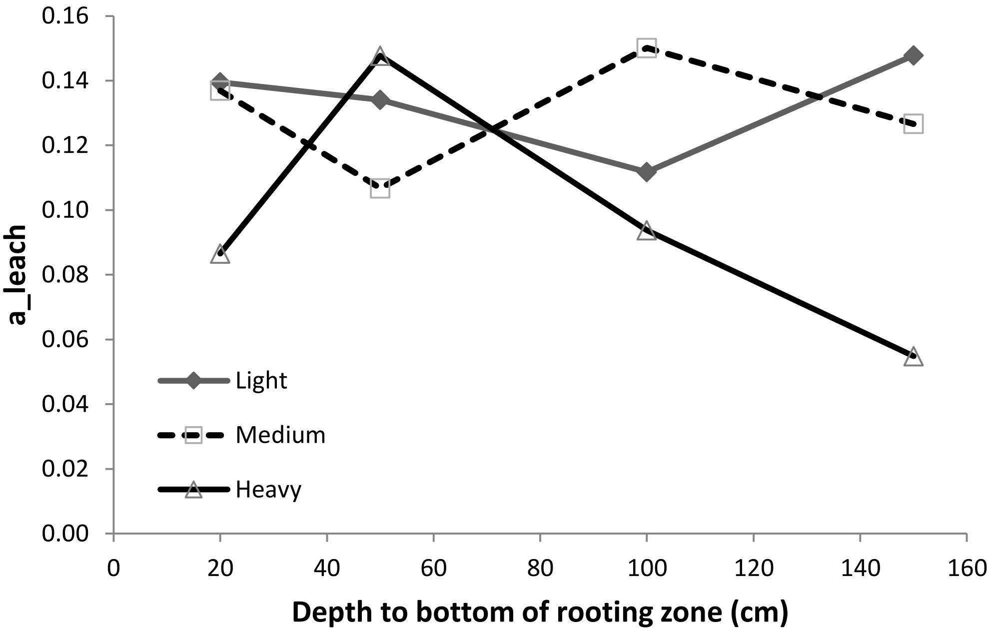

Figure 6. Effect of depth to bottom of rooting zone on a_leach.

Thus the maximum proportion of soil mineral N that leaches is estimated as:

Equation 62: a_leach = 0.127620 - (0.00039886 * depth * 100) heavy
= 0.131696 otherwise

depth is the depth to the non-standard layer (m), or 1.5 if an impeded layer is not present.

Given that non-standard layer is only used for one method of entering of soil property inputs, and that a standardised depth of 600 mm is used, then a_leach was assumed to be constant at 0.131696.

4.7.3. Drainage parameter for leaching

The curvature parameter, b_leached, was obtained from fitted values as part of the NMEA project (MPI 2008). The fitted value was 0.941, indicated a near-linear relationship between the ratio of drainage at 600 mm depth over profile available water to 600 mm and the maximum proportion of N that leaches (f_leach). Under high drainage (when monthly drainage exceeds PAW), the profile has been eluted and it was assumed that the proportion of available N that leaches is reduced. In this situation, a value of 0.6 is used (Figure 7).

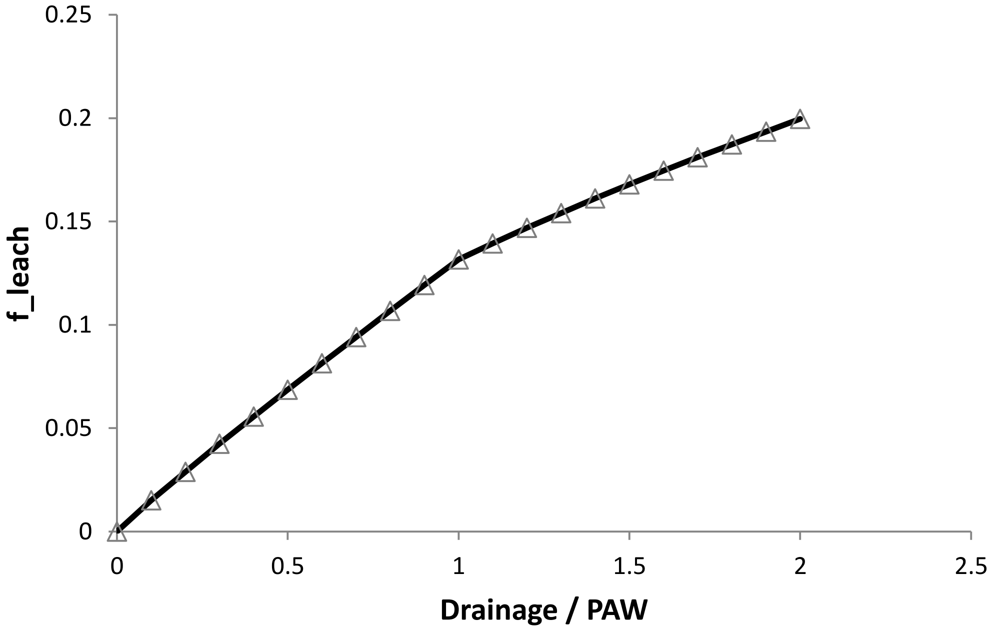

Figure 7. Relationship between the ratio of drainage at 600 mm depth over profile available water to 600 mm and the drainage parameter for leaching, and the maximum proportion of N that leaches (f_leach)

4.8. N shortage

The term N shortage was included to ensure closure of the N balance and enable an opportunity for feedback on the feasibility of the system being evaluated. When the crop demand (from user-specified yield) is higher than the supply (from user-specified fertilizer inputs, paddock history and residue management) the model computes a shortage of N.

Two approaches were considered, either keeping N content of the crop constant and allowing mineralisation to increase to compensate for the deficit in N supply, or allowing crop N content to decrease. When the shortage is small, the actual outcome would be a reduction in the N content of the crop. A reduction in yield would occur with larger shortages. However, the model has not been designed to account for variation in N content of the crop and as yield is user specified it cannot be adjusted by the model. Instead N shortage is flagged, giving the opportunity for users to review their inputs. Small values of N shortage may be attributed to variations in crop N concentration or uncertainties in N mineralization and therefore can be disregarded. However, when the N shortage value is large, the crop yield given by the user is not possible with the specified N inputs.

The amount of N supplied (N_Supply) is calculated as for the soil mineral N pool, except that N_Shortage and N uptake are omitted. If N_Uptake is greater than N_Supply, then the difference is assigned to N_Shortage.

4.9. Minimum annual leaching

The minimum annual leaching from the crop N model, based on expert opinion, was assumed to be:

- 1 kg N/ha/year if annual drainage is less than 40 mm.
- Annual drainage * 0.25 if annual drainage is less than 200 mm.
- 5 kg N/ha/year otherwise.

5. Outputs

5.1. Nutrient budget

The total amounts of N fixed, volatilised, denitrified, leached, immobilised, and mineralised from organic matter decomposition is estimated as the sum of the monthly outputs for the reporting year (months 13 to 24). These are used in the nutrient budgets. For crop blocks, the change in soil mineral N pool is also used in the nutrient budget.

The difference in the amount of residue (root and stovers) nutrients at the beginning and end of the year is used to show the change in residue pools in the nutrient budget for crops. This is taken as the difference in residual after calculations in months 12 (which corresponds to the beginning of month 13) and 24.

5.2. Pools

The amount of N in the standing crop (NPlant, kg N/ha) is estimated for crop blocks as the cumulative N uptake of the tops and roots, less any N that is removed due to defoliation. At the end of the crop, the standing crop N is removed as product, unutilised portion of the tops added as stover, and the roots added to the root residues.

The amount of N remaining in stover and roots (kg N/ha) is estimated each month as:

Equation 63: $Nstover = \sum_{mon\ =\ 0\ to\ mon2} (StoverN_{mon})$

mon2 is the month in the cycle.

StoverN is the N remaining in the cohort after decomposition has occurred.

A similar calculation is also undertaken for roots.

5.3. Graphs

Outputs from the N model are shown as graphs on the interface. The graphs show the monthly change in N pools, or the monthly pool value as indicated in Table 10. Example graphs are shown in Figure 98 and Figure 9 respectively. Hence plant N uptake each month is shown on the former, and total plant N taken up in a given month on the later.

Table 10. The graph line and associated data shown on the interface.

Graph line	Data	Section
Change in N pools		
Fertiliser	N_Fert + N_OrganicFert	4.4, 2.11
Effluent	N_Efffluent	4.5.2
Atmospheric	N_Rain + N_Fixed	4.2, 2.12
Soil organic matter	N_SOM	3.2
Residues	N_Residue	4.5.3
Uptake	N_Uptake	2.16
Volatilisation	N_Volat	2.11
Denitrification	N_Denit	4.6
Leaching	N_Leach	4.7
Deficit	N_Shortage	4.8
Irrigation	N_Irrig	2.8
Pools		
Mineral N	N_Min	4.1
Plant	NPlant	5.2
Stover	Nstover	5.2
Root	Nroots	5.2

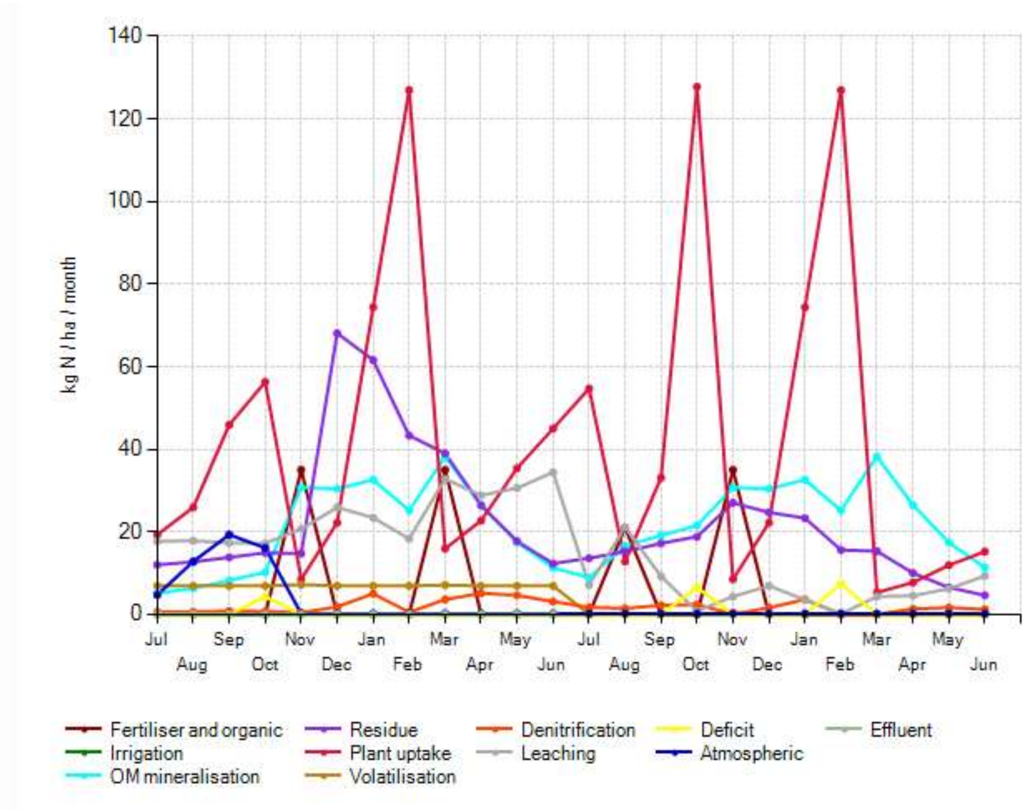

Figure 8. Example of graphical outputs for monthly change in N pools.

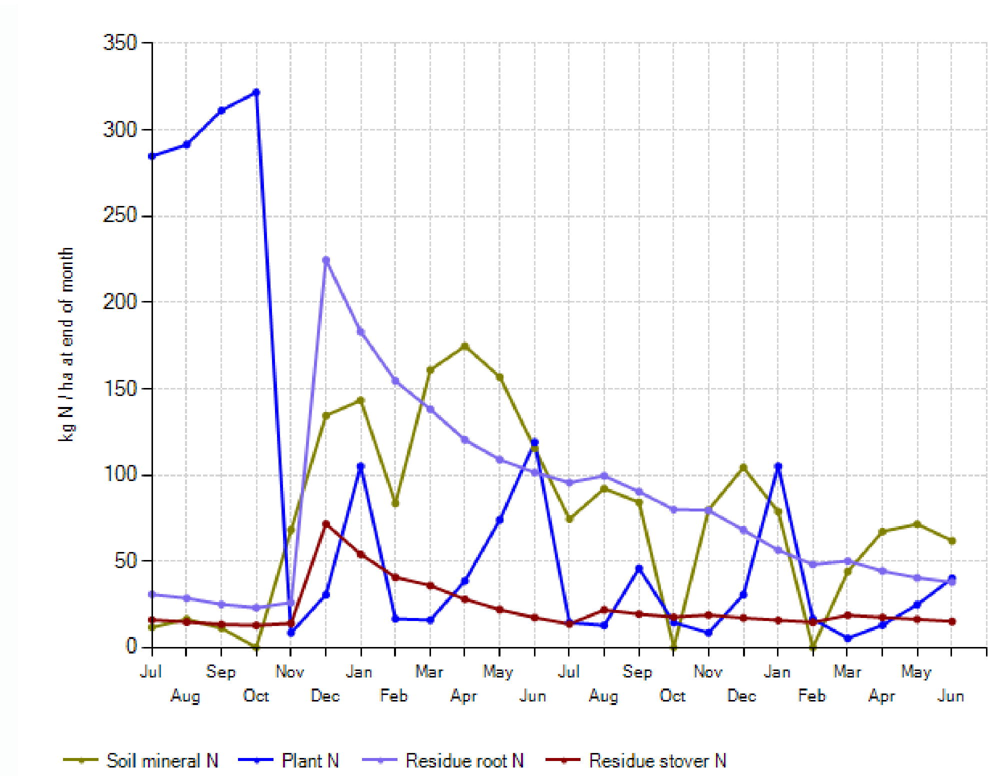

Figure 9. Example of graphical outputs for the monthly pool value.

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