OVERSEER® Technical Manual

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

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Characteristics of pasture

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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.

Contents

Characteristics of pasture

1. Introduction

1.1. Background

Characteristics of pasture are described by the following inputs:

- Pasture type
- Pasture metabolic energy (ME) content
- Pasture digestibility
- Clover level
- Utilisation by animals
- Pasture nutrient concentrations

Pasture type is user-selected, and by default, OVERSEER assumes a white clover/ryegrass pasture. Other options that are available are Browntop, Unimproved/tussock grasslands, Summer C4 (paspalum) pastures, C4 (Kikuyu) pastures, Lucerne, and Grass only.

ME content (MJ ME/kg DM) is an estimate of the energy in the diet that is available for maintenance and production in ruminant animals, that is, the energy in the feed use for metabolic purposes. This is estimated from other constituents of the feed rather than a measured value.

Digestibility (%) is the proportion of the feed that can be digested by ruminants. Digestibility reduces as the plant matures due to increased levels of structural cell-wall carbohydrates (cellulose and hemicellulose) and lignin.

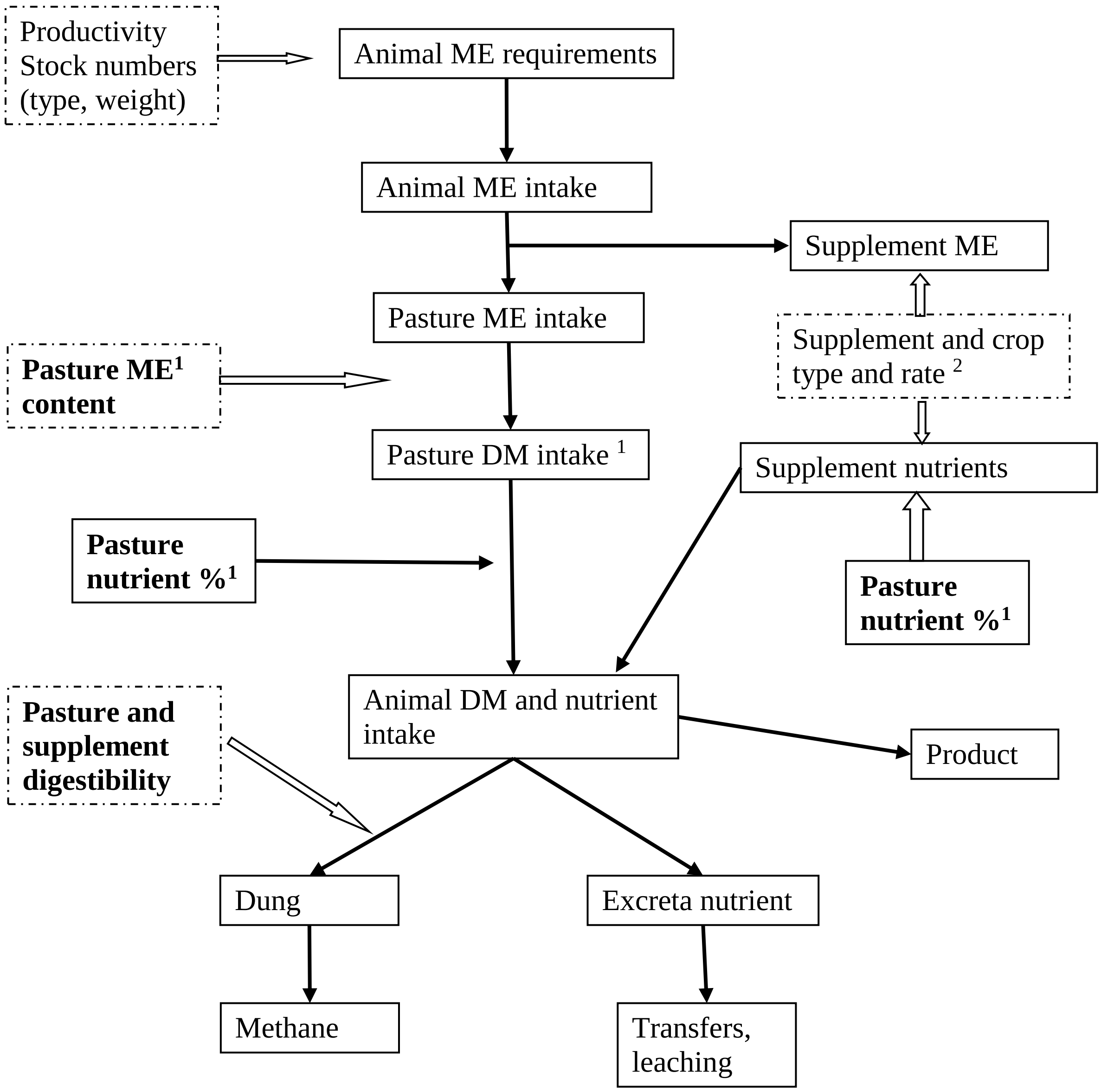
Pasture nutrient concentrations are estimated for N, P, K, S, Ca, Mg, and Na refer to the nutrients nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), and sodium (Na) respectively. Excess cations are also estimated as part of the acidity sub-model (section 5.1.6).

The input 'Clover content' is the annual average clover content (as a proportion of pasture dry matter) where fertiliser N inputs are not applied. Clover content is used in the estimation of N fixation, some pasture nutrient concentrations, and pasture yield distribution through the year. The N budget is sensitive to pasture clover level and it is recommended that medium clover level is used.

'Utilisation' is used to estimate total pasture production, and hence can affect the distribution of pasture intake between blocks if a pasture production based relative productivity assessment is selected. Biological N fixation is also based on total pasture production. Note that N leaching is not affected by utilisation unless pasture production is based on a relative productivity assessment entered by the user.

The intake sub-model requires ME content, digestibility, and nutrient concentrations of ingested material for calculation of DM and nutrient intakes (see Figure 1). For supplement removal, it requires the ME content, digestibility, and nutrient concentrations of removed material. Digestibility is used to estimate the dung dry matter.

Figure 1. Relationship between sections within the technical manual and estimation of



ME = metabolisable energy 1 = block scale, 2 = block and farm scale

pasture characteristics.

Besides pasture type, all other characteristics of pasture have default values calculated as shown in this document. The input 'Pasture type' is used to set default pasture ME content, digestibility, and nutrient concentrations. The estimation of pasture nutrient concentrations depends on soil test and fertiliser inputs. The user can enter monthly ME content and digestibility, clover level, utilisation and annual average pasture N % to over-ride these default values. When doing so care must be taken as no check is made to ensure that values entered are consistent and represent a legitimate farm system.

1.2. Data sources

In the 1990s AgResearch assembled data from trials undertaken by AgResearch and its predecessor, MAF, into three databases for P, K, and S (Edmeades *et al*., 1995). The distribution of trials in the S database is described by Wheeler and Thorrold (1997).

The N database contains N fertiliser trial data and is summarised as (Rajendram *et al*., 2009):

> *Data from 1,272 nitrogen (N) fertiliser trials from around New Zealand over the last 80 years were collated into an electronic database. Data collected included nitrogen (N) fertiliser forms, N application rates, plant dry matter (DM) yields, botanical composition, soil types and weather conditions. This data was sourced mostly from original, unpublished trial records and reports. In this paper, a summary of the information gathered from the database and relationships between the first cut N response and climatic factors are presented.*

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. Abbreviations and subscripts

<u>Abbreviations</u>

DM dry matter (kg)

ME metabolic energy (MJ)

NIR Near InfraRed

<u>Subscripts</u>

mon month

antype animal types within the model (dairy, dairy replacements, sheep, beef, deer, dairy goats, other)

2. Animal behaviour

Animals are known to eat selectively. For example, Pinares-Patino (2003) indicates that sheep tended to select out the better quality feed within the paddock, whereas alpaca tend to eat what is available. Beef cattle are less selective than sheep and for this reason tend to get the job of 'cleaning up'.

Dairy goats are fussy eaters as indicated by high supplement left over rates. Carlson *et al*. (2011) noted that:

> *Dairy goats have a different way of utilising feed than sheep. Dairy goats tend to select feed from the top down when grazing pasture or eating supplements (Clark D.A. et al., 1982). For grazed pasture, this is likely to result in different quality (N concentration, ME content and digestibility) of the pasture compared with that eaten by sheep. Thus, dairy goats tend to eat more high quality grass and less clover than sheep. However, no data on quality of eaten pasture were found for goats. Hence, pasture quality data for sheep was used.*

Difference in pasture characteristics are known to occur when using different sampling heights. For example, Litherland *et al*. (2002) reported differences in crude protein and ME between samples plucked and those harvested to ground level. In many pastures grazed by sheep, clover plants are more prostrate and may not be sampled being under the sampling height. If sheep eat this clover, and as clover usually has higher ME and pasture N concentrations, then sampling may be underestimating intake values. Hence, pasture characteristics are expected to differ depending on how the animal grazes the pasture.

The intake sub-model requires pasture ME, digestibility, and nutrient concentration of the ingested material. Ideally, any sampling technique adopted should represent what the animal consumes. Unfortunately, in most cases there was insufficient information to model ingested material. Animals are also known to ingest soil (Grace and Healy 1973) which can enhance adsorption of P, Ca, and Mg. Soil ingestion has not been considered in the intake sub-model. Consequently, for the most part animal behaviour has not been accounted for as pasture samples have been used instead of a truly representative sample of what was ingested.

3. Pasture ME content

Pasture ME and digestibility are used in the calculation of animal metabolic energy requirements (see Animal metabolic requirement chapter), and pasture ME in the estimation of ingested pasture DM (see Feed intake chapter). Thus pasture ME and digestibility should be of the ingested feed.

ME content is constrained between the limits of 5.8 and 14.8 MJ ME/kg DM.

3.1. Rye grass/white clover pastures

Litherland and Lambert (2007) reported monthly ME contents from pasture samples submitted to a commercial laboratory, with ME measured using NIR. Litherland and Lambert (2007) state that the database was:

> *"equally representative of pastures on both research and commercial farms, predominantly collected by plucking pasture to grazing height. Dairy farmers submitted the bulk of on-farm samples, and these farmers tend to only test their better quality pastures."*

Litherland *et al*. (2002) reported ME from samples plucked to simulate eaten pasture and cut to ground level to simulate 'offered' pasture. ME from plucked samples was higher than that in offered samples by 0.4 MJ ME/kg DM in Southland, 0.6 MJ ME/kg DM in Tararua and Canterbury and 0.9 MJ ME/kg DM in Waikato. The ME contents in samples reported by Litherland and Lambert (2007) tend to be higher than ME contents in offered pasture samples reported by Litherland *et al*. (2002) for all months by about 1 MJ ME/kg DM in the Waikato, and in summer and autumn for samples collected from Canterbury and Tararua. This may be due to differences in pasture type in the Waikato, and dry conditions in Waikato, Tararua, and Canterbury. However, the ME content from plucked samples was similar to that reported by Litherland and Lambert (2007). Hence, the values from Litherland and Lambert (2007) were used as defaults for ryegrass/white clover pasture type. This also meant that pasture N concentrations and ME content (see section 5.1.1) was based on the same data source.

Users can enter monthly pasture ME contents, which must be between 5.8 and 14.0 MJ ME/kg DM. Thus, ME content is estimated as:

Equation 1: ME_{mon} = user defined pasture quality
= $defaultME_{region, mon}$

$defaultME_{region, mon}$ is the default ME content (MJ ME/kg DM) [see Table 1 or Figure 2].

When calculating the default pasture ME content, other inputs that may affect pasture ME content have not been included, such as, clover content, irrigation (less dead matter) and grazing method. The data suggests that the default values could decreased for non-irrigated pastures in drought conditions, but this has not been included in the estimation of ME.

Table 1. Default pasture ME (MJ ME/kg DM) for each region and month.

Region	Average	Northern North Island	Southern North Island	South Island
January	10.65	10.89	10.28	10.78
February	10.55	10.50	10.44	10.61
March	10.43	10.39	10.33	10.56
April	10.93	10.72	10.92	11.14
May	10.90	10.61	10.94	11.14
June	10.91	10.89	11.00	10.83
July	10.95	11.17	10.94	10.75
August	11.04	11.17	11.33	10.61
September	11.31	11.67	11.28	11.00
October	11.31	11.56	11.22	11.17
November	11.14	11.47	11.44	10.50
December	11.06	10.83	11.556	10.78

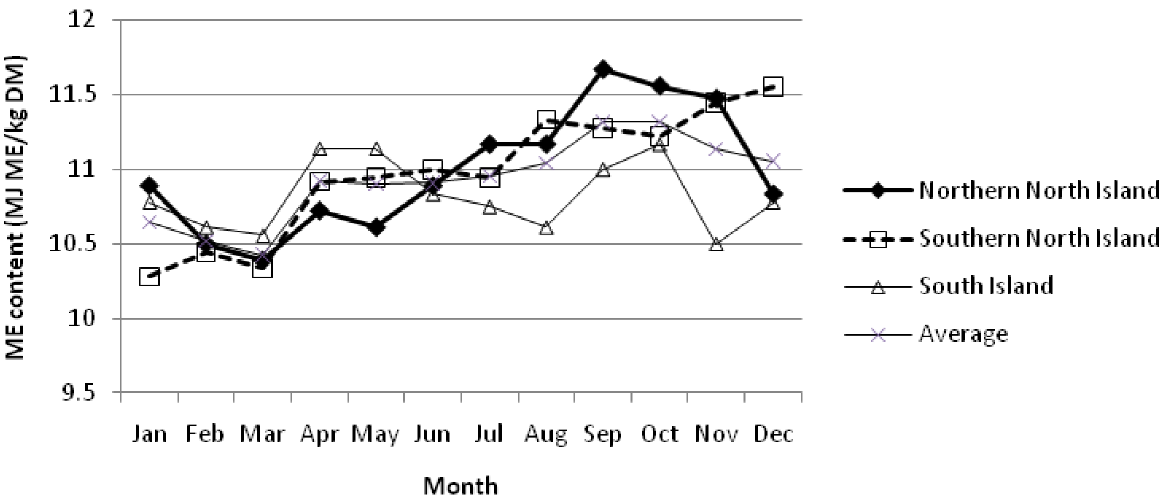


Figure 2. Default pasture ME content (MJ ME/kg DM).

3.2. Non-ryegrass based grass pastures

Litherland and Lambert (2007, Table 2) in a summary of data from two sources showed organic matter digestibility (OMD, g/kg DM) averaged 750 in C3 grasses, 655 in C4 grasses, and 850 in Tama ryegrass. Digestibility and ME content tend to be correlated (see section 4). Thus C4 pastures probably have ME contents that are about 15% lower than ryegrass based pastures. Browntop and unimproved/tussock grasslands probably also have lower ME contents due to the possible greater prevalence of seed heads.

In the Waikato, pastures tend to have a significant proportion of C4 species in late summer and autumn. Assuming 50% C4 content during this period, the ME content of summer pastures, is decreased from January to April by 7.5%.

To account for these, default ME was adjusted for pasture type using the values shown in Table 2. Thus, for non-ryegrass pastures except Lucerne, ME content (MJ ME/kg DM) is estimated as:

Equation 2: ME = user defined in pasture quality

= $MEryegrass_{mon}$ * fpasturetype

$MEryegrass_{mon}$ is the ME content for ryegrass based pasture (MJ ME/kg DM) [see section 3.1].

fpasturetype is a factor adjusting for pasture type [see Table 2].

Table 2. Pasture quality factor for adjusting digestibility for each pasture type.

Pasture type	Browntop	Unimproved/ Tussock grasslands	Summer C4 (paspalum) pastures	C4 (Kikuyu) pastures	Grass only
quality factor	0.95	0.92	0.90 from January to April	0.85	1.0

3.3. Lucerne

Moot (2009) reported that ME content of lucerne varied between palatable and unpalatable fractions of the plant, and that ME content of the whole plant decreased as standing DM increased. Based on standing DM at grazing of 2 T/ha, the ME content was estimated at 10.8 MJ ME/kg DM. There was no information on whether ME content varied with season. Thus, ME content (MJ ME/kg DM) of lucerne is estimated as:

Equation 3: ME = user defined in pasture quality

= 10.8 (MJ ME/kg DM)

4. Pasture digestibility

Pasture digestibility is related to pasture ME content using the conversion from Feeding Standards for Australian Livestock (1994). Thus, digestibility (%) is estimated as:

Equation 4: digestibility = ME / 18.45 / 0.8 * 100

18.45 is the energy content of digestible organic matter (MJ/kg DOM).

0.8 is the ratio of metabilisable energy to digestible energy.

This equation is applied to all pasture types, including lucerne. Digestibility is constrained between the limits of 40% and 100% inclusive.

5. Pasture nutrient concentrations

Within OVERSEER, pasture nutrient concentrations are used in the estimation of animal nutrient intakes and the amount of nutrient removed from the pasture when supplements are made.

Most experiments have focused on nutrient content of harvest material and models based on these data are extensively used. However, these values may differ from pasture nutrient content of ingested pasture if animals can select the feed eaten.

Pasture nutrient concentrations for N are required on a monthly basis, and on an annual basis for other nutrients.

5.1. Rye grass/white clover pastures

5.1.1. Nitrogen: Background

Pasture nitrogen concentrations can have a significant impact on N leaching via intake. A 10% change in pasture N concentrations can lead to a similar change in N leaching.

5.1.1.1. *Annual average N concentrations*

A limited survey of New Zealand data on pasture N concentrations was undertaken and a summary of the results is given below:

1) Ledgard *et al.* (2003) summarised pasture N concentrations from a range of trials and data collections. A summary of the information follows with numbered tables referred to being those presented in Ledgard *et al*. (2003).

    - A summary of field trials where pasture N concentrations were measured mentioned that:

        - pasture N concentrations on sheep and beef farms averaged 2.6% in a trial in Waipawa, Hawkes Bay and 3.2% in a range of other trials.
        - on sheep and beef farms, low fertility sites as defined by lower soil tests and lower soil fertility, generally had lower N contents than high fertility sites (Table 7)
        - in a trial on a Waikato sheep and beef farm, mean pasture N concentration at camp sites was 3.9%, on medium slopes about 3.5%, and on steep slopes 3.0%.
        - pasture N concentrations were, on average, 0.6% lower on steep slopes compared to camp sites on a Waikato site (Table 7), and 0.4% lower on steep slopes compared to easy slopes in a trial in Waipawa, Hawkes Bay (Table 8)
        - N concentrations for a sheep/beef trial were 0.6% lower on steep slopes compared to camp sites on a Waikato site (Table 7).
        - on dairy farms, pasture N concentrations ranged from 2.8% to 3.6%, with 1 trial in Taranaki at 4.5% (Table 9); these were higher than sheep and beef farms (average: 3.1%, range: 2.4-3.5%).

    - N concentrations of samples submitted to a commercial lab between 1992 and 1999 averaged 3.49% on sheep/beef farms and 4.02 on dairy farms (Table 10 and Table 11). There were no consistent differences between soil types but there were differences between regions. Pasture N concentrations tended to be slightly lower in the North Island than South Island. Pasture N concentrations were lower in the drier regions of Hawkes Bay and Gisborne regions but not the Wairarapa and Canterbury regions.

- From a series of additional samples taken in autumn:
  - average pasture concentrations were 3.45 on flat slopes for samples collected from sheep and beef farms, and 4.15% on dairy farms (Table 13)
  - N concentration decreased as slope increased for sheep/beef farms, being 0.16, 0.24, and 1.1% lower on rolling, easy hill and steep slopes than on flat slopes (Table 12), and 0.6% lower on steep slopes compared to camp sites on a Waikato site (Table 7).

2) Litherland and Lambert (2007) published crude protein and ME content from samples submitted to a commercial testing lab using NIR. There results indicated that:

- on average, pasture N concentrations were 0.23% greater in the South Island than in the North Island. Northern North Island samples consistently had lower concentrations than South Island samples, but the differences between South Island or northern North Island and southern North Island were not consistent.
- on average, N concentrations from samples were 3.44%, 3.55%, and 3.66% from Northern North Island, Southern North Island, and South Island respectively.
- crude protein concentrations of C4 grasses were not consistently less than C3 grasses.

3) Litherland *et al.* (2002) showed that crude protein levels were 20.8, 21.8, 18.9, and 22.9 (3.33, 3.49, 3.03, 3.66 % N) on sheep/beef farms from Waikato, Tararua, Canterbury and Southland for offered pasture. However, crude protein levels were similar across regions (average crude levels 25% of DM, 4.0 % N, although lower in Canterbury (average of 22%)) for plucked herbage (to simulate eaten pasture).

4) Samples were taken from a 500 x 500 mm quadrant cut to grazing height (King and Rennie, pers. comm.) from paddocks in 3 general locations (Lincoln, Palmerston North and Ruakura) at 3 sampling times (autumn and spring 2009, and autumn 2010). These paddocks were predominately grazed by dairy animals. These samples indicated that:

- N content was generally low, averaging 3.04-3.34% on dairy pasture from different sites. N content tended to be higher at Lincoln than Ruakura.
- The range in N content was similar all year round
- NIR spectroscopy underestimated %N compared to wet chemistry methods at high N contents. Samples analysed to be 1.6% N_{WC} (by wet chemistry) gave NIR %N values that were slightly higher, at 2.4% N_{WC} the two methods were similar, at 3.2% N_{WC} NIR %N was 0.12% lower and at 4% N_{WC}, NIR %N was 0.24% lower.
- There was generally a poor relationship between crude protein and clover content, although there was a tendency in some samplings for %N to be greater than 3.2% if the clover content exceeded 15%. Clover levels varied from 0 to > 50%.

5) N concentrations from individual sources indicated that:

- analysis of data extracted from the P database indicated that in control treatments, N concentrations in pastures on dairy farms were 0.3-0.5% higher than in pastures on non-dairy farms, except in February, March, and April, when they were similar.

- analysis of the N database indicated that control N concentrations ranged from 3.0-5.0% (two outliers at 2.5%) for trials on yellow brown loams (YBL), from 4.0-5.0% for trials on yellow brown pumice soils (YBPS), from 3.0-5.0% for trials on gley soils (but most were > 4.0%) and 4.0-5.0% for trials on organic soils. Thus organic and gley soils tended to have values > 4.0 %.
- Monaghan *et al*. (2005) reported that in the absence of N fertiliser applications the N concentration of cattle-grazed pasture grown on a pallic soil at Edendale increased over time to be 3.08%, 4.08%, 4.11% and 4.71% for 4 consecutive years. This trial was initially sheep/beef pasture, but was drained, and capital fertiliser P applied to increase Olsen P from the original 11-12. Clover yield doubled in years 3 and 4, while grass yields went up about 30% in year 3, and nearly doubled in year 4.
- From a trial at Tussock Creek on a commercial dairy farm, grass N concentrations averaged 3.7% (C Smith, AgResearch, pers. comm. (2007)), and varied by more than 1.0% during the year.

Table 3. Pasture N concentrations from a trial at Tussock Creek.

Year	Average	Minimum	Maximum
1	4.00	3.5	5.4
2	3.66	3.1	4.3
3	3.68	2.8	4.9
4	3.76	2.4	4.8
5	3.39	2.6	4.2

When interpreting this data, bias should be considered. Ledgard *et al*. (2003) noted:

> *"Caution should be exercised in extrapolating from this database to average farm values, since historically, samples were submitted from higher producing farms. Data are unbalanced for the different categories. The number of records per region suggests that in areas with a strong consultancy base, such as Taranaki, more samples were analysed and they may have represented the more productive farms. For example, a significant number of samples from Taranaki dairy farms were from a consultancy group whose farmers apply very high rates of N fertiliser. Thus, the data provides an indication of some factors causing variation in pasture N concentration but it is probably biased in representing higher than average values."*

A similar cautionary note would also apply to the data of Litherland and Lambert (2007) where they state that the database was:

> *"equally representative of pastures on both research and commercial farms, predominantly collected by plucking pasture to grazing height. Dairy farmers submitted the bulk of on-farm samples, and these farmers tend to only test their better quality pastures."*

Although the true bias is unknown, these sets of data still remain a good source of information.

Overall, pasture N concentrations were lower in sheep and beef farms than dairy farms, higher in the South Island, lower at low fertility sites, and lower for low fertility or C4 species. In general, pasture N concentrations were also higher on gley and organic soils and lower in regions or sites where dry conditions are likely to occur. The data indicates that reasons for differences in pasture N concentrations between dairy farms and sheep and beef farms could include lower soil fertility, steeper slopes, the presence of lower fertility grasses, a higher incidence of dry conditions, and different pasture compositions. The differences in pasture N concentrations between sheep and beef farms, between slopes and seasonal variability could be due to the same factors.

Ledgard *et al*. (2003) reported,

> *"Most dairy farming in New Zealand occurs on relatively flat land. Data for research studies on dairy farms with no N fertiliser showed an annual average of 3.7% N. Similarly, if the average autumn value for "average" dairy farms in Table 13 was adjusted for the ratio of annual-average to autumn-average values (i.e. 4.02/4.43) it would give an estimated annual average of 3.7% N."*

Additional data for pasture N concentrations on dairy farms tended to be in the 3.4 to 3.6% range, which is lower than the average estimated by Ledgard *et al*. (2003). Part of this reason may be due to the NIR method consistently underestimating wet sample N concentrations. Other reasons could be the increases in clover diseases and insect problems, along with increased use of N fertiliser reducing clover content. The impact of clover content on pasture N concentrations has been ignored.

Regions that were dry had lower N concentrations. This could be modelled by reducing N concentrations as a function of soil moisture content

Pasture N content on sheep and beef farms was consistently lower than on dairy farms but the reason for this difference is unclear. Ledgard *et al*. (2003) noted that:

> *"Much land in New Zealand used for sheep and beef cattle farming occurs on rolling to steep sloping hill land. The four hill research studies gave an average N concentration in pasture of 3.0% N. Data for easy sloping land averaged 3.2% N, but if this were adjusted for the ratio of annual-average to autumn-average values (i.e. 3.49/3.69) it would reduce to 3.0% N. Thus, as a first approximation, 3.0% N could be used as an average pasture N concentration for sheep and beef farms in New Zealand."*

Data from the new sources since Ledgard *et al*. (2003) and medium to flat slopes indicated pasture N concentrations of 3.3% to 3.6% N. The data of Gillingham and During (1973) reported in Ledgard *et al*. (2003) indicates that N concentrations at campsites on steep hill country can approach those found in dairy pastures. The effect of selectivity is more likely to be seen with sheep than other animal types (see section 2). Thus for sheep, although bulk pasture N concentrations may be lower, the N concentrations of the ingested material may be more similar to that seen for dairy pasture. Therefore, sheep/beef farms on flat topography were assigned a value of 3.3%.

There is considerable variation in pasture N concentrations between sites. A variation of 1% would lead to about a 20% to 30% difference in the estimated amount of N leached. The reduction in N leaching from mitigation options such as substituting N fertiliser for maize silage would depend also on pasture N concentrations. Hence, actual site pasture N concentrations can be important, especially when calibrating field trials. Ledgard *et al*. (2003) reported that:

> *"If dairy pasture was assumed to have the same N concentration as the 3.0%N for easy hill land for sheep and beef instead of 3.7%N, it would result in a 22% lower estimate of N excretion by dairy cows and an 8% lower estimate for national sheep+beef+dairy animals. The potential effect of variation in pasture N concentration with land slope on estimates of N excreted was larger. If pasture consumed by sheep and beef cattle had a value of 3.5% N (approximating that for flat land) it would result in a 19% higher value for N excreted, and a 12% higher estimate for national sheep+beef+dairy animals. Conversely, if pasture was assumed to be 2.2% N, applicable for steep land, it would give a 30% lower estimate for sheep and beef cattle, and a 19% lower value for national sheep+beef+dairy animals."*

5.1.1.2. *Monthly N concentrations*

Seasonal patterns were similar across all sources of information. In general, pasture N concentrations were lower in October to March (late spring to early autumn) than winter and early spring, although exceptions were noted (e.g., a dairy trial in Taranaki reported in a summary by Ledgard *et al*. (2003)). The pattern for the three regions in Lambert and Litherland (2007) are shown in Figure 3. The average N concentration of the South Island was 3.66%, with a range 3.13% to 4.09%.

The pattern for the average of the three regions in Lambert and Litherland (2007), and seasonal means for dairy and sheep and beef farms from Ledgard *et al*. (2003) are shown in Figure 4. Figure 4 Ratio of monthly to average annual N pasture concentration (average of three regions for data extracted from Litherland and Lambert (2007) and dairy and sheep from Ledgard *et al*. (2003)).

For autumn, winter and summer, the average from Litherland and Lambert (2007) was similar to Ledgard *et al*. (2003) data. The exception was autumn, where the average of the three regions of Litherland and Lambert (2007) were generally lower.

Ten measurements of pasture N concentrations per year were made on a series of lime trials in Hawkes Bay where grazing and mowing trials were adjacent to each other, and a mowing trial near Te Kuiti. On average, 10 measurements of pasture N concentrations per year were made (Wheeler *et al*., 1997). There was less seasonal variation in mowing trials than grazing trials in pasture N concentrations (unpublished data). This was due to mowing trials having lower pasture N concentrations in spring compared to grazing trials.

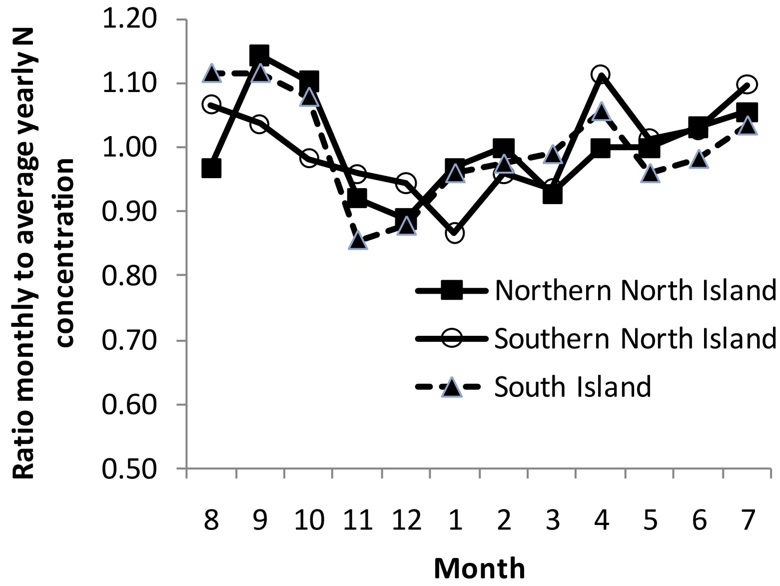


Figure 3 Ratio of monthly to average annual N pasture concentrations for 3 regions (extracted from Litherland and Lambert (2007)).

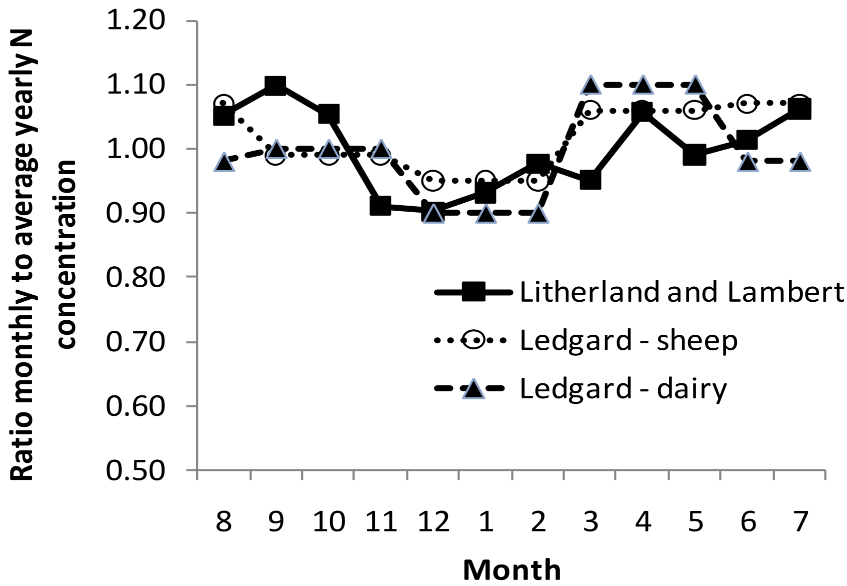


Figure 4 Ratio of monthly to average annual N pasture concentration (average of three regions for data extracted from Litherland and Lambert (2007) and dairy and sheep from Ledgard *et al*. (2003)).

5.1.1.3. *Effect of Fertiliser*

Data from the N fertiliser database (see section 1.2) was extracted and analysed to determine the average change in pasture N concentrations after the application of N fertiliser. For most trials, a single application of N was applied. As OVERSEER requires an estimate of N concentrations of eaten herbage, the effect of fertiliser N on pasture N concentrations 30-60 days after application was used.

There was a tendency for the difference in pasture N concentrations between the nil (control) and plus N fertiliser treatments to decrease as the control N concentrations increased, particularly on pumice soils and to a lesser extent on YBL. If control plant N concentrations were less than 4.0%, differences were usually positive.

There were differences in the range of control plant N concentrations and differences between N and no-N treatments between soil groups (Table 4). On average, differences were highest in pumice soils and lowest in organic and gley soils, and higher when control pasture N concentration was less than 4.0%.

Table 4. Range of plant N concentrations in no-N treatment, and differences in plant N concentrations between N and no-N treatments between soil groups from the N database.

Soil group	No-N treatments	Difference between N and no N		
		Average	Range	Average when no N < 4.0
YBL	3.0-5.0	0.09	-0.8 - 0.8	0.20
YBPS	3.0-5.0	0.39	0.0 - 1.0	0.76
Gleys	4.0-5.0	-0.14	-0.8 - 0.7	
Organics	4.0-5.0	-0.29	-1.5 - 0.5	

The average difference increased as the rate of N fertiliser applied increased. Thus, the average difference over all samples was -0.21%, 0.02%, 0.13% at 25, 50 and 100 kg N/ha applied respectively, and 0.31% (0.12% excluding pumice soils, pumice soils difference was 0.78%) and 0.45% for 50 and 100 kg N/ha applied respectively when control pasture N concentration was less than 4.0%. This equates to a response in pasture N concentrations of 0.0041% per kg N applied in a given month.

These average differences are based on limited trial data, and there is wide variation in values within a category. In the limited number of trials with more than two rates of N and a control, the difference tended to be higher in the higher N treatments.

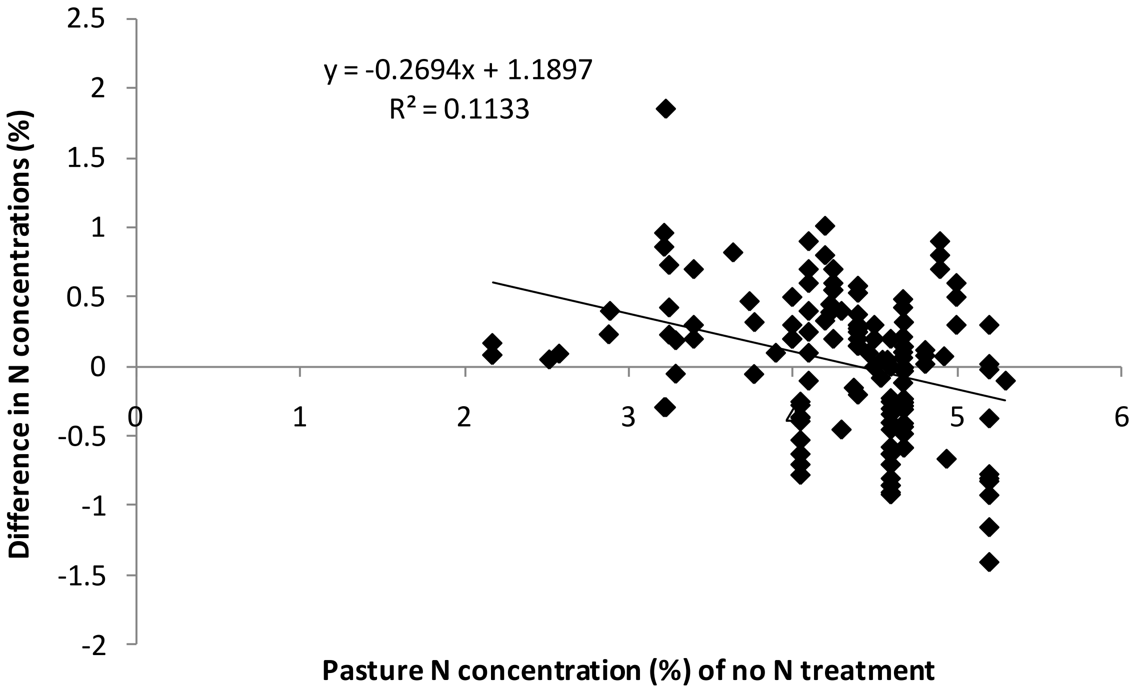


Figure 5. Relationship between pasture N concentrations of the nil N treatment and the difference between no-N and plus N treatments.

In a trial on Waikato dairy research farm, (Ledgard pers. com) N was applied frequently after grazing throughout the year at differing rates per application so that total applications totalled about 200 N or 400 N respectively. On 400 N pastures application also had low and high stocking rate treatments. On average, the application of N fertiliser increased plant N concentrations by about 0.50% in the 200 N, and 400 N high stocking rate treatment. In the 400 N low stocking rate treatment, the increase was 0.47 in year 1, and then averaged 0.75% for subsequent years.

Table 5. For a trial on Waikato dairy research farm, nil N grass N concentration (%) and the difference in grass N concentration between the nil and plus N treatments.

	Nil N pasture N concentration (%)	Difference in pasture N concentration (%)		
		200 N	400 N Low stocking rate	400N High stocking rate
Year 1	3.11	0.57	0.47	0.46
Year 2	3.21	0.31	0.74	0.52
Year 3	3.25	0.54	0.78	0.60
Year 4	3.03	0.46	0.67	0.36
Year 5	3.05	0.54	0.80	0.58
Average	3.13	0.48	0.69	0.50

In the first year, there was an increase in pasture N concentration due to N fertiliser application but no difference between treatments. The difference between the low and high stocking rate treatments suggest that at low stocking rates, the underlying N soil fertility can build up leading to an increase in response rate. The clover N concentrations were slightly higher (0.05) when N fertiliser was applied, being 4.55%, 4.62%, 4.62% and 4.61% for 0, 200, 400 and 400 high stocking rate treatments respectively.

On an annual basis, pasture N concentrations increased by about 0.0014% per kg N fertiliser. Assuming an average application rate of 17 and 35 kg N/ha/month, the response rate for pasture N concentrations on the Waikato trial was 0.0149% per kg N applied.

At a trial at Edendale (R Monaghan, AgResearch, pers. comm.), multiple applications of 50 kg N/ha were applied to give 3 plus N treatments. The increase in pasture N concentrations due to the application of fertiliser decreased over time. The highest rate of change in year 1 was similar to the rate of change on the Waikato dairy research farm. This site was compounded by the control plant N concentrations increasing from 3.08% to 4.79% over 4 years.

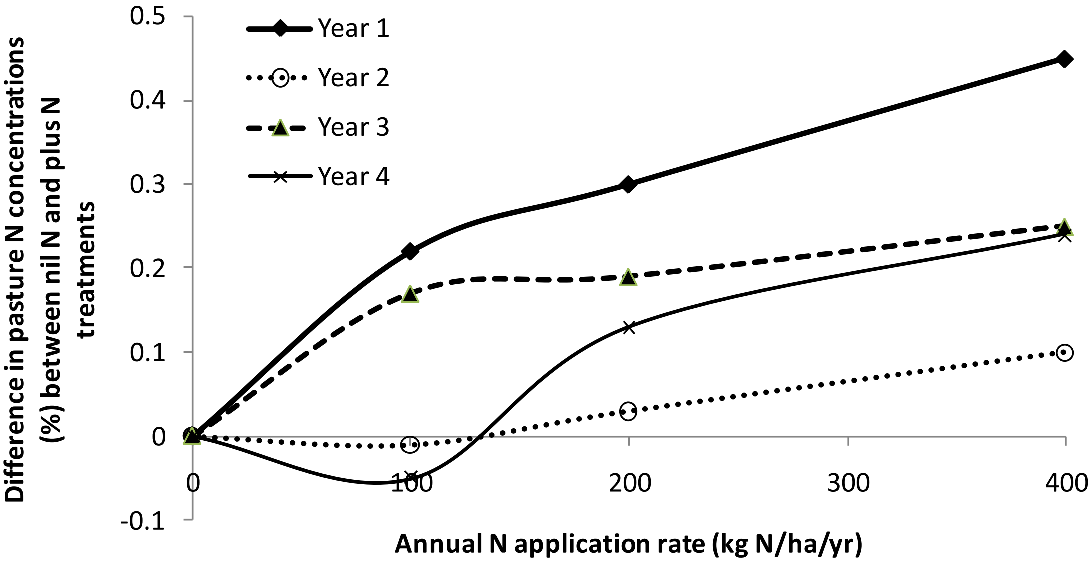


Figure 6. For a trial in Edendale, the relationship between annual N application rates and the difference in pasture N concentration between the nil and plus N treatments.

In both the trials on Waikato dairy research farm and the Edendale site, N fertiliser was applied at regular intervals over multiple years. The increase in response rate at 400 N on the Waikato farm indicates that there may be a build-up in soil N status that also contributed to the response rate. This effect is equivalent to 0.001% per kg annual N applied. An alternative interpretation of the Edendale data is that the increase in pasture N concentrations averages about 0.22, except at high (4.79) pasture N concentrations, and that at high rates (≥ 100 kg N/ha/year) there is an underlying fertility effect of 0.0075% per kg annual N applied.

A response rate of 0.22% is similar to the average response rate for YBL from the database. Assuming an increase of 0.22% for 50 kg N applied, and combining the database and Edendale trial suggests that the response rate to a single application is 0.0048 % per kg N applied. The reason for the high difference for pumice soils (0.0154% per kg N applied) is unclear but these are more similar to the Waikato trial.

It is unlikely that very low applications would result in an increase in pasture N concentrations. For the Waikato trial, the 200 N treatment generally had monthly applications between 11 and 35 kg N/ha/application and plant N concentrations increased. Therefore, it was considered an increase in plant N concentrations would decrease once application rates were less than 19 kg N/ha/application.

The Edendale trial, organic and gley soils could all be undergoing a build-up in soil fertility that results in high (>4.0%) pasture N concentrations and lower response rates to a single application. It seems probable that the response rate is lower, but there is currently no method available to indicate when a farm may be in this state. However, this is probably more likely to occur when a site is in transition (i.e. moving from a sheep/beef operation to a dairy operation) and hence is outside the scope of OVERSEER.

There was insufficient information to indicate the most appropriate method to model the effect of N fertiliser. Therefore, a combination model combining an effect due to an application rate plus the impact of long-term use of N on N soil fertility status was adopted. It was assumed that pasture N concentrations in the absence of N are 4.0% or lower, and hence no adjustment was made for pastures with high N concentrations.

5.1.1.4. *Measured N concentrations*

One option considered was to allow users to supply pasture N concentrations. Available data indicates that there is considerable year-to-year variability, and hence the sampling regime is important if entering user-defined data. It was decided to allow entry of pasture N concentration providing the value entered represented samples collected over 4-5 years. Given the effect of both ME content and pasture N concentrations on N intake, it is recommended that both be measured. It is recommended that the value entered be based on a minimum of 6 evenly spaced samples per year with sampling continuing over a 4-5 year period.

The increasing use of regular pasture sampling using remote sensing systems means that this is increasingly becoming a viable option provided adequate sampling protocols are developed.

5.1.2. Nitrogen: Implemented model

Annual average N concentration (base N) for a dairy farm on flat topography was about 3.7%. At most sites where measurements were made, there was some summer dryness. Setting a base N concentration to 3.8% and applying soil moisture factor gave an annual average N content of 3.7%. Base N concentrations for other animal types were made relative to 3.8% for dairy farms on flat land based on the data in section 5.1.1.1. Thus base N concentration of 3.8, 3.7, 3.6 and 3.3 for dairy, dairy replacement, beef and other based pastures were used. Pasture N concentrations were then modelled by adding regional adjustments based on data from Litherland and Lambert (2007), and then adjusted to a monthly values based on the average curve of Litherland and Lambert (2007).

The data indicated that the impact of different factors affecting base N concentrations could be confounded. To avoid a high multiplicative effect, the maximum impact of factors affecting a given block was used. The factors considered were:

- blocks with merino animals, as it was considered that these blocks probably have lower soil fertility with tussock/unimproved tussock.

- pastures with C4 or unimproved/tussock grasslands.
- in dry conditions in proportion to the ratio of soil moisture content to field capacity.
- non-flat slopes based on Ledgard *et al*. (2003).

Pasture N concentrations were increased to take account of inorganic N applied (N from fertiliser, irrigation, as well as inorganic N in effluents) using a split model that included total annual and application rate for a given month. It was assumed that the pasture was eaten 4-8 weeks after the N was applied. Hence, inorganic N applied in the previous month is required.

On pastoral blocks only, the model also adjusts the pasture N concentration based on the clover content.

Thus, pasture N concentrations (%) on a given block for a given month was modelled as:

Equation 5: $PlantN_{block, mon}$ = user supplied annual average N concentration
= user supplied average monthly N concentration
= $Nconc_{mon}$ otherwise

where the monthly N concentration (%) is estimated as:

Equation 6: $Nconc_{mon} = (AnnualN * seasonNconc_{mon}) + AdjFactors + FertAdj_{mon} + CloverAdj$

AnnualN is a annual N concentration (%) [Equation 7].

$seasonNconc_{mon}$ is 0.93, 0.98, 0.95, 1.06, 0.99, 1.01, 1.06, 1.05, 1.10, 1.05, 0.91, 0.90 for January to December, based on Figure 4.

AdjFactors is an adjustment for stock type, moisture and topography [Equation 9].

FertAdj is an adjustment factor for fertiliser [*Equation 10*].

CloverAdj is an adjustment factor for clover levels [Equation 11].

Annual N concentration is based on a base rate and a region adjustment. Thus:

Equation 7: $AnnualN = (base + NConcAdj_{region})$

base	= 3.8	if > 50% dairy intake
	= 3.7	if > 50% dairy replacement intake
	= 3.6	if > 50% beef intake
	= 3.3	otherwise

Based on Litherland and Lambert (2007), a regional adjustment (%) was applied.

Equation 8: NConcAdjregion	= 0.12	for Southern North Island
	= 0.23	for South Island
	= 0	otherwise

Pasture N concentrations were then increased or decreased for stock type (user selected a merino block), pasture type (user selected pasture type, soil moisture status as calculated by the hydrology sub-model, and user selected topography. Only soil moisture status varies monthly. Thus, AdjFactors (%) is estimated as:

Equation 9: AdjFactors = min(FPasturetype, FStocktype , Fmoist, Ftopo)

FStocktype = -0.4 if merino

= 0 otherwise

FPasturetype = 0 ryegrass/white clover

= PastNReduct other pasture types [section 5.2].

Fmoist = $-(1 - SM_{mon} / SMfc)$

SM is the average soil mositure for month [Hydrology chapter].

SMfc is the fisoil mositure content at field capacity [Hydrology chapter].

Ftopo = -1.1 steep

= -0.24 easy hill

= -0.16 rolling

= 0 otherwise

Fertiliser adjustment is split between the effect of total N applied, and the N applied in a given month, and is estimated as:

Equation 10: $FertAdj_{mon} = Rapplication_{mon} + Rannual$

where the effect of the month of application is estimated as:

$Rapplication = 0.22$ $InOrgNApplied_{month} > 10$

$= 0.22 * InOrgNApplied_{mon-1} / 10$ otherwise

and the effect of the total annual application is estimated as:

Rannual = (InorgAnnual – 100) * 0.001 if InorgAnnual > 100

= 0 otherwise

$InOrgNApplied_{mon-1}$ is the inorganic N applied in the previous month (kgN/ha/month).

InorgAnnual is the annual amount of N fertiliser applied (kg N/ha/year).

The effect of clover level assumes that the change in pasture N content is a function of the change in clover levels and assuming that clover N content is 5%. Thus:

Equation 11: CloverAdj = 1 non-pastoral blocks

$= \sum_{ansys}(diffClover * blockSU_{block, antype} * (5.0 - Nconc_{mon}))$

5.0% is typical clover N concentration.

$blockSU_{block, antype}$ is the proportion of intake for an animal type.

Nconc is the estimate pasture N content before appling the clover adjustment factor.

where the difference in clover levels is estimated as:

Equation 12: $diffClover = clovercontent_{antype, clover} - clovercontent_{antype, medium}$

clover is the selected or default clover level.

clovercontent is proportion of clover in sward [section 10].

5.1.2.1. *Alternative approach*

An alternative approach considered was to model the components separately, such that:

Equation 13: Pasture N concentration = grassN * (1-pclover) + cloverN * pclover

where grassN and cloverN are the grass and clover N concentrations respectively and pclover is the proportion of clover in the sward. A survey of the literature indicated that typically grass N concentrations ranged from 2 to 4%. Clover N concentrations ranged from 4.0 to 5.0% with less variation than grass N concentration. There was insufficient information describing the factors affecting the variation of component N concentrations to be able to validate this model against whole pasture N concentrations.

5.1.3. Phosphorus and potassium

The pasture P and K concentrations (%) are based on an analysis of the P and K databases (see section 1.2) and are estimated as:

Equation 14: Plant P = (hPmin + (hPmax - hPmin) * (1 - Exp(-hP * rate))) * 100
rate is the labile and fertiliser P added (kg P/ha).
hPmin is the minimum herbage P (0 kg P/kg DM).
hPmax is the maximum herbage P (0.005 kg P/kg DM %).
hP is ln(10)/herbP90.
100 converts to %.

Equation 15: Plant K = (hKmin + (hKmax - hKmin) * (1 - Exp(-hK * rate))
rate is the plant available K in the soil and fertiliser K added (kg K/ha).
hKmin is the minimum herbage K (1 %).
hKmax is the maximum herbage K (3.5 %).
hK is ln(10)/herbK90.

Note that a maximum K level of 3.5% does not allow for luxury uptake, for example that may occur on effluent blocks with a high rate of effluent applied.

5.1.4. Sulphur

The equations to determine plant S concentrations were determined from data extracted from the S fertiliser trial database (see section 1.2). As phosphate extractable organic sulphur (PESo) was not measured on most trials, PESo was estimated using the relative yield using the above relationship in section 7.2. The relationship between PESo and plant S concentrations in the absence of fertiliser S was determined, with the relationship differing between organic and non-organic soils (unpublished data).

The rate of change of plant S concentrations in the presence of S fertiliser was approximately linear, although the rate of change varied between sites (unpublished data). Sites with low rates of change tended to be those to which a high Sulphur Leaching Index (SLI, see Cornforth and Sinclair 1984) would be assigned to, such as pumice soils. Conversely, those with a high rate of change tended to be dry land sites, which would have a low SLI. Therefore, the rate of change was adjusted according to the SLI index of the site.

The procedure used is:

Equation 16: plantS = base + (-0.0004 * Ln(SLI) + 0.0015) * rate
base is the base S concentration (%) [Equation 17].
SLI is the Sulphur leaching Index [Characteristics of soils chapter].
rate is the rate of sulphur fertiliser (kg/ha/year).

and where the base S concentration (%) is estimated as:

Equation 17: base = 0.0076 * PESo + 0.0644 peats
= 0.0106 * PESo + 0.0894 others
PESo is the phosphate extractable organic sulphur [Characteristics of soils chapter].

5.1.5. Calcium, magnesium and sodium

The sub-models for Ca, Mg, and Na were developed using limited data (Carey and Metherell 2002, Carey unpublished Microsoft excel workbooks). The relationships estimating Ca, Mg, and Na plant concentration were based on twelve trials; five trials for Ca two of which that had high rates of lime applied, four trials for Mg and three trials for Na.

Plant Mg and Na concentrations are lower when K is applied as fertiliser, irrigation, or effluent. For Na, there is no fertiliser input effect on rate. The original relationship to determine the effect of K on plant Mg concentrations was modified to ensure realistic Mg concentrations were achieved for blocks with high application rates of K (e.g. effluent blocks). The new and old relationships largely overlap up to 200 kg of applied K.

There was an indication that the relationship between soil Na levels (as measured by QT Na) and plant Na levels vary with soil group, but there were only 1 or 2 trials within each soil group. Re-examination of the data used by Metherell and Carey (2002) indicates that the behaviour of peaty soils may differ from pumice and YBL soil groups (see Figure 7). These have been separated although the relationship for peat is based on a single trial sampled at 6 and 30 weeks after application (O'Connor *et al*., 1989). The non-peat relationship is based on data from trials on YBL and YBPS soils in the same series as the peat, plus an additional trial on an YBL (McNaught and Kavlosky 1964) that had higher plant Na concentrations.

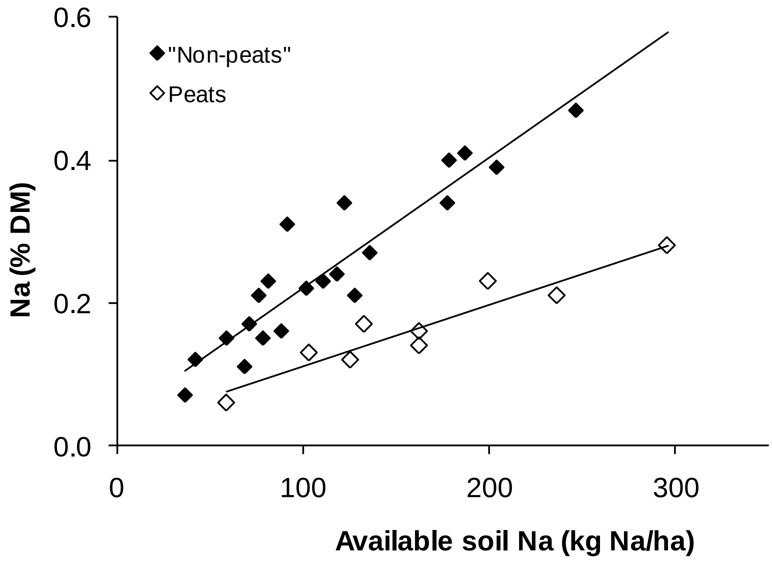


Figure 7. Relationship between available soil Na (kg Na/ha/year) and mixed pasture Na levels (%DM).

The change in Na soil test values when fertiliser Na was applied was variable, even within a soil group. The data of O'Connor *et al*. (1989) indicated that pasture Na levels varied with QT Na levels and that QT Na varied with fertiliser Na application rates and time since application. Thus, fertiliser Na inputs per se were not included in the estimation of Na pasture concentrations.

Based on McNaught and Karlovsky (1964) data on an YBL and Smith *et al*. (1983) on an YBPS, fertiliser K applications were found to reduce pasture Na levels about 40% (see Figure 8). McNaught *et al*. (1973) data also showed that at 377 kg KCl/ha, fertiliser K applications reduced pasture Na levels about 12-45%, with an average reduction of 30%.

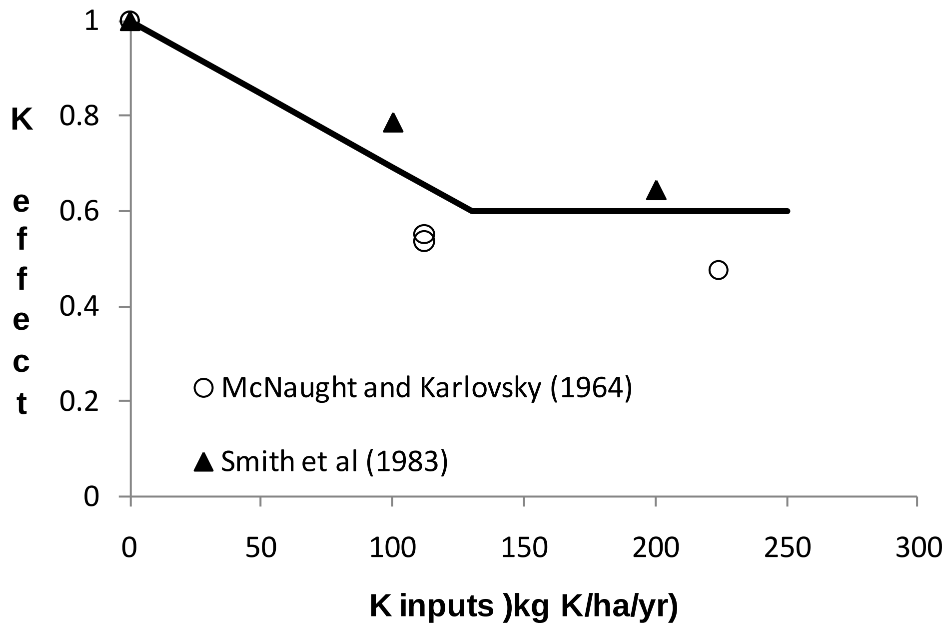


Figure 8. Relationship between K inputs (kg K/ha/year) and K effect, the relative effect of K on pasture Na levels.

Pasture Ca concentrations (%) are estimated as:

Equation 18: Plant Ca = (grassconc * (1 - clover) + legconc * clover)

Grassconc = $0.0643 * rate^{0.2884}$

Legconc = $0.1065 * rate^{0.3157}$

rate is the amount of Ca in soil and fertiliser Ca added (kg Ca/ha) [Block characteritics].

clover is the block clover levels [section 10].

Pasture Mg concentrations (%) are estimated as:

Equation 19: Plant Mg = (hMgmin + (hMgmax - hMgmin) * (1 - Exp(-hMg * rate))) * ferteffect

hMgmin is the minimum herbage Mg (0.05 %).

hMgmax is the maximum herbage Mg (0.33 %)

hMg is 0.01, derived from ln(10)/herbMg90 where herbMg90 is 237.

rate is the amount of Mg in soil and fertiliser Mg added (kg Mg/ha) [Block characteritics].

ferteffect accounts for the effect of fertiliser K and lime on pasture Mg concentrations [Equation 19].

The effect of fertiliser K and lime on pasture Mg concentrations is estimated as:

Equation 20: ferteffect = Kferteffect * limeeffect

where:

Equation 21: Kferteffect = exp(-0.00084 * Kin)

Kin is the amount of inorganic K added (kg K/ha/year).

and

Equation 22: limeffect = 1 + flime * limeCa / 1000 * 100/40

limeCa is the amount of Ca added as lime (kg Ca/ha/year).

flime = 0.0112	dolomite, pumice soils
= 0.04	dolomite, other soils
= -0.003	non-dolomite

Dolomite is a lime with > 10% Mg

Pasture Na concentrations (%) are estimated as:

Equation 23: Plant Na = (0.0009 * rate + 0.0245) * kferteffect	peat
= (0.0018 * rate + 0.038) * kferteffect	otherwise

rate is the amount of Na in soil (kg na/ha) [see Block characteritics].

kferteffect = 1 - 0.4 * Kin / 130   kferteffect > 0.6

Kin is the amount of inorganic K added (kg K/ha/year).

0.4 is the average reduction in Na levels when Kin > 130

130 is the point at which K doesn't have any additional effects on pasture Na levels.

5.1.6. Acidity

The acidifying effect of removing pasture is estimated from the excess cation content (EC) of the material. EC can be estimated from the cation and anion content of the herbage. Plant cation and anion concentrations to calculate EC are estimated, with the exception of chloride (Cl). deKlein (pers. comm.) noted that:

> *'Cl concentrations are higher on pasture (1-1.2%) because K is applied as KCl, whereas hay and silage paddocks often receive effluent i.e. high K but lower Cl concentrations'.*

However, chloride levels in pasture samples are rarely measured. Therefore, the model uses estimates of EC measured on grass and clover in field trials (de Klein *et al.* 1997).

The relationship used differs from that published in that data including the effect of rates of N fertiliser has been included. The published table of EC indicates that ryegrass EC increased with urea, ammonium, and nitrate N fertiliser applications, with the rate of increase larger for nitrate fertiliser urea. The model currently ignores N fertiliser form. The published data also suggests that when P is applied, EC increases at low N concentrations, but decreases at higher N concentrations when compared to the no P treatment. This has also been ignored.

Thus, acidity concentrations for pasture are the estimated total EC:

Equation 24: Plant H = clover * ECc + (1 - clover) * ECg

clover is the block clover content [section 10].

ECc and ECg is excess cations in clover and grass [Equation 25 and Equation 26].

and where excess cations in clover and grass is estimated as reported by de Klein *et al.* (1997) as:

Equation 25: $ECc = (1.35 - 0.0001 * Fertiliser_N) / 1000$

Equation 26: $ECg = (0.5 + 0.0003 * Fertiliser_N) / 1000$

$Fertiliser_N$ is the fertiliser N inputs (kg N/ha/year).

5.2. Non-ryegrass based grass pasture

Pasture N concentrations from individual sources indicated that:

- N concentrations extracted from the P database (see section 1.2) indicated that N concentrations for unimproved or tussock pasture type were on average 0.5% lower than N concentrations in ryegrass/white clover pasture. This data came from predominately mowing trials.
- In a trial from Marua extracted from the P database (see section 1.2), N concentration in browntop pasture was, on average, 0.65% lower than in ryegrass-based pasture.
- Ledgard *et al*. (2003) noted that on a farm with little difference between slopes, there was a dominance of *Holcus lanatus* across all slopes. The low N concentrations on the easy and steep slopes of the one King Country farm coincided with the presence of *Paspalum dilatatum*, which is a C4 grass of low N concentration. Thus, pasture species composition can have a significant effect on the N concentration of mixed pasture.

The difference between slopes and farm types could also be due to differences in pasture composition. This was factored in using the same calculations for N concentrations from ryegrass pastures but reducing N concentration for other pasture types as:

Equation 27: PastNReduct	= -0.4 %	browntop
	= -0.4 %	unimproved and tussock lands or merino
	= -0.4 %	for summer C4 pastures and months December, January, February and March
	= -0.4 %	for kikuyu C4 pastures and months November, December, January, February, March and April
	= 0	otherwise

Pasture nutrient concentrations of P, K, S, Ca, Mg, and Na are also likely to be lower in non-ryegrass pastures, although no data was found on the size of the reduction. To account for this, ryegrass based estimates were reduced by 10%.

It was assumed that the non-ryegrass pasture excess cations were the same as for ryegrass/ white clover based pastures.

5.3. Lucerne

Moot (2009) showed that crude protein content or plant N concentrations (%) declined as the stage of development increased due to decrease in N concentration in the palatable fraction, and increase in the proportion of the unpalatable fraction. Thus:

- 3.63%, 3.11%, 2.95% and 2.71% at 20 cm, 40 cm, 60 cm and start of flowering respectively.
- 4.96% at pre-floral bud but dropped to 4.16 at floral bud stage.
- 4.0%, 3.28%, 2.78% and 2.61% at 3, 4, 5, and 6-week cutting intervals respectively.

Cornforth and Sinclair (1984) also reported optimum N concentrations for top 15 cm of growth as 4.5%-5.0%, and 3.0%-3.5% for hay. Litherland and Lambert (2007) also reported values close to 4.5%.

Moot (2009) suggested that grazing starts at about 1.5-2 T/ha DM in spring so that a round can be completed, and that lucerne ME content and pasture N content decrease as standing DM before grazing increases.

The optimum range of the top 15cm of growth for growing Lucerne and for hay (Cornforth and Sinclair, 1984; see Table 6) indicate that like N, the concentrations of other nutrients also decline as lucerne matures. Non-New Zealand data reported by Reuter and Robinson (1986) was in a similar range to Cornforth and Sinclair (1984).

When being grazed, the average quality of lucerne is probably better than that for hay, and the upper value of the range for hay is used for ingested lucerne nutrient concentrations. Lucerne is a natrophobe and has low concentrations of Na (0.04%) in the leaf (Smith *et al*. 1983).

Table 6. Optimum nutrient concentrations for lucerne.

	Top 15 cm[1]	Hay[1]	Top 15 cm [2]	Value used
N	4.5-5.0	3.0-3.5	2.5-4.0	3.5
P	0.26-0.7	0.20-0.25	0.25-0.45	0.25
K	2.5-3.8	1.5-1.8	2.25-3.40	1.8
S	0.26-0.50	0.18-0.23	0.7-2.5	0.23
Ca	0.51-3.00	0.5-0.8	0.25-0.7	0.8
Mg	0.31-1.00	0.12-1.5	0.25-0.50	1.5
Na				0.04

[1] Cornforth and Sinclair (1984).
[2] in Moot (2009) for top 15 cm at first flower.

This approach means that in contrast to pasture, lucerne concentrations are not dependent on soil test, fertiliser nutrient additions, or other site factors.

It is assumed that the excess cation content of lucerne is similar to clover (see section 5.1.6).

6. ME and N concentration interactions

Within OVERSEER, ME content drives DM intake, and DM intake and pasture N content drive N intake, N excreta and hence N leaching. To keep relativity between different farms it is important that pasture quality and pasture N content are commensurate with one another. In most situations, poor quality pasture is associated with lower N content. Although the user can modify ME content monthly, they currently can only modify annual average pasture N content.

Unpublished data supplied by King and Rennie showed that ME increases as crude protein increases for March, April and May samplings such that ME was 8 when N equalled 1.28%, and ME was 12 when N equalled 4.00%. However, for October and December samples, ME was constant, averaging 12 at Lincoln and the Waikato for October samplings and 11.5 for December samplings. This data suggests that in most cases, ME content and pasture N concentrations should be commensurate with one another in spring, but they vary independently in autumn. No information was found for the relationships for non-ryegrass species.

Using default settings, changing pasture type tends to lead to a small increase in N leached (1-2 kg N leached/ha/year) for non-ryegrass pastures and a larger increase if the pasture is lucerne. The large increase with lucerne is due to increased N intake, and the balancing effect of high N fixation.

7. Relative yield

7.1. P, K, Ca, Mg, and Na

The relative yield for P is based on Metherell *et al*. (1995). Estimation of relative yield for K used a similar method to Metherell *et al*. (1995) but is unpublished. For Mg, the published equation for Mg was rearranged to have the same form as for P and K. For Ca, Carey and Metherell (2002) noted that:

> *'there is little evidence that a relative yield relationship is obtainable at QT Ca levels above 1 units'*

Thus:

Equation 28: $RY_P = 1 - Exp(-kp * rate)$

$kp = ln(10)/kp90$

kp90 is the labile soil P at 0.90 relative yield (kg P/ha).

rate is the labile and fertiliser P added (kg P/ha).

Equation 29: $RY_K = 1 - Exp(-kk * rate)$

$kk = ln(10)/kp90$

kk90 is the labile soil P at 0.90 relative yield (kg P/ha).

rate is the labile and fertiliser K added (kg Ka).

Equation 30: $RY_{Ca} = 1$

Equation 31: $RY_{Mg} = 1 - Exp(-kmg * rate)$

rate is the labile and fertiliser Mg added (kg Mg/ha).

The relationship between soil K levels or Olsen P and relative yield for lucerne (see Moot 2009) are similar to those for pasture on sedimentary soils. Thus, it was assumed that the same relationships could be applied to lucerne.

7.2. Sulphur

The equation for relative yield for S combines the effect of the organic S fertility of the site represented by the phosphate extractable organic S test (PESo) with the addition of the effects of S inputs (fertiliser, rainfall, irrigation). Thus:

Equation 32: RY_S = 1 - Exp(-kq * PESo - ks * rate)
= 1 - Exp(-kts * totalStest - ks * rate)
kq = 0.19.
ks = 0.06.
kts = 0.03583 Waller (pers comm.).
rate is the S inputs from fertiliser, rainfall and irrigation (kg S/ha).

This model is an adaption of the model of Thorrold and Woodward (1995) except that they estimated available S rather than rate to take account of elemental S.

As this model is a long-term equilibrium model, it is assumed that the rate of input and release of elemental S is in equilibrium.

A value for k_q (0.19) was obtained by fitting the above equation to the organic S test calibration data (Watkinson and Kear 1996). There were no grounds on which to differentiate between soil groups or climate zones in the relationship between organic S test and relative yield (Watkinson and Kear 1996). We assume, therefore, that k_q is the same for all sites within New Zealand. A calibration with total S test using the same data as Watkinson and Kear (1996) showed an improved relationship using total S (Rajendram *et al*., 2008).

Values for k_s were obtained from yield response trials on pasture sites extracted from the S fertiliser trial database (see section 1.2) by fitting the above equation to the pasture response data. The relative yield in the control treatment (RY_0) was included in the equation as the term exp (k_q * PESo) because very few sites had organic S soil test values. The other terms were obtained from the trial records. Values for k_s were obtained after excluding those trials where RY_0 was greater than 1.1 or k_s was negative. There was considerable variation in the trial data, with little grounds for distinguishing between soil groups or regions.

A value of k_s was selected to produce yield response curves that were consistent with the measured data. Consequently the selected value of k_s is lower than the average value. The lower value of k_s compared to the average value ensures that yield predictions are not overestimated at low S application rates, although this is at the expense of some possible overestimation of S requirements at high target RY.

8. Pasture growth rates

OVERSEER estimates pasture production from animal productivity. However, N sub-model requires an estimate of monthly production to estimate N uptake. The distribution of pasture growth is based on a simple growth model used in the crop sub-model. This sub-model was modified so that the soil moisture effect was a combination of soil dryness and the amount of transpiration that occurs relative to potential evapotranspiration. The two are generally closely correlated but it is possible to get situations where there still may be some soil water but transpiration has decreased. Thus, the amount of pasture production that occurs in a given month is estimated as:

Equation 33: $DM_{mon} = DMyear * ppasture_{mon}$

$ppasture_{mon} = PastureYield_{mon} / (\sum_{mon} PastureYield)$

Where the monthly pasture production (T DM/ha/month) is estimated as:

Equation 34: $PastureYield_{mon} = (yldclover * CloverContent + yldgrass * (1 - CloverContent)) * 1000$

yldclover is the yield of clover component (T DM/ha/month) [Equation 35].

yldgrass is the yield of clover component (T DM/ha/month) [Equation 35].

CloverContent	= 100	for lucerne pasture type
	= 0	for grass only pasture type
	= see section 10	for pasture

The yield of the grass and clover components (T DM/ha/month) is estimated as:

Equation 35: yld = (refyield * tempresponse * fmoist))

Refyield is the reference yield (kg DM/ha/month) when ftemp is 1 and soil moisture is not limiting.

tempresponse is the response to temperature [Equation 36].

fmoist is a fator for soil moisture [Equation 37].

The reference yield is 1.9 T DM/ha/month for white clover, and 1.2 for ryegrass. The temperature response is estimated as:

Equation 36: $tempresponse = ftemp_{mon} - mintemp$

ftemp is the monthly crop temperature factor [Crop N sub-model chapter].

mintemp is the minimum temperature factor (ftemp) below which no response occurrs, and is 0.7 for clover and 0.2 for ryegrass.

with a minimum value of zero, and a maximum response (T DM/ha/month) of 1.2 for white clover and 1.4 for ryegrass. The factor for moisture is estimated as:

Equation 37: $fmoist = (Transpir_{month} / ETP_{month} * 0.5) + (0.5 * (SM_{month} - WP) /(FC - WP))$

$Transpir_{month}$ is the transpiration rate (mm) [Hydrology chapter].

ETP_{month} is the evapotranspiration rate (mm) [Hydrology chapter].

SM_{month} is the soil moisture (mm) [Hydrology chapter].

WP is the wilting point (mm) [Characteristics of soil chapter].

FC is the field capacity (mm) [Characteristics of soil chapter].

9. Utilisation

Utilisation is the proportion of total pasture grown that is eaten by animals on an annual basis. The default pasture utilisation for a block is based on animal type default values for the animal types that are grazing the block. Default animal type utilisation was estimated at 0.85 for dairy, 0.75 for dairy replacements, and 0.7 for sheep, beef, and deer. Utilisation is expected to be higher on finishing blocks, and lower on merino blocks where extensive management systems are used. Thus utilisation is increased by 15% on beef or deer finishing blocks, and decreased by 5% on merino sheep blocks.

Utilisation is not affected by pasture type or time of year.

Pasture utilisation on a given block is estimated as:

Equation 38: $utilisation_{block}$ = utilisation / 100 if entered

$= \Sigma_{antype} (DefUtil_{antype} * blockSU_{block, antype} / 100 * Futil_{block})$

$blockSU_{antype}$ is the percentage of total intake by a animal type [Animal model chapter].

DefUtil	= 0.85	for dairy
	= 0.75	for dairy replacements
	= 0.7	otherwise
Futil	= 1.15	if finishing block
	= 0.95	if merino
	= 1	otherwise

10. Clover content

Clover content is based on clover level, with values of very low, low, medium, high and very high. The default is a clover level of medium, and this is what the N leaching model is calibrated against.

Clover content is defined as the annual average clover content (as a proportion of DM) of pasture where fertiliser N inputs are not applied. Clover content is defined for each animal type and clover level. The dairy clover content at medium clover level was based on a limited set of data from dairy study sites. The relativity between animal types was based on limited data from sheep study sites and research from Boswell (unpublished data) which showed lower clover contents in sheep systems than cattle systems. Deer, dairy goats, and others were made the same as sheep.

Thus, block clover content is estimated as:

Equation 39: $clover_{block} = \Sigma_{antype} (clovercontent_{antype, clover} * blockSU_{antype}/100)$

$clovercontent_{antype, clover}$ is the clover content (kg/kg).

clover is the clover level which has a default of 3 or is a user input.

$blockSU_{antype}$ is the percentage of total intake by a animal type [Animal model chapter].

N fixation is modelled separately, including the fertiliser induced reduction in N fixation. The model currently does not allow for changes in clover content associated with any other inputs or for differences in clover levels to modify other parameters (e.g. feed quality parameters) unless otherwise stated.

The clover level selected does not affect N leaching or denitrification losses directly, and the change in N fixation associated with the selected value is balanced by changes in immobilisation. The amount of N fixation affects the change in acidity and hence maintenance lime. However the model also assumes that clover level is another factor affecting N immobilisation status, and indirectly N leaching and denitrification rates. Thus it is recommended that clover level be set to medium, the default value, unless there is a good reason to change this. If clover levels are naturally low or high, these differences are captured on a long term annual average basis by the amount of N fertiliser used.

11. Symbiotic N fixation

This section describes the initial estimates of N fixation. The estimated amount of N fixed has no effects on pasture production or pasture N concentrations, and hence on N leaching.

Within a nutrient budget, the model assumes that inputs equal outputs (nutrients removed and changes in long-term storage pools). The difference between initially estimated inputs, including N fixation, and outputs is the balancing error. To balance the budget, the 'balancing error' is allocated to items within the nutrient budget, including N fixation.

11.1.1. Pastures

For pasture, the amount of N_2 fixation, in the absence of added N inputs, is calculated from annual pasture production, average clover content in pasture, and an N fixation rate.

Equation 40: NBNfix = DMpasture * clover * N fixation rate – NO3reduct

DMpasture is the annual block DM production (kg DM/ha/year).

clover is the block clover content [Equation 39].

N fixation rate is a rate of N fixation (kg N fixed/kg DM).

NO3reduct is the reduction due to inorganic N levels (kg N/ha/year) [Equation 42].

The N fixation rate was based on clover N concentration, proportion of total clover N from N_2 fixation (Ndfa) and a correction to account for N_2 fixation associated with stolons, roots, and nodules (Ledgard *et al*., 1987, 1996, 2001; Jorgensen and Ledgard 1997). Thus, the N fixation rate is estimated as:

Equation 41: N fixation rate = CloverN% / 100 * Ndfa * 1.7

CloverN% is the typical annual average clover N concentrations.

Ndfa is the proportion of total N uptake that is fixed.

1.7 is the correction to account for N_2 fixation associated with stolons, roots, and nodules.

Using a typical annual average clover N concentrations of 4.78%, an Ndfa of 0.8, and a correction to account for N_2 fixation associated with stolons, roots, and nodules of 1.7 gave an N fixation rate of 0.065 kg N/kg pasture DM.

The amount of N_2 fixation is reduced according to effects of various added N inputs (fertiliser, irrigation, effluent, supplements) since legumes can substitute uptake of inorganic N for N_2 fixation. The effect of fertiliser N on reducing N fixation was based on Ledgard (2001), and it was assumed that inorganic N from other sources would have a similar effect. Thus the reduction in N fixation due to inorganic N applications is estimated as:

Equation 42: NO3reduct = InorgN * 0.4

InorgN is the annual inorganic N added (kg N/ha/year).

The annual amount of inorganic N added (InorgN) is estimated as the sum of N in fertiliser less volatilisation losses, the inorganic N in organic fertilisers and effluents, and N in irrigation waters.

The model assumes that there is a minimum of 8 kg N fixed in all pastures. This would also include any non-symbiotic fixation.

11.1.2. Lucerne

Moot (2009) reviewed N fixation in lucerne and reported an annual rate of 25 kg N/t DM. This suggests lucerne plants preferentially utilize soil available N.

Equation 43: NBNfix = DMpasture * 25/1000 * 1.1 – NO3 reduct

DMpasture is the annual block DM production (kg DM/ha/year).

1000 converts kg to tonnes.

25 is the annual fixation rate (kg N/t DM).

1.1 is the correction to account for N_2 fixation associated with stolons, roots, and nodules.

NO3reduct is the reduction due to inorganic N level (kg N/ha/year) [Equation 44].

Moot (2009) also indicated that lucerne preferentially utilize soil available N, and presented one set of data that indicated N fixation in lucerne decreased to very low levels when soil nitrate to 120 cm at planting was 40 kg N/ha or greater. Thus it was assumed that any addition of N would reduce N fixation quicker than in pastures, and was modelled:

Equation 44: NO3reduct = InorgN * 0.8

InorgN is the annual inorganic N added (kg N/ha/year).

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