# Capturing Mitigation Technology Effects in National Agricultural Greenhouse Gas Emission Inventories

## Final Report

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# Contents

## Summary

This report assesses the potential and required changes in activity data and/or inventory structure to most effectively capture benefits of four mitigation technologies in ruminant methane ($CH_4$) and agricultural soils nitrous oxide ($N_2O$) emissions inventories. The work was carried out by Landcare Research and AgResearch for the Ministry of Agriculture and Forestry (Project Code CC MAF POL_0708-67) from 4 April 2008 to 19 June 2008.

Grazing animals are the main contributors to New Zealand's $CH_4$ and $N_2O$ emissions inventories. It is a tremendous challenge to mitigate these emissions with up to 85 million sheep, cattle and deer fed by year-round grazing on pasture. The emissions and effects of mitigation technologies can vary throughout the year. To capture such changes in the $CH_4$ and $N_2O$ emissions inventories, understanding is required of mechanisms underlying the mitigation technology, inventory structure to match these mechanisms, and the information and research needs.

This report analyses four potential mitigation technologies, comprising nitrification inhibitors, feed pads, and two alternative feeds – maize silage and high sugar grasses. We conclude insufficient evidence currently exists to mount a credible case for the inclusion of the mitigation effects of high sugar grass cultivars on $CH_4$ and $N_2O$ emissions. The other three technologies have demonstrated merit, but it must be emphasised that there are some complex issues, few field trials have been done in New Zealand and more farming system studies involving these technologies need to be done. For all four technologies, we determine changes required in the inventories to most effectively capture the potential emissions mitigation benefits and identify information gaps. Following good practice guidance, we recommend inventory structural changes at two levels, called Tiers 1 and 2, to capture the mitigation effects. Tier 1 is the simplest approach possible for acceptable capture of the mitigation effects. Tier 2 is more complex, so requires more information, but it optimises capture of the mitigation effects.

To account for the use of nitrification inhibitors, hereafter DCD, additional information is required for calculating the $N_2O$ emissions inventory but not for $CH_4$. We recommend that DCD application to soils should follow strictly prescribed best management practice. This connects a calculated reduction in $N_2O$ emissions to the field trial evidence. In a Tier 1 approach accounting for DCD effect, there is no need for structural change to current inventory methodology, except separate calculations will need to be done for the May–September and October–April periods and the former period calculations are modified to account for the DCD effect. To most effectively account for the effect of DCD on the direct $N_2O$ emissions, $EF_3$ would be disaggregated into urine and dung and adjusted downwards. For the indirect $N_2O$ emissions, a similar approach would be followed for $Frac_{LEACH}$. The additional activity data required for a Tier 1 approach included annual DCD sales (kg), land area grazed by animal type (dairy cattle, beef cattle, sheep and deer) and fraction of grazed land area treated by DCD by animal type. It is anticipated DCD application will be restricted to land grazed by dairy cattle. A Tier 2 approach has a monthly accounting system for DCD application throughout the year. This approach refines accounting for the sensitivity of DCD degradation rate to temperature in soils (explained in Appendix A) because DCD effectiveness is predicated on its presence. It requires seasonal disaggregation of EF3 and

$Frac_{LEACH}$ as well as monthly records for DCD sales and fraction of grazed area treated by animal type and location (North Island and South Island disaggregation is recommended).

Account for the use of feed pads begins with animal confinement that reduces activity relative to grazing animals, so reducing the energy (ME) requirement. Consequently, the feed dry matter intake (DMI) would be proportionally reduced (on the feed pad) unless the feed has a different energy density to that of pasture. The $CH_4$ conversion rate is not necessarily changed, but the reduced DMI corresponds with reduced enteric $CH_4$ emissions. This reduction depends on the time spent on the feed pad. Reduced DMI on the feed pad should correspond with reduced N intake, assuming feed N content has not been proportionally increased (N intake = DMI * feed N content). This means N excretion rate should also be reduced. Thus, during periods of feed pad use, reduced N excretion rate means a reduction in the quantity of N to be applied to soils. In this way, $N_2O$ emissions are reduced. Feed pad use is anticipated to be limited to dairy cattle, so additional activity data are the fraction of total dairy cattle and number of months involved. It is expected that feed pad use would occur in winter, but more refined information may be needed. It is anticipated the months of feed pad use need to be specified because the ME requirement of breeding animals is affected by the stage of pregnancy as well as the live-weight and production rate.

A Tier 1 approach accounting for feed pad effect does not require any structural changes to the $CH_4$ and $N_2O$ emissions inventories. However, an 'implied' emission factor is needed to capture effects of the mitigation technology, connecting the number of animals and the reduced emissions. This would involve repeated use of the inventory's ME requirement model for the months of feed pad use. Firstly, the model would be run with all (mature breeding) dairy cattle fed by year-round pasture grazing. This yields monthly base values of the dairy cattle population ME requirement and DMI as well as $CH_4$ emissions. Next, the model is run again with all (mature breeding) dairy cattle virtually confined to feed pads. This yields appropriately reduced monthly dairy cattle population values of ME requirement and DMI. Combined with the $CH_4$ conversion rate, one obtains the implied $CH_4$ emissions factor. For mitigating $N_2O$ emissions, feed pad use is also based on confinement reducing the ME requirement, DMI and thus the N excretion rate. In addition, the N excreted may be stored and later reapplied to land, rather than directly deposited onto pasture. Combined with $EF_1$ (direct $N_2O$ emissions factor for organic manure that is reapplied to land) and $Frac_{LEACH}$, one obtains an implied $N_2O$ emissions factor for N excreted on a feed pad.

A Tier 2 approach accounting for the effect of feed pad use requires structural changes to the $N_2O$ emissions inventory. Seasonal emission factors, including $EF_3$, $EF_1$ and $Frac_{LEACH}$, would most effectively capture the benefit of feed pad use. During winter, $EF_3$, $EF_1$ and $Frac_{LEACH}$ should be significantly larger than during other seasons. Further, $Frac_{LEACH}$ currently acts upon 7% of N applied to soils, ignoring issues related to season and N accumulation in soils. However, field trials and modelling analyses will be needed to seasonally disaggregate the $N_2O$ inventory emission factors to acceptable standards for international review.

For dairy cattle, the addition of maize silage to protein-rich pastures reduces dietary N concentrations and N concentration in urine patches and it increases the ratio of excreta N in dung to that in the urine. Consequently, the use of maize silage can reduce $N_2O$ emissions. Enteric $CH_4$ emissions should either remain the same or slightly increase. Accounting relies on the proportion of dairy cattle fed a mixed diet of known proportions of pasture and maize with combined ME and N contents. Maize silage use should occur May–September, but more refined information may be needed. A Tier 1 approach will require structural changes to the inventory. To most effectively capture the mitigation effect, excreta should be disaggregated into dung and urine. Separate inventory calculations will need to be conducted for May–Sept, when silage is used, and October–April. Following a process similar to that outlined for feed pads, additional, 'implied' emission factors will be needed. For Tier 2 the required additional information is the same, but on a monthly basis.

In an Appendix (C) written by H. Clark, there is a review of the evidence on the mitigation effects of high sugar grass (HSG) cultivars on $CH_4$ and $N_2O$ emissions. Using HSG as an example of a forage that reduces $N_2O$ emissions we suggest that considerable changes will be needed to the structure of the national inventory even if a Tier 1 approach to the inclusion of mitigation is followed. The additional data required to adopt a comprehensive Tier 2 approach are, to some extent, prohibitive and in practice a comprehensive approach is likely to be a hybrid Tier 1/Tier 2.

# 1. Introduction

This report assesses the potential and required changes in activity data and/or inventory structure to most effectively capture benefits of four mitigation technologies (nitrification inhibitors, feed pads, maize silage and high sugar grasses) in ruminant methane ($CH_4$) and agricultural soils nitrous oxide ($N_2O$) emissions inventories. The work was carried out by Landcare Research and AgResearch for the Ministry of Agriculture and Forestry (Project Code CC MAF POL_0708-67) from 4 April 2008 to 19 June 2008.

# 2. Background

Pastoral agriculture contributes significantly to New Zealand's greenhouse gas emissions. For the 2005 inventory, ruminant $CH_4$ emissions were 23 919 Gg $CO_2$-eq – 31% of the country's greenhouse gas emissions and the largest single contributor. The corresponding agricultural soils $N_2O$ emissions were 12 710 Gg $CO_2$-eq. Since the Kyoto Protocol baseline year of 1990, agricultural soils $N_2O$ emissions have increased more than ruminant $CH_4$ emissions (2670 vs 2121 Gg $CO_2$-eq).

Grazing animals are the main contributors to New Zealand's $CH_4$ and $N_2O$ emissions. It is a tremendous challenge to mitigate these emissions with up to 85 million sheep and cattle fed by year-round grazing on pasture. Both emissions inventories depend equally on accurate and precise estimation of pasture herbage consumption from the animal's energy requirement for maintenance and production. Accounting for the effects of $CH_4$ and/or $N_2O$ mitigation technologies acting upon these animals adds another dimension to the challenge. The biological systems determining $CH_4$ and $N_2O$ emissions are dynamic. The emissions and effects of mitigation technologies vary or change throughout the year. To capture these changes in the $CH_4$ and $N_2O$ emissions inventories, a clear understanding is required of (1) the mechanisms of the mitigation technology, (2) the required inventory structure to match these mechanisms, and (3) the information and research needs to comply with the 2006 guidelines and pass future UNFCCC expert reviews.

Based on the available data, distillation of the technologies into agreed effects for inventory analysis will be required to capture the effects of mitigation. Good practice guidance is insufficient and data are sparse, so fresh analysis is warranted. Potential mitigation technologies include nitrification inhibitors, feed pads, maize silage and high sugar grasses..

# 3. Objectives

- To identify the required changes in activity data and structure of ruminant $CH_4$ and agricultural soils $N_2O$ emissions inventories to capture the effects of potential mitigation technologies.
- To develop protocols and checklists for the QA/QC requirements and 2006 GPG information needs (including different tiers) for incorporating potential mitigation technologies into the inventory methodology.

# 4. Current Inventory Methodology

## 4.1 Methane

Enteric $CH_4$ emissions are calculated for animals fed by year-round forage grazing. Figure 1 summarises the method and required activity data.

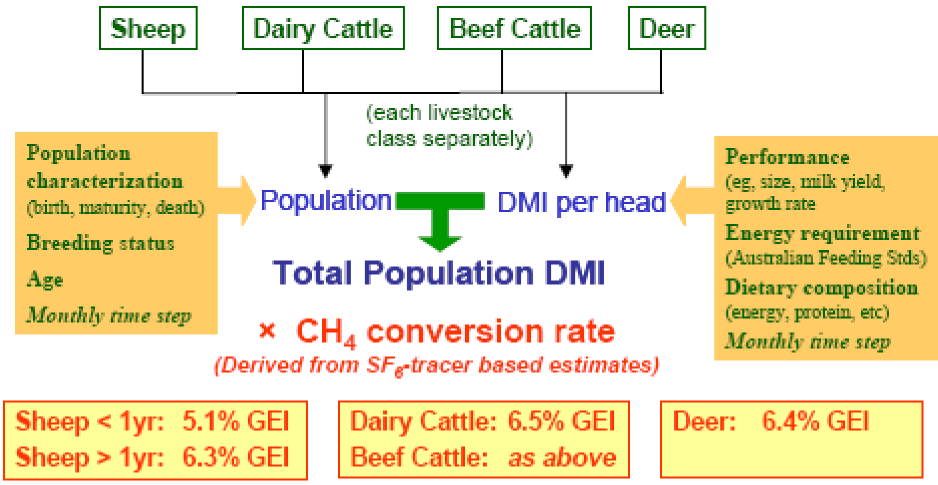


**Fig. 1** Activity data required for calculating enteric methane emissions from grazing animals in New Zealand. Total population dry matter intake (DMI) calculated monthly. $CH_4$ conversion rates are averages.

The $CH_4$ conversion rates in Fig. 1 are expressed as a percentage of the animal's gross energy intake, denoted GEI. The rate may also be expressed as $CH_4$ emissions (grams, g) per dry matter intake (DMI) (kilograms, kg). Rates used in inventory calculations are measured averages. Thus, for dairy and beef cattle, the $CH_4$ conversion rate is 21.6 g $CH_4$ per kg DMI. For sheep < 1 y old and sheep > 1 y old, corresponding values are 16.8 and 20.9 g $CH_4$ per kg DMI, respectively. For deer, the $CH_4$ conversion rate is 21.25 g $CH_4$ per kg DMI.

## 4.2 Nitrous oxide

Agricultural soils $N_2O$ emissions are estimated from the amount of nitrogen (N) excreted by animals plus the amount of N applied to agricultural soils in the form of fertiliser. The calculation is directly linked with the $CH_4$ emissions inventory methodology because it uses the same **Total Population DMI**.

$N_2O$ total = N excreted × $N_2O$ emission $factor_{excreta}$ + N fertiliser use × $N_2O$ emission $factor_{fertiliser}$

Where, N excreted = [**Total Population DMI** × N content feed – N in products]

Nitrogen (N) excreted calculated **monthly**
**Total Population DMI** is the same for methane and nitrous oxide
N fertiliser use from industry sales record (**annual** data)
N content feed and N in products are averages
$N_2O$ emission factors are averages

The computation of N excreted recognises that some N is retained by the animal. The $N_2O$ emissions factors include the direct and indirect emissions. The direct emissions factor applies to excreta and fertiliser N and a New Zealand specific value is used (1%), based on field trial measurements. The indirect emissions factor also applies to excreta and fertiliser N but it has not been measured in New Zealand, so a default value is used (2.5%).

## 4.3 Activity data required to determine $CH_4$ and $N_2O$ emissions

The current information requirements for estimating $CH_4$ and $N_2O$ emissions are listed in Table 1.

**Table 1** Information requirements for the current $CH_4$ and $N_2O$ emissions inventories

| Information | Data |
|---|---|
| Production | Annual production (milk, beef, lamb/mutton, venison, wool) |
| Animal characteristics | Number and type of animals |
| | Average live weight by animal type |
| | Breeding status |
| | Age |
| Fertiliser | N applied to agricultural soils |

# 5. Nitrification Inhibitors

## 5.1 Nitrification inhibitors – Tier 1

### Activity data

To account for the use of nitrification inhibitors, hereafter DCD, additional information is required for calculating the $N_2O$ emissions inventory, but not for the $CH_4$ emissions inventory. The use of DCD may correspond with increased pasture growth as a result of N conservation. However, DMI is determined by the metabolisable energy (ME) requirement assuming sufficient feed is available. Thus, the present inventory calculations of DMI would not recognise increased pasture growth rate (if it corresponded with DCD use). This means DCD will have no (additional) effect on enteric $CH_4$ emissions. We expect DCD to have no (additional) effect on anthropogenic carbon dioxide emissions.

The application of DCD to soils is aimed at reducing direct and indirect $N_2O$ emissions from N excreted by grazing animals onto soils. Since the current inventory methodology estimates the amount of N excreted per animal type, the additional activity data requirements to capture DCD effects by a Tier 1 $N_2O$ methodology, are:

- Annual DCD sales records for each type of animal (dairy cattle, beef cattle, sheep and deer)
- Land area grazed by each type of animal
- The fraction of each animal type's grazed land area(s) treated by DCD

The application of DCD to soils does not permanently reduce $N_2O$ emissions. The chemical has a bacteriostatic mode of action, so it does not kill soil bacteria but rather inhibits or reduces their activity. We recommend that DCD application to soils should follow strictly prescribed best management practice based on field trials summarised by Kelliher et al. (2007). Kelliher et al. recommend two applications each year, one in May (target = final grazing in autumn) and the other in August (target = first grazing in spring). By this stipulation, DCD was considered effective for 5 months of the year (May–October). The DCD application rate should be 10 kg DCD/ha. Application of DCD to soils following best management practice connects a calculated reduction in $N_2O$ emissions to the field trial evidence.

### DCD sales records per animal type

In the foreseeable future, DCD application should be restricted to land grazed by dairy cattle. The national, annual sales records could then be restricted to dairy cattle. However, in future, when other sectors are adopting this mitigation technology, sales records would be required on an animal type or **sector** basis.

### Total land area grazed by different animal types

In 2007, according to Statistics New Zealand (data from spreadsheet dated 14 May 2008), the national land area classified as grassland was 8.1 million hectares (M ha). Additional data are required to disaggregate this land area by animal type. For the 2006/07 milking season, the national effective land area grazed by dairy cattle was 1.4 M ha (Livestock Improvement Corporation Regional Dairy Statistics). Combining these two sources of data, it may be deduced that 6.7 M ha was grazed by beef cattle, sheep and deer. While accurate partitioning of this 6.7 M ha into three portions by animal type is challenging, in the foreseeable future, DCD application is forecast to be restricted to the 1.4 M ha of land grazed by dairy cattle. However, we acknowledge other intensive, flat land animal management activities (such as beef fattening) may also involve DCD application in future.

### Fraction of land treated with DCD

From activity data providing annual sales of DCD (kg) attributable to dairy cattle, assuming best (DCD application) practice, one can estimate the fraction of land grazed by dairy cattle that was treated by DCD. However, refined information could be made compulsory by DCD applicator certification based on the inclusion of a global positioning system (GPS certification for the DCD application). As an example, an analogous system exists for the information provided on work done by certified electricians to the homeowner and governing council.

### Inventory structure

For the Tier 1 approach, there is no need for a structural change to the current inventory methodology, except that, as explained below, separate inventory calculations will need to be done for the May–September and the October–April periods and the former period calculations are modified to account for the DCD effect. This idea came from Clough et al. (2007) and they offered illustrative calculations.

As discussed earlier, N excretion is calculated by animal type. For May–September, N excretion for dairy cattle could be multiplied by the fraction of land grazed by dairy cattle that was treated by DCD. To compute the direct $N_2O$ emissions, this combination would next be multiplied by $EF_3$, adjusted downwards for the effect of DCD use. For the indirect $N_2O$ emissions, a similar approach would be followed by downwards adjusting $Frac_{LEACH}$ for the effect of DCD use. For October–April, the Tier 1 method would not recognise the application of DCD, so the calculation of $N_2O$ emissions for these 7 months would not need to be changed from the current inventory procedure.

Setting aside ammonia volatilisation for the purpose of illustration, for each animal type (dairy cattle, beef cattle, sheep, deer) during May–October, the Tier 1 method for DCD use may be written as a simplified equation:

{[Fraction of land area treated with DCD × N excreted × $EF_3$ reduced due to inhibitor use] + [Fraction of land area treated with DCD × N excreted × $Frac_{LEACH}$ reduced due to inhibitor use × $EF_5$]}

### Adjustments to $EF_3$ and $Frac_{LEACH}$

After DCD (10 kg/ha) was applied with bovine urine (700–1200 kg N/ha) to five soils throughout New Zealand, with latitudes up to 1450 km apart, the reduction in direct $N_2O$ emissions ($EF_3$) was significant and remarkably consistent (71 ± 8%, average ± standard error) according to Kelliher et al. (2008). The consistency of results from these trials corresponded with soil temperature, generally <10°C, typical of the autumn and winter seasons. This indicated a connection between DCD effectiveness in reducing direct $N_2O$ emissions and the temperature dependence of DCD degradation in soils. This aspect will be developed for a Tier 2 method. Combining peer-reviewed and confidential trial data, for dairy cattle and artificial urine applied to five soils (including some of the soils subject to direct $N_2O$ emissions measurement), DCD application corresponded with a 48 ± 31% reduction in nitrate leaching ($Frac_{LEACH}$) according to Kelliher et al. (2007).

As indicated, DCD has been applied with bovine urine to soils. A MAF-funded trial is in progress that included DCD application to cattle dung. Pending these results, it is recommended that the effect of DCD on $EF_3$ for dairy cattle urine be applied to dairy cattle dung. When disaggregated into urine and dung, Kelliher et al. (2005) reported the NzOnet $EF_3$ data for dairy cattle varied by 33-fold from 0.1%, the minimum for dung, up to 3.3%, the maximum for urine. For dairy cattle urine, 17 field trials yielded a geometric average value of $EF_3$ = 0.9%. For dairy cattle dung, six field trials yielded a geometric average value of $EF_3$ = 0.2%. To most effectively capture the mitigation effect of DCD, it is recommended that separate values of $EF_3$ be applied to dung and urine. This recognises that excreta N is already available on a monthly basis disaggregated into urine and dung.

## 5.2 Nitrification inhibitors – Tier 2

A Tier 2 method to capture the effect of DCD application may be developed using a similar approach to the Tier 1 method, the major difference being that the Tier 1 method has a monthly time, and thus accounts for DCD application throughout the year. Best management practice would continue to be recommended, stipulating a DCD application rate of 10 kg/ha.
The Tier 1 method accounted for DCD use by stipulating application seasons and period of effect (May–Sep), implicitly including the sensitivity of DCD degradation rate to temperature (T) in soils because DCD effectiveness is predicated on its presence. A Tier 2 method develops this aspect of the accounting method, requiring some explanation and data analyses contained in Appendix A.

**Table 2** Information to account for the use of nitrification inhibitors (red font indicates information **not** currently used in the inventory calculations).

| Information | Tier 1 | Tier 2 |
|---|---|---|
| Nitrification inhibitor use | Amount sold annually by animal type | Amount sold monthly by animal type and location (North and South islands) |
| Soil temperature | | Estimated monthly averages for North and South islands |
| $N_2O$ emission factor | | Seasonal/monthly $EF_3$ |
| Nitrification inhibitor effectiveness | Percentage reductions in $EF_3$ and $Frac_{LEACH}$ | Percentage reductions in $EF_3$ and $Frac_{LEACH}$ |

# 6. Feed Pads

## 6.1 Feed pads – Tier 1

A feed pad is an unroofed area with a hard surface, usually in close proximity to the dairy shed, where stock can be held for some time and provided with supplementary feed. Feed pads are usually included in a farm system to improve the efficiency of supplementary feeding. This technology is probably currently confined to dairy cattle. Further information is provided in Appendix B.

The use of feed pads can reduce $CH_4$ emissions. This comes from confining the cattle to the feed pad, reducing its activity relative to grazing cattle, so reducing the ME requirement that determines the DMI in the inventories. In practice, this would need to be recognised in the animal feeder. Further, the DMI reduction would obviously be overcome by a proportionate increase in the number of animals, such that there was no reduction of (total) feed consumption. The reduction in activity can be visualised by comparison of the areas available to dairy cattle while grazing and on feed pads. Webb et al. (2001) studied the extent and frequency of use of 'hard standing' areas in England and reported mean areas of between 1.7 $m^2$ and 3.4 $m^2$ per animal were typical for dairy cows. In New Zealand, as an approximate average, 100 $m^2$ per animal would be available for grazing by dairy cattle. Consequently, while on a feed pad, the DMI would not be proportionally reduced but there would be a significant reduction (of order 15% attributable to term $E_{GRAZE}$ going to zero as explained in CSIRO (1990)) unless the feed has a different energy density to that of the grazing cattle. The $CH_4$ conversion rate is not changed, but the reduced DMI corresponds with reduced $CH_4$ emissions. This reduction depends on the time spent by the cattle on the feed pad, but it is not permanent. When cattle return to the paddock and are fed by grazing pasture, $CH_4$ emissions return (the same day) to the higher level. Whether or not on the feed pad, cattle must be fed daily. If cattle are fed on the feed pad, there may be (additional) carbon dioxide emissions associated with (energy required for) the feed's cut and carry system (Basset-Mens et al. 2008).

Reducing cattle DMI should correspond with reducing N intake, assuming feed N content has not been proportionally increased (N intake = DMI * feed N content). This means N excretion rate should also be reduced. We assume feed pad use will not affect N fertiliser application to soils, so during periods of feed pad use, reduced N excretion rate by the cattle means a reduction in the quantity of N to be applied to soils. In this way, $N_2O$ emissions are reduced, again depending on the time spent by the cattle on the feed pad. There may be further reduction by avoiding the application of excreta onto soils during wet winter periods when $EF_3$ is highest, according to the field trials of de Klein et al. (2006) and Luo et al. (2008a). For these trials, when the cattle were removed from the pasture for 18 h per day during late autumn/winter, the daily, direct $N_2O$ emissions from the pasture (grazed 6 h per day) was reduced by about 60%.

Feed pad use involves the temporary storage of excreta. It is assumed that all excreta is collected and passed through the dairy effluent treatment system prior to storage followed by application onto soils. During storage in anaerobic ponds, there may be $CH_4$ emissions but also an opportunity for energy production (Craggs et al. 2008). An innovative proposal by

Lieffering et al. (2008) to digest unutilised forage for energy production involved reductions in $CH_4$ and $N_2O$ emissions. We are aware of no published studies conducted in New Zealand on $N_2O$ emissions from stored effluent. A review of stored manure management under European conditions and $CH_4$ and $N_2O$ emissions was recently published by van der Meer (2008).

Feed pad use can also reduce indirect $N_2O$ emissions. Using feed pads, reducing the quantity of excreted N applied to soils will reduce nitrate leaching because $Frac_{LEACH}$ is a constant value of 0.07. Further, avoiding the application of excreted N onto soils when they are wettest should reduce the potential for nitrate leaching. In the Waikato Region, a dairy pasture farmlet including feed pad use during winter had a 25% lower, annual nitrate leaching rate than the control (Ledgard et al. 2006). In Southland, feed pad use on dairy farms corresponded with an estimated reduction in annual nitrate leaching rate of 15–30% according to Monaghan et al. (2008).

Another issue related to indirect $N_2O$ emissions is the ammonia volatilisation rate from excreta N during feed pad use (Luo et al. 2008a) (also see Appendix B). As stated, the feed pad surface is a hard one that should be impervious to urine, unlike soils. Thus, for the feed pad, the soil's buffer capacity and, in some cases, variable charge attributes are not available to mitigate ammonia volatilisation. However, as stated, the excreta should be collected regularly for storage prior to application to soils. The ammonia volatilisation rate depends on the period of excreta exposure on the feed pad and the corresponding rainfall, temperature and wind speed. Increased rainfall and decreased temperature and wind speed should reduce the ammonia volatilisation rate from excreta on the feed pad. The same factors will affect ammonia volatilisation rate during storage. Thus, a storage cover should eliminate ammonia volatilisation. In the $N_2O$ emissions inventory, term $Frac_{GASM}$ is the fraction of excreta N applied to soils that is volatilised as ammonia. The international default value, equal to 0.2, is used in the New Zealand inventory. The excreta N volatilised as ammonia is then redeposited onto soils and subject to the indirect $N_2O$ emissions factor $EF_5$. In the New Zealand inventory, $EF_5$ (2.5%) > $EF_3$ (1%), so a change in $Frac_{GASM}$ induced by feed pad use corresponds with increased indirect and total $N_2O$ emissions. The 2006 IPCC guidelines recommend the default value of $EF_5$ be changed downwards to 0.75 ≈ 1%. If this recommendation was applied to the New Zealand inventory, ammonia volatilisation would affect $N_2O$ emissions differently because $EF_5$ would then be less than $EF_3$.

### Activity data

To account for feed pads as a mitigation technology, assuming no change of the feed ME or N contents, the following additional activity data are required:

- Fraction of total dairy cattle kept on feed pads
- Fraction of the year dairy cattle are kept on feed pads

The Tier 1 method will not change the determination of ammonia emissions (the default value of $FRAC_{GASM}$ would apply to the feed pad) and it recognises that this mitigation technology will probably be confined to dairy cattle. In the inventory, this would be further specified to the mature milking cows. Therefore, the Tier 1 method will use the number of dairy cattle on feed pads for its accounting system. It is expected that feed pad use would occur in winter, but more refined information may be needed. It is anticipated the months of feed pad use may need to be specified because the ME requirement of breeding animals is affected by the stage of pregnancy as well as the live-weight and production rate.

### Inventory structure

The Tier 1 approach does not require any structural changes to the inventory. However, an additional, ‘implied’ emission factor is needed to capture effects of the mitigation technology. The implied emission factor connects the number of animals (on feed pads) and the reduced $CH_4$ emissions. This would involve repeated use of the inventory’s animal ME requirement model for the months of feed pad use. Firstly, as usual, the model would be run with all (mature breeding) dairy cattle fed by year-round pasture grazing. This yields monthly base values of the dairy cattle population ME requirement and DMI as well as $CH_4$ emissions. Next, the model is run again with all (mature breeding) dairy cattle virtually confined to feed pads. This yields appropriately reduced values of the ME requirement and DMI on a monthly basis for dairy cattle. Combined with the $CH_4$ conversion rate, the implied $CH_4$ emissions factor is obtained as:

‘Implied’ $CH_4$ emissions factor =
$[\text{DMI} \times CH_4 \text{ conversion rate}]_{\text{feed pad}}$/dairy cattle population

The implied CH4 emissions factor may be used to convert the number of dairy cattle on feed pads into a $CH_4$ emissions rate. This may be done monthly and the calculation assumes the cattle were on the feed pad for the entire month, but fractions of a month could also be accommodated by suitable calculations. The $CH_4$ conversion rate should not change by feed pad use unless the involved feed induced a rate significantly different to 21.6 g $CH_4$/kg DMI, that currently used for dairy cattle.

For mitigating $N_2O$ emissions, feed pad use is also based on confinement reducing the ME requirement, DMI and thus the N excretion rate. In addition, the N excreted is stored and later reapplied to land, rather than directly deposited onto pasture. A simplified equation for an implied $N_2O$ emissions factor for N excreted on a feed pad may be written (assuming no application of N fertiliser onto soils during winter):

‘Implied’ $N_2O$ emissions factor =
{([N excreted by dairy cattle $_{\text{feed pad}}$] × $EF_1$) + ([N excreted by dairy cattle $_{\text{feed pad}}$] × $Frac_{LEACH}$ × $EF_5$)} / number of dairy cattle kept on a feed pad

As before, on monthly or longer bases, the implied $N_2O$ emissions factor may be used to convert the number of dairy cattle on feed pads into an $N_2O$ emissions rate. To estimate the $N_2O$ emissions from N excreted on the feed pad, the current inventory methodology applies $EF_1$ to any organic manure that is reapplied to land. The New Zealand specific values of $EF_1$ and $EF_3$ are identical. On the basis of this equality, and the inability to disaggregate feed pad effluent into urine and dung, we suggest a Tier 1 method should use the New Zealand specific value of $EF_3$ for excreta N collected from feed pads and irrigated onto soils. There is another issue about the spatial distribution of stored excreta irrigated onto soils. The equality of $EF_1$ and $EF_3$ implied a lack of N dose effect on direct $N_2O$ emissions. The N application rate to soils in a dairy cattle urine patch can be up to 1300 kg N/ha, while typically, fertiliser dressings on dairy farm soils do not exceed 60 kg N/ha (de Klein & Eckard 2008). The N application rate for excreta N irrigated onto soils should be much more similar to that of typical N fertiliser dressings than in the urine patch. For example, if N application rate in the dairy cattle urine patch was 1300 kg/ha and urine patches covered 5% of the grazed area (an estimate for a single grazing event), the same quantity of excreta N irrigated uniformly across the grazed area would correspond with an (average) N application rate of 65 kg/ha. We reiterate that the Tier 1 method will assume this reduced N application rate onto soils will not correspond with reduced $N_2O$ emissions. When fertiliser N dressings were applied to pasture in the Waikato Region at 50 kgN/ha throughout the year, the annual average value of $EF_1$ was 0.6% and not significantly different to the 1% value used in the New Zealand inventory (Luo et al. 2007). We are aware of no published studies of $EF_1$ from dairy cattle excreta applied as a mixed slurry to pastoral soils under New Zealand conditions.

Indirect $N_2O$ emissions occur after N as nitrate is lost from agricultural soils in drainage water and runoff. The leached N enters water bodies (groundwater, rivers and estuaries) from which $N_2O$ may be emitted. The lost N fraction is denoted in the implied $N_2O$ emissions factor equation as $Frac_{LEACH}$. The effect of feed pad use on indirect emissions from N excreted, $Frac_{LEACH}$, can be estimated by downwards adjusting $Frac_{LEACH}$. There is a New Zealand specific value for $Frac_{LEACH} = 0.07$, an average based on sheep, dairy and beef cattle farm scenario analyses using model OVERSEER as reported by Thomas et al. (2005). Feed pad use has been estimated to reduce nitrate leaching losses by 15–30% (Ledgard et al. 2006; Monaghan et al. 2008).

## 6.2 Feed pads – Tier 2

Combining the grazing dairy cattle and those on feed pads, enteric $CH_4$ emissions may be determined:

$CH_4$ emissions =
$[\text{DMI} \times CH_4 \text{ conversion rate}]_{\text{grazing}} + [\text{DMI} \times CH_4 \text{ conversion rate}]_{\text{feed pad}}$

The number of grazing cattle will determine their (population) DMI, used in the above equation, and their $CH_4$ conversion rate should remain 21.6 g $CH_4$ per kg DMI. On the feed pad, DMI will be reduced and there is scope for adjusting the $CH_4$ conversion rate if required according to the supplemental feed.

The New Zealand climate is characterised by significant rainfall during winter (high soil moisture content exceeding field capacity) and spring (fluctuating soil water content) and low rainfall in autumn and summer (dry soil-moisture conditions). $N_2O$ is mostly generated from N in the dung and urine excreted by grazing animals and from N in fertiliser. These emissions are higher during the wet winter period compared with other seasons (de Klein et al. 2006; Luo et al. 2008b). With the use of feed pads, animals are kept off grazing paddocks, so excreta deposition is reduced at a time when it would lead to greatest N losses. The best practice for feed pad use requires collecting the animal excreta from the feed pads and applying it evenly to pasture at targeted rates and at optimum times (dry soil-moisture conditions) when the risk for N losses through both leaching and $N_2O$ emissions is minimal (Luo et al. 2008c; van der Meer 2008).

This practice has implications for the $N_2O$ inventory calculations, and needs to be incorporated into a Tier 2 method (Table 2).

### Activity data

To account for feed pads as a mitigation technology by a Tier 2 approach, assuming no change of the feed ME or N contents, the additional activity data requirements to recognise the effects are:

- Months (or portions) of feed pad use including the number of animals
- Monthly application to soils of N excreta from feed pads

**Inventory structure**

The Tier 2 approach requires structural changes to the $N_2O$ emissions inventory. Seasonal emission factors, including $EF_3$, $EF_1$ and $Frac_{LEACH}$, would be required to most effectively capture the benefit of feed pad use as a mitigation technology, as was found for nitrification inhibitors. During winter and spring, $EF_3$ and $EF_1$ measurements have yielded significantly larger values than summer and autumn according to Luo et al. (2007, 2008d). For the NzOnet trials, seasonal $EF_3$ values for dairy cattle urine were in the order winter > autumn > spring > summer according to Kelliher et al. (2005)(de Klein et al. 2003). For $Frac_{LEACH}$, it may be constructive to consider a nitrate leaching season, recognising there is no leaching outside this period. However, the accounting system would become more complex than the current one acting upon 7% of N applied to soils and ignoring issues related to season and N accumulation in soils. Another issue of complexity is the leaching season varies throughout the country depending upon rainfall, evaporation and drainage rates. It is anticipated further field trials and modelling analyses will be required to seasonally disaggregate the $N_2O$ inventory emission factors to acceptable standards for international review.

Again setting aside ammonia volatilisation, for feed pads, the Tier 2 approach for direct $N_2O$ emissions on a seasonal basis is:

Direct $N_2O$ emissions =
$[\text{DM intake} \times \text{N excreted}_{\text{per unit of DM intake}}]_{\text{grazing}} \times EF_3 + [\text{DM intake} \times \text{N excreted}_{\text{per unit of DM intake}}]_{\text{feed pad}} \times EF_1 + \text{N fertiliser use} \times EF_1$

For indirect $N_2O$ emissions, N applied to soils is acted upon by $Frac_{LEACH}$ and $EF_5$. As above, the N excreted onto feed pads could be subject to a different value of $Frac_{LEACH}$ than N excreted onto soils by grazing cattle following Clough et al. (2007) (done by them for DCD application to soils).

**Table 3** Information to account for the use of feed pads in the inventory calculations (red font indicates information **not** currently used in the inventory calculations).

| Information | Tier 1 | Tier 2 |
|---|---|---|
| Animal | Monthly data for the number of animals kept on feed pads | Monthly data for the number of animals kept on feed pads |
| Excreta N applied to pastures | | Monthly data |
| $N_2O$ emission factor | | Seasonal/monthly $EF_3$ |
| Feed pad effectiveness | Percentage reductions in $Frac_{LEACH}$ | Percentage reductions in $EF_3$ (monthly) and $Frac_{LEACH}$ |

# 7. Maize Silage

## 7.1 Maize silage – Tier 1

Research has shown that incorporation of maize silage can reduce $N_2O$ emissions. Integration of the fertiliser N-boosted pasture with low-protein maize silage could reduce dietary-N concentrations, reduce environmental N emissions, and consequently increase N use efficiency (e.g. Jarvis et al. 1996; Oenema et al. 1997; Ledgard et al. 2004; Misselbrook et al. 2005).

Maize silage is an important supplementary feed in the dairy industry (e.g. Basset-Mens et al. 2008). While there is currently little use of maize silage by the beef sector, this may increase in future years. However, we will limit the current evaluation of this mitigation technology to the dairy sector as a means of illustrating required activity data and inventory structural changes.

While maize silage is primarily used in the North Island partly due to its availability through local production, there is growing use of maize silage in the South Island, particularly in Southland. Dairy farmers include maize silage as a supplementary feed during summer and autumn to extend lactation, during the pre-calving period to maintain or increase cow condition, and during early lactation to increase milk production through an improved balance of crude protein (CP, CP content divided by 6.25 equals the N content used elsewhere in this report), carbohydrate and fibre (Millner et al. 2005). In practice, approximately one-third of the maize silage is used by the dairy industry in April–May to extend the lactation into autumn, while the remaining two-thirds are used from July to September providing an improved feed balance from pre-calving through to spring (Paul Sharp, ruminant nutritionist, pers. comm.). Spring pastures lack carbohydrates and fibre but contain excessive protein levels (up to 24–34% CP or 3.8–5.4% N content). Lactating cows only require 18–22% CP in their diet at peak lactation (September). Consequently, the surplus N is excreted, typically around three-quarters as urine and one-quarter as dung (Ledgard et al. 2003). The cow will use energy to excrete this N – a double inefficiency.

The addition of maize silage to protein-rich pastures provides an opportunity to reduce dietary N concentrations, reduce N concentration in urine patches (Jarvis et al. 1996; Oenema et al. 1997) and increase the ratio of excreta N in dung to urine (Ledgard et al. 2003). It is generally thought that $N_2O$ emission factors from dung patches are lower than from urine patches (van Groenigen et al. 2005). Maize silage contains high carbohydrates, moderate fibre and low protein levels (around 5–7%), thus providing a more balanced, lower N content diet. In a study comparing a pasture-based dairy system, stocked at 3.0 cows/ha and a maize supplementation pasture, stocked at 3.8 cows/ha, slightly lower $N_2O$ emission rates per hectare were measured on the maize supplementation pasture (Luo et al. 2007). However, when calculated at a farm system level, including emissions associated with growing the maize crop, $N_2O$ emissions per unit of milk product were reduced by 22% with the maize supplementation.

As stated earlier, DMI is determined by the ME requirement assuming sufficient feed is available. Let's assume maize silage is used as a supplementary feed from May to September (as this is its typical use), and let's also assume the maize silage is 25% of the total diet in terms of DM intake. For dairy cattle in the inventory, during the 5 months of late autumn to early spring (May–September), the monthly values of pasture ME average 11.9 ± 0.2 MJ ME/kg DM (± standard error). For seven hybrids of maize grown for silage, ME averaged 10.7 ± 0.1 MJ ME/kg DM (10% less) according to Millner et al. (2005). However, while the diet over this 5-month period now contains a supplement with a lower ME, this does not mean the ME of the overall diet per kilogram consumed has declined. ME is a relative indicator of the available energy. One is not able to treat the ME values of different components of the diet in an additive sense. As an example, let's look at the ME values reported above. Cows grazing on the pasture over the 5-month period with an average ME of 11.9 then have one-quarter of their diet replaced by maize silage with an ME of 10.7. The overall diet will now have an improved digestibility, resulting in an increase in the ME to, say, ~12.5. This is due to a more balanced intake of fibre, fill, protein and carbohydrates. The calculation of ME is strongly influenced by the digestibility of a feed stuff, for example maize stover digestibility strongly influences the ME content of maize silage (Millner et al. 2005).

Consequently, feeding cattle maize silage as a supplementary feed to pasture may affect enteric $CH_4$ emissions per unit of output due to the change in the diet's ME content compared with pasture. While the ME of the diet increases, the DMI is likely to stay the same, or may even slightly increase due to a better balanced diet being offered. However, the conversion efficiency is improved due to the improved digestibility, resulting in increased productivity per cow. As the DMI will either remain constant or lift slightly, enteric $CH_4$ emissions per cow would be expected to either remain the same or slightly increase, but there should be a reduction in emitted $CH_4$ per unit of milk product.

Maize silage can also reduce indirect $N_2O$ emissions. A reduction in N excretion will result in reduced nitrate leaching because $Frac_{LEACH}$ is a constant value of 0.07. The increase in the proportion of N excreted as dung will also reduce nitrate leaching; however, to capture this in the inventory, disaggregation of $Frac_{LEACH}$ for urine and dung will be required. It is suggested that this is included within a Tier 2 approach.

This mitigation technology is often applied with the previously discussed technology, feed pads. Maize silage is fed out to dairy cows either on feed pads or on the dairy platform. There is no current requirement to know the proportion of maize silage fed out onto feed pads, as these activity data are already captured within the current structure.

### Activity data

To account for maize silage as a mitigation technology, the following additional activity data are required for a Tier 1 approach:

- Fraction of total dairy herd fed maize silage
- Fraction of year when maize silage is used
- Proportion of diet that is maize silage
- N content of maize silage
- ME content of maize silage
- ME content of total diet for different ratios of pasture to maize

As for feed pads, the Tier 1 method will recognise that this mitigation technology will probably be confined to dairy cattle. This mitigation technology relies on knowing the fraction of dairy cattle being fed a mixed diet of known proportions of pasture and maize, with a known combined ME and N content. For dairy cattle in the inventory, pasture N content is a constant 3.7%. For the seven maize hybrids, on a whole crop (above-ground) basis, N content averaged 1.10 ± 0.02% (70% less). To account for this option, both Tier approaches needs to be able to adjust the N excreted based on changes in the composition of the diet. The combined ME for the diet will need to be calculated; this is discussed later.

It is expected that maize silage use would occur for the 5 months of May–September, but more refined information may be needed. It is anticipated the months of maize silage use may need to be specified because the ME requirement of breeding animals is affected by the stage of pregnancy as well as the live-weight and production rate: this may become part of a Tier 2 approach.

In terms of sourcing these activity data, the most comprehensive record of feed inputs to the dairy cattle herd is currently captured within the Overseer Nutrient Budgets. As of 2007, these have been conducted for nearly every dairy farm (>97%) in New Zealand, as part of the requirement for dairy farmers to comply with the Clean Streams Accord. Nutrient budgets are completed by the fertiliser industry field staff. It may be possible to source national data from the fertiliser industry for national reporting purposes.

### Inventory structure

A Tier 1 approach will require structural changes to the inventory. Excreta deposition from dairy cows on maize supplements is likely to result in reduced emissions. To most effectively capture the mitigation effect, it will be necessary to disaggregate excreta into dung and urine. It will also be necessary to determine the emission factor for urine with a lower N concentration. Separate inventory calculations will need to be conducted for the May–September period and the October–April period, where the former period calculations are modified to account for the low N and increased ME diet effect. The required changes to $EF_3$ will be outlined below.

It will also be necessary to determine what the ME is for a mixed diet of pasture and maize silage. This will require a theoretical calculation, based on the diet’s protein, carbohydrate and fibre content. A more correct method for determining the ME of this diet would be based on its digestibility; however, this type of research has not been conducted within New Zealand. The estimated ME for the mixed diet can then be used to determine potential adjustments to the DMI, which will influence enteric $CH_4$ emissions.

An additional, ‘implied’ emission factor is needed to capture effects of this $N_2O$ mitigation technology on potential increases in $CH_4$ emissions per animal. Following a similar process outlined for feed pads, the implied emission factor connects the number of animals (on maize supplement) and the (potentially) increased $CH_4$ emissions. This would involve repeated use of the inventory’s animal ME requirement model for the months of maize supplementation. Firstly, the model would be run with all (mature breeding) dairy cattle fed by year-round pasture grazing. This yields monthly base values of the dairy cattle population ME requirement and DMI as well as $CH_4$ emissions. Next, the model is run again with all (mature breeding) dairy cattle on a mixed diet of maize silage and pasture (e.g. the total diet could be assumed to be 25% maize silage during the 5 months May–September). This yields corrected monthly dairy cattle population values of ME requirement and DMI called $[\mathrm{DMI}]_{\text{maize supplementation}}$. Combined with the $CH_4$ conversion rate, the implied $CH_4$ emissions factor is obtained as:

'Implied' $CH_4$ emissions factor =
$[\mathrm{DMI} \times CH_4 \text{ conversion rate}]_{\text{maize supplementation}}$/dairy cattle population

[The $CH_4$ conversion rate should not change by feed pad use unless the involved feed induced a rate significantly different to 21.6 g $CH_4$/kg DMI, currently used for dairy cattle.]

### Adjustments to $EF_3$

As discussed previously, low dietary N can reduce the N concentration in urine patches and increase the ratio of excreta N in dung to urine. Likewise, when disaggregated into urine and dung, $EF_3$ for dung is about 20% of the New Zealand specific value = 1% supported by the 17 dairy cattle urine trials of NzOnet. A MAF-funded trial is in progress, which will assist in providing data for a proposed $EF_{3\text{-URINE}}$ and $EF_{3\text{-DUNG}}$. Additional research is required to determine $EF_3$ values for urine with varying N concentrations.

## 7.2 Maize silage – Tier 2

For Tier 2 the required additional information is the same, but on a monthly basis. This will include monthly data on the fraction of total herd being fed maize silage, and monthly data on fraction of total diet as maize silage. There will also be a requirement for seasonal $EF_{3\text{-URINE}}$ and $EF_{3\text{-DUNG}}$ in addition to the disaggregation of $Frac_{\text{LEACH}}$ into $Frac_{\text{LEACH-DUNG}}$ and $Frac_{\text{LEACH-URINE}}$ to refine capturing the effect of this mitigation option; this latter requirement is outlined below.

The determination of the ME for a mixed diet of pasture and maize silage should include varying ratios of pasture to silage, and should also be calculated with monthly time steps since pasture ME varies from month to month. As for the Tier 1 approach, the ME content will need to be estimated using a theoretical calculation, based on the diet's protein, carbohydrate and fibre content.

Currently the inventory methodology uses an average of 3.7% N in diet for dairy cattle and 3.0% for sheep, beef and deer. Based on the proportion of the diet that will be replaced by maize silage, this N percentage can be adjusted accordingly on a monthly basis. Instead of using an annual figure of, say, 3.7% N in pasture for dairy cattle, it is suggested that monthly pasture N content data are used to better reflect dietary N intake.

### Activity data

The following additional activity data are required for a Tier 2 approach:

- Monthly data on fraction of total herd fed maize silage
- Monthly data on proportion of total diet as maize silage

As for the Tier 1 approach, Overseer Nutrient Budgets may be a suitable source of activity data for a Tier 2 approach for dairy cattle, as supplementary feed is inputted monthly.

### Inventory structure

The Tier 2 approach requires structural changes to the $N_2O$ emissions inventory. Seasonal and disaggregated emission factors for $EF_{3\text{-URINE}}$ and $EF_{3\text{-DUNG}}$ and $Frac_{LEACH\text{-}DUNG}$ and $Frac_{LEACH\text{-}URINE}$ (see below) would be required for calculating the full potential of this mitigation technology on both direct and indirect $N_2O$ emissions. While field trial work is currently under way to help quantify $EF_3$ for dung and urine, it is likely more research will be required to ensure a robust dataset is produced to meet the requirements of the IPCC if changes to the national inventory methodology are to be pursued.

### Adjustment to $Frac_{LEACH}$

In addition to seasonal $EF_3$ for both dung and urine, disaggregation of excreta into the two forms will require separate $Frac_{LEACH}$ values ($Frac_{LEACH\text{-}DUNG}$ and $Frac_{LEACH\text{-}URINE}$). The New Zealand specific value for $Frac_{LEACH}$ (0.07) is an average based on sheep, dairy and beef cattle farm scenario analyses using model OVERSEER as reported by Thomas et al. (2005). Nitrate leaching primarily comes from urine patches, with little from dung pats. Therefore, $Frac_{LEACH\text{-}DUNG}$ will be required to fully account for the reduced nitrate leaching that has been observed using low N diets such as maize supplements, as estimated by Luo et al. (2007).

**Table 4** Information to account for the use of maize silage in the inventory calculations (red font indicates information *not* currently used in the inventory calculations).

| Information | Tier 1 | Tier 2 |
|---|---|---|
| Animal | Fraction of dairy cattle fed maize silage | Monthly data on fraction of herd fed maize silage |
| Animal | Fraction of year when maize silage is used | Monthly data on proportion of total diet that is maize silage |
| Animal | Proportion of diet that is maize silage | |
| Diet | N content of maize silage | |
| Diet | ME content of maize silage | |
| Diet | ME content of total diet for different ratios of pasture to maize | |

# 8. High Sugar Grasses

## 8.1 High sugar grasses – Tier 1

We have concluded from a thorough review of the available literature that insufficient evidence exists at present to mount a case for including the mitigation effects of high sugar grasses into the national inventory (Appendix C). However, it is still possible to outline the steps that need to be taken for a mitigation technology such as HSG forages to be included in the national inventory at some future stage. The essential features of such a technology are that some/all of its effects are potentially variable in time and/or space meaning that regionalisation and the development of within-year algorithms may be needed for the full potential of the technology to be realised. In the discussion below, which uses HSG as an example, it is assumed that information on the magnitude of the effect of HSG on greenhouse gas emissions in space and time are known. The following example assumes that HSG only influences $N_2O$ emissions. However, the changes in structure needed to the inventory are essentially the same if HSG also has an impact on $CH_4$ emissions.

### Activity data

To account for HSG grasses as a mitigation technology, the following additional activity data are required for a Tier 1 approach:

- Total area sown to HSG grasses and total pasture area
- Average digestibility and ME content of these HSG compared with standard pasture
- Average crude protein content of these HSG compared with standard pasture

In a similar manner to feed pads and maize silage the Tier 1 method will recognise that this mitigation technology will probably be confined to dairy cattle in the first instance since this is where most of the reseeding occurs. This would imply that the area sown to HSG may have to be discounted to allow for non-dairy effects. If data are available to disaggregate the area sown to HSG by sector then calculations can be carried out separately for each sector. However, it is currently difficult to obtain data on total reseeding let alone reseeding by sector. The mitigation effect relies on knowing the average effect that an increase in water soluble carbohydrate (WSC) has on N partitioning between dung and urine. The Tier 1 approach will work on the premise that any effects on $CH_4$ and the total amount of N retained will work through changes in digestibility, N content of the diet, and achieved changes in milk quantity and quality.

### Inventory structure

A Tier 1 approach will require substantial structural changes to the inventory. For the beneficial effects of any change in N partitioning between dung and urine to be captured in the inventory two things must occur. First N excreta must be apportioned in some way between that excreted in urine and that excreted in dung. This is done already in the national inventory method using an algorithm developed by Dr Stewart Ledgard, but is ignored for reporting purposes. To ensure that we continue to comply with IPCC ‘good practice’ it may be necessary to review the robustness of this algorithm. Second differential emission factors need to be developed for $N_2O$ emissions arising from dung and excreta.

The method of calculation would be as follows:

Adjust digestibility, ME and N values used in the national inventory by scaling them according to the annual average % change that occurs in HSG and the proportion of the land area sown to HSG. For example, if the digestibility of HSG is 5% higher than conventional pasture and 10% of pasture is sown to HSG cultivars then an adjusted digestibility value is

Current ME $\times(1 + .05 \times 0.1)$.

Modify the algorithm used to apportion N not retained in product to dung and urine to reflect the effects of HSG on this partitioning and the proportion of the land area sown to HSG. For example the current algorithm apportions approximately 70% of N to urine and 30% to dung. If the proportion allocated to dung is increased by 10% and that to urine decreased by 10% in HSG and 10% of pasture is sown to HSG cultivars then the adjusted values for urine and dung respectively are

$70\% \times (1 - 0.1 \times 0.1)$ and $30\% \times (1 + 0.1 \times 0.1)$.

Modify $EF_3$ and $Frac_{LEACH}$ to account for differential direct and indirect emissions from dung and urine. The current inventory structure allows for this to happen but at present the same values are used for emissions from dung and urine.

One additional factor that needs to be considered is how long after sowing does the high sugar trait continue to be exhibited. Over time the proportion of 'sown' species declines and this would mean that the magnitude of the HSG effect declines over time. In the method outlined above careful thought needs to be given as to how this effect is included. One method would be to sum the total area sown to HSG grasses over a number of years (e.g. the average time between reseeding) and then weight the HSG effect for each year. For example, if the area sown in each of four separate years is denoted by W, X, Y and Z, the average time between resowing is 4 years, the effect of WSC is an increase in dung N of 10% and the WSC effect declines by 10% units per year then, in year 5, the total area affected by high HSG is the sum of W, X, Y and Z, while the dung adjustment factor is

$$(W \times 0.1 + X \times 0.09 + Y \times 0.08 + Z \times 0.07)/(W + X + Y + Z)$$

### Adjustments to $EF_3$ and $Frac_{LEACH}$

As discussed previously, low dietary N can reduce the N concentration in urine patches and increase the ratio of excreta N in dung to urine. It is generally thought that $N_2O$ emission factors from dung patches are lower than from urine patches. A MAF-funded trial is in progress that will assist in providing data for a proposed $EF_{3\text{-URINE}}$ and $EF_{3\text{-DUNG}}$. For a Tier 1 approach to mitigation it is assumed that a single value will be assigned to $EF_3$ for both urine and dung and that no attempt will be made to make adjustments for the fact that the change in N content of urinary and faecal material may itself influence the quantity of $N_2O$ emitted. In addition to annual disaggregation of $EF_3$ for both dung and urine, disaggregation of excreta into the two forms will require separate $Frac_{LEACH}$ values ($Frac_{LEACH\text{-DUNG}}$ and $Frac_{LEACH\text{-URINE}}$). The New Zealand specific value for $Frac_{LEACH}$ (0.07) is an average based on sheep, dairy and beef cattle farm scenario analyses using model OVERSEER, but nitrate leaching primarily comes from urine patches, with little from dung pats. Therefore, $Frac_{LEACH\text{-}DUNG}$ will be required to fully account for the reduced nitrate leaching, and subsequent indirect $N_2O$ emissions.

## 8.2 High sugar grasses – Tier 2

For a Tier 2 approach two principal factors have to be considered. First, the expression of the HSG trait may not be uniform throughout the country since expression seems to be linked to temperature. Second, and for a similar reason, the trait expression is likely to vary with time. This means that to adopt a comprehensive Tier 2 approach consideration must be given to disaggregating the national inventory in space as well as time. As with the Tier 1 approach it is assumed that all the necessary data on the mitigation impact of HSG are available to allow a disaggregation by space and time.

### Activity data

The following additional activity data are required for a comprehensive Tier 2 mitigation approach:

- Total area sown to HSG grasses on a regional and sectoral basis and total pasture area for each region and sector
- Monthly digestibility and ME content of these HSG compared with monthly values for standard pasture
- Monthly crude protein content of these HSG compared with monthly values for standard pasture
- Animal populations on a regional basis

The basis for dividing the country into regions will have to be a compromise between data availability and biological desirability. Given that accurate population data are crucial to the inventory, the availability of population data are likely to drive the regions chosen; these could range from a simple North Island, South Island split through to the full range of regions used in the annual population census/survey. Obtaining data on reseeding rates on a regional and sectoral basis is likely to be very challenging in the short term and this may be another reason for a simple North Island, South Island population disaggregation. A GPS area certification process for the sowing of HGS comes from the recommendation made earlier for verification of DCD application to soils. Obtaining monthly pasture quality data is very difficult even at the national scale, and without a substantial research/survey effort, it may prove impossible to obtain these data at anything other than a very crude regional split; once again an argument for a simple North Island, South Island split. This would also mean that obtaining regional and temporal data to allow adjustments of these values for the effects of HSG would be feasible.

### Inventory structure

The Tier 2 approach requires some of the same structural changes to the $N_2O$ emissions inventory that have been outlined for the Tier 1 approach, i.e. the disaggregation of dung and urine and the development of separate emission factors for $EF_{3\text{-}URINE}$, $EF_{3\text{-}DUNG}$, $Frac_{LEACH\text{-}DUNG}$ and $Frac_{LEACH\text{-}URINE}$. In addition, because the effects of HSGs may only be apparent at certain times of the year, to attain the full potential of this mitigation technology, these emission factors need to be further disaggregated on a monthly/seasonal basis. This would mean that the current inventory computer model, which calculates emissions on a monthly basis but uses the same values for things like $EF_3$ in each month of the year, will have to be substantially rewritten.

Once the data and parameters values for $EF_3$ etc. have been obtained the calculation method **for each region** could be as follows:

Adjust current monthly digestibility, ME and N values by scaling them according to the percent change that occurs in HSG and the proportion of the land area sown to HSG. For example, if in January the digestibility of HSG is 5% higher than conventional pasture and 10% of pasture is sown to HSG cultivars then an adjusted digestibility value for January is

January ME × (1 + 0.05 × 0.1).

This would need to be repeated for each month of the year and each sector.

Modify the algorithm used to apportion N not retained in product to dung and urine to reflect the effects of HSG on this partitioning and the proportion of the land area sown to HSG. For example, the current algorithm apportions approximately 70% of N to urine and 30% to dung. If in January the proportion allocated to dung is increased by 10%, and that to urine decreased by 10% in HSG cultivars and 10% of pasture is sown to HSG cultivars then the adjusted values for urine and dung respectively in January are

70% × (1 − 0 .1 × 0.1) and 30% × (1 + 0.1 × 0.1).

This would need to be repeated for each month of the year and each sector.

Modify $EF_3$ to account for the differential emissions from dung and urine. The current inventory structure allows for this to happen on an annual basis meaning that the inventory structure would need to be changed so that $N_2O$ emissions were calculated using, at a minimum, seasonal $EF_3$ values for dung and urine. Separate monthly $Frac_{LEACH\text{-}DUNG}$ and $Frac_{LEACH\text{-}URINE}$ parameters may also be needed and these would be handled in the same way as $EF_3$.

In common with the Tier 1 approach the issue of longevity of expression of the HSG trait in pastures needs to be considered. In principle it can be handled in the same way as suggested for the Tier 1 method. Therefore on a regional and sectoral basis it would be necessary to sum the total area sown to HSG grasses over a number of years (e.g. the average time between reseeding) and then weight the HSG effect for each year (see Tier 1 approach above). However, some complexity may arise in that the effect may not simply be able to be scaled annually since the change over time may interact with time of year such that it disappears at some times of year but not others. This would mean applying the method outlined in the Tier 1 approach on a monthly basis. For example, if the area sown in each of four separate years is denoted by W, X, Y and Z, the average time between resowing is 4 years, the effect in January of WSC is an increase in dung N of 10% and the WSC effect declines in January by 10% units per year then, in year 5, the total area affected by high HSG in January is the sum of W, X, Y and Z, while the dung adjustment factor for January is

W × 0.10 + X × 0.09 + Y × 0.08 + Z × 0.07/(W + X + Y + Z).

This may need to be repeated for each month of the year and each sector.

### 2.8.3 Adjustment to $EF_3$ and $Frac_{LEACH}$

For the Tier 1 approach annual changes were need in $EF_3$ and $Frac_{LEACH}$ for both dung and urine. A Tier 2 approach would, in addition, require a temporal adjustment (month/season) for these parameters. Consideration may also need to be given to separating these by species but this will involve a considerable amount of research investment and the costs/benefits of doing this need to be carefully considered. In the first instance disaggregation of $EF_3$ and $Frac_{LEACH}$ on a seasonal basis would appear to be the highest priority for research.

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## Appendix A Nitrification inhibitors – Tier 2: Accounting for the sensitivity of DCD degradation in soils to temperature

Based on published data from controlled-environment studies of soils sampled in four countries, the relation between T and the time for DCD concentration in soils to decline to half its application value ($t_{½}$) was $t_{½}$ [T] = 168 $e^{-0.084T}$ with parameter standard errors of ± 16 days and ± 0.011 days, respectively (*n* = 16) (Kelliher et al. 2008; citations were provided earlier in the References). For example, at 5°C a 1°C increase in T reduced $t_{½}$ from 110 to 101 days whereas at 25°C the reduction was 20 to 19 days. For a Tier 2 method, recognising the monthly determination of Nex by animal type, monthly estimates of T are required to quantify the DCD degradation rate. However, the inventory is done at a national level and variance in T across the country creates uncertainty in the accounting system.

Analysing monthly average T regimes across New Zealand begins with long-term weather station records. Beneath grass that was mowed regularly, the soil temperature was measured daily (at 0900 hours, depth = 0.1 m, Table 2; New Zealand Meteorological Service 1983). Data (30–41-year averages) from four weather stations, selected by Kelliher et al. (2007), provide a national latitudinal record. From Rukuhia near Hamilton to Invercargill, there was nearly a 9-degree increase in the latitude (Table A1). During autumn, winter and early spring, when DCD is applied for the Tier 1 method, monthly average T ranged from 4 to 13°C (Tables A2 and A3). Thus, T was generally <10°C in accordance with the Tier 1 method. For T ≥ 10ºC, the $t_{½}$ [T] relation (above) indicated $t_{½}$ ≤ 73 days (2 months). During late spring and summer, monthly average T was generally >10°C and up to 20°C (Table 4). For T ≥ 20ºC, $t_{½}$ ≤ 31 days (1 month). These calculations were interpreted to suggest DCD effectiveness during late spring and summer would require monthly to bi-monthly application to soils during October–April.

The variance in monthly average T was affected by the latitude as well as the season. Using a digital expression of latitude for the four weather stations as an independent variable, linear regression accounted for 88–99% of the variance in monthly average T for October–April (Table A3). The regression slope averaged −0.58 ± 0.02 ºC per degree of latitude (± standard error, *n* = 7). This means that, on average, a 1-degree increase of latitude corresponded with a 0.58ºC decrease in the monthly average soil temperature. Separately analysing the data from summer (November–January), linear regression accounted for 88–92% of the variance in T, while a curvilinear (second-order polynomial) model accounted for 99% based on a better fit to the Invercargill data. For the other four months analysed, the linear and curvilinear models were indistinguishable.

The T analyses yielded a potential Tier 2 inventory structure to account for the the sensitivity of DCD degradation rate in soils to T, so DCD effectiveness during October–April. This begins with determination of nationally averaged monthly-T for these months. We recommend these data come from long-term records and a larger set of (representative) weather stations than was analysed here for the purpose of illustration. From the analyses done here, we conclude monthly T across New Zealand could be reliably estimated from national-average data and latitude.

A Tier 2 method also relies on the extent and location of DCD application, available on a regional basis according to Statistics New Zealand. During the year ended 31 June 2007, these data indicated DCD was applied to 68 983 ha, in total, with 38%, 12% and 15% of this land area located in the Canterbury, Otago and Southland regions, respectively. In the North Island, 13% and 2% of the 68 983 ha was located in the Waikato and Taranaki regions, respectively. Thus, 80% of the land area treated by DCD was located in these five regions. Though unstated, this land was covered by pasture and probably grazed exclusively by dairy cattle. During the 2006/07 milking season, 67% of the national milk solids production came from these five regions (Livestock Improvement Corporation Regional Dairy Statistics). While the similarity of 80% and 67% is striking at the national level, the North to South regional distribution of milk solids production was different to that of DCD application.

For a Tier 2 accounting method, based on the current spatial distribution of DCD application, there is probably merit in data aggregation between the regional and national scales. One suggestion is to distinguish the data on the basis of the North and South islands. Given the current and likely future spatial distribution of dairy production, this aggregation scale should also be suitable for the T data. For October–April, on average for the North and South islands, monthly T should be acceptably estimated from national-average data and latitude.

**Table A1** Four former weather stations of the New Zealand Meteorological Service located along a North to South transect and the period (years) of soil temperature measurement (New Zealand Meteorological Service 1983).

| Weather station | Latitude, Longitude, elevation (ma.s.l.) | Period |
|---|---|---|
| Rukuhia | 37°50’ S, 175°18’ E, 66 | 1946–1980 |
| Palmerston North | 40°23’ S, 175°37’ E, 34 | 1939–1980 |
| Lincoln | 43°39’ S, 172°28’ E, 11 | 1943–1980 |
| Invercargill Airport | 46°25’ S, 168°20’ E, 0 | 1951–1980 |

**Table A2** Monthly average soil temperature during autumn, winter and early spring at four locations along a North to South transect described in Table 2. Measurements were made daily at 0900 hours and the thermometer was located at a depth of 0.1 m beneath mown grass. The averages were computed from 30–41 years of data. During these months, rainfall generally exceeds evaporation, so soils become wet. If the soil’s water storage capacity is exceeded, there will be drainage.

| | Month | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|
| Location | Rukuhia | 11.1 | 8.7 | 7.6 | 8.5 | 10.7 |
| | Palm. North | 10.1 | 7.7 | 6.7 | 7.6 | 9.9 |
| | Lincoln | 7.4 | 4.5 | 3.9 | 5.0 | 7.5 |
| | Invercargill | 6.7 | 4.6 | 3.5 | 4.3 | 6.5 |

**Table A3** Monthly average soil temperatures during late spring and summer. Measurements were made daily at 0900 hours and the thermometer was located at a depth of 0.1 m beneath mown grass. The averages were computed from 30–41 years of data.

| | Month | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|
| Location | Rukuhia | 13.4 | 15.8 | 18.1 | 19.5 | 19.5 | 17.6 | 14.3 |
| | Palm. North | 12.5 | 15.1 | 17.3 | 18.5 | 18.1 | 16.3 | 13.2 |
| | Lincoln | 10.8 | 13.8 | 16.4 | 17.4 | 16.7 | 14.3 | 10.9 |
| | Invercargill | 9.0 | 11.1 | 13.3 | 14.1 | 13.6 | 12.1 | 9.5 |

## Appendix B Feed pads – Emissions issues

A feed pad is a type of winter management system in which an area, usually in close proximity to the dairy shed, is built with concrete. Its principal purpose is to provide an area where supplements are fed to cows so as to avoid losses that occur if animals trample feed into wet ground. The hard surface is durable and easy for farmers to clean. However, there could be a risk of injury due to slipping and prolonged standing could damage hooves and legs. There is a capital cost associated with building feed pads, with labour and other costs associated with removing manure from the surface. This is usually done by scraping and washing. A storage pit and/or other facilities are required to hold the manure/effluent prior to land application.

The advantages include a possible reduction in greenhouse gas emissions and a reduction in feed wastage compared to paddock feeding, as the trough or feed lanes are mounted above ground. A concrete surface is easily scraped by a tractor with a large scraper blade and a final hosing down produces a relatively small amount of liquid waste (effluent). However, to protect the environment, the manure storage facility and tank (or pond) receiving liquid wastes needs to be large enough to contain the effluent until conditions are suitable for land application, which allows return of excreted nutrients to the farm.

Although feed pads can improve environmental outcomes, there could be some adverse effects, particularly those associated with undesirable gaseous losses. For example, de Klein and Ledgard (2001; citations were provided earlier in the References) predicted that the total $NH_3$ losses in a nil grazing system (housing system) were higher than those from conventional grazing systems and that losses of total nitrogen were also 10–35% higher than under conventional grazing system.

The length of time the animals are present on 'hardstanding' areas affects the amount of urine and faeces deposited. Webb et al.. (2001) studied the extent and frequency of use of 'hardstanding' areas in England and reported mean areas of between 1.7 $m^2$ and 3.4 $m^2$ per animal were typical for dairy cows. Misselbrook et al. (2001) studied several farms at different times of year and reported no obvious seasonal influence on $NH_3$ emissions. Table B1 gives average $NH_3$ emission factors for different animal yards in the UK.

**Table B1** Ammonia emission factors for different yards in the UK

| Source | Emission factor<br>(g $NH_3$–N $m^{-2}$ $day^{-1}$) | Source |
|---|---|---|
| Dairy cattle collecting yard | 4.9 | Misselbrook et al. 1998 |
| | 6.7 | Misselbrook et al. 2001 |
| Dairy cattle exercise yard | 4.3 | Keck 1997 |
| Dairy cattle feeding yard | 16.6 | Misselbrook et al. 2001 |
| Beef cattle feeding yard | 5.3 | Misselbrook et al. 2001 |

## Appendix C Potential of high sugar grasses to reduce methane and nitrous oxide emissions under New Zealand conditions

This appendix was written by H. Clark and peer-reviewed by R.J. Hegarty. (The citations for this appendix were provided earlier in the References.)

### INTRODUCTION

High sugar grasses (HSG; grasses bred specifically for enhanced water soluble carbohydrate (WSC) concentrations) have been promoted as a possible means by which greenhouse gas emissions from pastoral agriculture can be reduced (O'Hara et al. 2003). It is postulated that these grass cultivars could reduce emissions in three principal ways:

- By increasing nutritive value (e.g. increased digestibility) such that less herbage is consumed to obtain a given level of output. This would result in both less methane ($CH_4$) and less nitrous oxide ($N_2O$) being produced per unit of product.
- By improving the balance of energy and protein supply to the rumen so that a greater proportion of dietary protein is captured in microbial biomass resulting in more nitrogen (N) being captured in product and a smaller proportion of excreted N appearing in the urine. More N retained in product would reduce the quantity of N excreted by grazing ruminants and hence reduce the amount of $N_2O$ emitted from pastoral soils. A reduction in the N concentration of urine would also reduce $N_2O$ emissions since the quantity of $N_2O$ released per unit of N deposited as urine is higher than that released per unit of N deposited as dung.
- By directly affecting the quantity of methane ($CH_4$) emitted per unit of feed digested in the rumen.

This literature review will examine the evidence currently available on HSG and assess whether sufficient evidence exists for HSG to be promoted as a valid greenhouse gas mitigation technology for New Zealand and what steps are needed to allow the mitigation potential of HSG to be incorporated into the national inventory.

### BACKGROUND TO THE DEVELOPMENT OF HIGH WSC GRASSES

Improving 'herbage quality' has long been a goal of plant breeders and this aim has been to some extent achieved by development of tetraploid cultivars which have been shown to have higher WSC than their diploid counterparts (Castle & Watson 1971; Wilkins 1991). More recently, *diploid* perennial ryegrass cultivars with enhanced WSC have also been developed (Humphreys 1989; Turner et al. 2006).

The development of high-WSC-content perennial ryegrasses has centred on increasing the accumulation of the high-molecular-weight storage sugars, fructans (Pollock & Cairns 1991; Pavis et al. 2001a, b). In cool-temperate perennial ryegrasses, sugars accumulate substantially in leaf blades and these sugars are predominantly sucrose and smaller equal quantities of glucose and fructose. Sugar concentrations are greatly elevated (for a given light energy) by low temperatures, partly because low temperatures reduce growth more than photosynthesis, but there is also a seasonal, longer-term accumulation of sugars, notably as fructans. Fructans increase throughout flowering in spring, through summer and autumn, reaching a peak in midwinter (where in high latitudes/altitudes they may provide for freezing tolerance), and fructans fall rapidly in early spring. High-WSC ryegrass cultivars seem to predominantly increase the expression of fructans in leaf blades (Pollock & Jones 1979).

The development of the high WSC trait in diploid perennial ryegrass has long been a specific target for the Institute of Grassland and Environmental Research (IGER) in the UK and they began marketing a HSG ryegrass cultivar (‘AberDart’) in 2000.

## EVIDENCE THAT HIGH SUGAR GRASSES CAN INCREASE ANIMAL PERFORMANCE

Miller et al. (2000; 2001a) and Moorby et al. (2006) in a series of trials examined the response of Holstein-Friesian cows (c. 600 kg) to ryegrass diets differing in sugar content. The comparisons were between ‘AberDove’, an HSG that was developed by IGER but never marketed, and ‘AberElan’, a diploid control perennial ryegrass cultivar with matching heading date. The studies took place over three separate years (1998–2000) and the animals were stall-fed indoors, in the morning and evening, on a diet of ryegrass that had been cut from the field and blast frozen and/or maintained at 4°C. In addition to ryegrass all animals received an additional 4 kg/day of concentrate. An important point relating to this series of experiments is that in only one case was the material growing in the field judged by the authors to have sufficient difference in WSC content to test the benefits of high WSC versus ‘normal’ WSC cultivar diets. Therefore in two of the three years, methods were used to accentuate the differences between cultivars, to test ‘proof of concept’.

Miller et al. (2001a) reported dairy cow responses in *late lactation* to material cut at the end of one 6-week regrowth in summer (July in UK) and fed to cows indoors. Total WSC was elevated by some 39 g/kg (165 v. 126 g/kg in high-WSC and control cultivars respectively) and this was associated with a small decline in crude protein (CP) (92 v. 106 g/kg) and in neutral detergent fibre (NDF) (544 v. 589 g/kg). Milk yield was increased significantly by 2.7 kg/day (15.3 v. 12.6 kg/day) with no significant effects on milk composition. Total dry matter intake (DMI) was not significantly different between the high-WSC and control cultivars (11.6 v. 10.7 kg DM/day, but there was significantly higher DM digestibility in the high-WSC cultivar (71% v. 64%), suggesting that the increased milk yield resulted from an increased *digestible* DMI.

Moorby et al. (2006) reported dairy cow responses in *early lactation*. However, to obtain diets differing substantially in WSC content, the ‘high sugars’ diet was achieved by harvesting the high-WSC ‘AberDove’ in the afternoon, but the control grass in the morning. Milk yield and milk composition were not significantly affected by dietary treatment despite greater digestible DMI resulting from greater total intake, as well as slightly higher digestibility (75% v. 72%) in the high-WSC cultivar. This paper fails to confirm the benefits of a high-WSC diet in milk yield, and also that greater milk yields in a high-WSC cultivar do not necessarily arise from greater total and/or digestible DM intake.

The final study in the series (Miller et al. 2000) reported dairy cow responses in *mid-lactation*. To obtain diets differing substantially in sugar content (and other characteristics) the control-cultivar plots (only) were fertilised with 50 kgN/ha 3 weeks prior to harvest. This increased crude protein levels in the *control* forage (145 v.107 g/kg in the control and hig-WSC cultivars, respectively) and decreased sugar content in the control (194 v. 234 g/kg respectively). In common with Moorby et al. (2006), there was no significant difference in milk yields between high-WSC (21.4 kg/day) and control (21.9 kg/day) cultivars or in milk composition. Dry matter intake was not significantly different, nor was NDF, nor digestibility (of DM).

In a companion trial to the ones outlined above Miller et al. (2001b) measured animal responses to high-WSC cultivars in cows grazing at pasture (once again all cows receiving 4 kg/day high-value concentrate). However, in order to accentuate the differences between cultivars, an extra 50 kgN/ha was applied to the control grass ('AberElan') only, which decreased WSC, raised CP, and slightly lowered NDF in the control grass. The WSC in 'AberDove' was significantly higher (236 v. 166 g/kg) and the CP significantly lower (128 v. 176 g/kg) and NDF similar, compared with the control, 'AberElan'. There were no significant differences in milk yield and milk composition at pasture, and total DMI was not significantly different.

Another comprehensive series of studies, including both indoor feeding and grazing at pasture, was conducted in the Netherlands. The series involved Holstein-Friesian cows, spanning a range of stages of lactation. In all cases, the animals received additional concentrates of typically 3–5 kg/day. The work involved eight diploid ryegrass cultivars, differing in WSC, NDF, crude protein, and other characteristics such as tensile strength and sward structure in the pasture.

Tas et al. (2005) in a 2-year study (2000–01), where forage was cut and fed *ad libitum* to dairy cows indoors, report intake, digestibility and milk yield responses from eight cultivars. In all cultivars, digestibility was high (>77%) and CP was 150–160 g/kg. Two of the eight cultivars showed consistently greater WSC, and slightly lower NDF. Despite this DMI and milk yield were not affected by cultivar.

A further study, by Taweel et al (2005a, b), focused on a comparison of two 'high' WSC cultivars, and four 'low' WSC cultivars. The 'high' WSC cultivars had sugar contents that were 24–31 g/kg higher than their 'low' sugar counterparts and in addition had small but significantly lower NDF and CP content. No significant differences were found in milk yield or milk composition, and DMIs were similar (16.2 v. 16.6 kg/day, 'high' v. 'low').

In addition to these indoor trials the same group conducted field studies looking at dairy cow responses to high-WSC cultivars under grazing. Tas et al. (2006b) grazed cows, over two years (2002–03), on four cultivars two of which had consistently higher WSC and slightly lower NDF. In year 1 of the trial (2002) the cows grazing the cultivar with the lowest WSC had the lower herbage DMI, N intake, milk yield, and milk N yield. However, these differences disappeared in year 2 of the study despite similar differences in WSC and chemical composition between cultivars.

Cosgrove et al. (2007), in the only published New Zealand study, compared milk yield and milk composition in Friesian cows grazing the high-WSC diploid 'AberDart', the New Zealand standard diploid 'Impact', and the New Zealand tetraploid Italian ryegrass 'Moata'. The high-WSC 'AberDart' had similar WSC to 'Moata', and both were 20–40 g/kg greater in WSC than 'Impact' (control). There were no significant effects of ryegrass variety on milk yield or milk solids in either spring, although in successive autumns significant differences occurred in milk yield (and in one year milk composition) despite there being no significant differences in sugar concentrations between the cultivars (0–9 g/kg).

In addition to these studies on lactating dairy cows Lee et al. (2001) examined the effect of HSG on grazing lamb liveweight gain in three separate 21-day periods. These authors used an experimental HSG (Ba11353) and an intermediate HSG control (var. 'AberElan'). In common with many of the dairy studies inherent differences in WSC were artificially enhanced, in this case by harvesting at different times of the day. In two out of the three periods large differences in WSC were achieved (period 1, 89 v. 143 g/kg DM; period 2, 75 v. 113 g/kg DM). In addition NDF, ADF and dry matter digestibility were significantly lower in the HSG than in the control variety. On average lamb liveweight gain was 23% higher on the HSG diet, and there was a positive relationship between liveweight gain and the WSC concentration of the herbage, and a negative relationship between fibre concentration and liveweight gain ($r = 0.67$ and $-0.73$; $P < 0.05$, respectively).

## EVIDENCE THAT HIGH SUGAR GRASSES CAN INCREASE NITROGEN RETENTION AND/OR NITROGEN PARTITIONING BETWEEN DUNG AND URINE

The majority of the studies reported in the previous section also examined N retention/partitioning. Miller et al. (2001a) found a significant reduction in the percentage of N eaten that was released in urine in the high WSC (25%) than control (35%) cultivar, and an increase in the percentage of N eaten retained as N in milk (30% v. 23%). This was in a situation where total N intake was not significantly different in the high-WSC than control cultivar and milk yield was significantly enhanced. Moorby et al. (2006), in a trial in which milk yield was not increased, found no change in the N composition of milk but reported a significantly lower percentage of dietary N in urine for the high-WSC (20%) than control (27%) cultivar. Similarly, Miller et al. (2000) found no change in milk composition but reported a significantly lower percentage of dietary N in urine in the high-WSC (17.8%) than control (26.7%) cultivars. However, this was in a situation in which total N intake was lower on the high-WSC diet. Lee et al. (2001) do not report data on N retention in their study with lambs but in a companion study (2002) using the same forages fed to cattle found that high-WSC diets did not influence microbial protein synthesis or N supply to the duodenum.

Interpreting the influence of high-WSC diets on N retention and partitioning in the Dutch studies is, in common with the UK studies, complicated by their often being differences between diets in N concentration as well as WSC concentration. Tas et al. (2005, 2006a) found no differences in the quantity of N retained in milk but did find that that the WSC diets, which also had a lower intake of N, resulted in lower urine N excretion. Taweel et al. (2005a, b) also found that high-WSC diets did not increase N retention in milk, as did Smit et al. (2005). Tas et al. (2006b) found contrasting results in two years despite the diets being similar in both years and concluded: 'At relatively high N concentrations in grass and only small differences among cultivars in NDF concentrations, cultivars with an elevated WSC concentration did not increase N utilisation in grazing dairy cows.'

## EVIDENCE THAT HIGH SUGAR GRASSES CAN INCREASE/DECREASE METHANE EMISSIONS

There are no reports in the literature of the influence of HSG forage cultivars on $CH_4$ production. From a theoretical perspective the work of Blaxter and Clapperton (1965), which shows that high digestibility diets produce less $CH_4$ per unit of feed processed in the rumen, suggests that if HSG forages have higher dry matter digestibility they will reduce $CH_4$. However, work in New Zealand by Molano and Clark (2008) failed to demonstrate over the range of digestibilities found on-farm that digestibility per se had any effect on the quantity of $CH_4$ produced per unit of DMI. High sugar grasses could reduce $CH_4$ per unit of production if feeding high-WSC diets resulted in increased individual-animal productivity due to the increased efficiency of conversion of dietary intake to animal product brought about by the dilution of the proportion of energy needed for maintenance. However, the productivity benefits of high-WSC diets have already been shown to be inconsistent.

Although there are no studies that have measured $CH_4$ emissions from animals consuming HSG forage cultivars, Lee et al. (2002) and Taweel et al. (2005a) measured the effect of diets contrasting in WSC content on volatile fatty acid profiles. This can give an indication of likely effects on methanogenesis since increased proprionic:acetic acid ratios generally result in lower $CH_4$ emissions (Moss 1993). However, the results from these two trials are inconsistent since Taweel et al. (2005a) found no effect of WSC on proprionic:acetic acid ratio, whereas Lee et al. (2002) found that a high-WSC diet increased the ratio. A factor in this could be that in the study by Lee et al. (2002) the difference in WSC concentration between the 'high' and 'low' diets was of the order of 80 g/kg DM but it was only a maximum of 31 g/kg DM in the Taweel et al. (2005a) study.

## IS THE HSG TRAIT CONSISTENTLY EXPRESSED?

The previous sections demonstrate that in some circumstances high-WSC diets may increase productivity and change N partitioning, but an important question remains. Do HSG cultivars consistently exhibit higher levels of WSC than non-HSG cultivars? This question is prompted in part by the need in many of the experiments reviewed to artificially induce significant differences in WSC.

Edwards et al. (2007) have comprehensively reviewed European studies that have used the IGER varieties 'AberDove', 'AberElan' and 'AberDart' and concluded that, in Northern Europe at least, there is consistent expression of elevated sugars. However, the elevation in sugar concentration is in general relatively modest (i.e. <40 g/kg).

In contrast to the European studies, in New Zealand Parsons et al. (2004) showed small and inconsistent differences between 'AberDart' and the UK control 'Fennema' in WSC content under grazing. Subsequent controlled-environment studies, using 'AberDove' and 'AberDart' as high-WSC grasses and 'Fennema' as a control, found that a significant difference between the high-WSC cultivars and 'Fennema' was apparent only after all the cultivars were subjected to a sustained period of cold and short days (conditions comparable with leaving a UK winter).

Long-term trials have also been conducted at two sites (Gore and Palmerston North) using a range of cultivars supplied by Germinal Holdings and two standard New Zealand cultivars ('Bronsyn' and 'Impact'). The results from these trials are not published but Edwards et al. (2007) quote an agreed statement from AgResearch and Germinal Holdings, part of which is reproduced below:

> Data for WSC content showed some inconsistency between harvests and sites but overall, AberAvon and AberMagic showed 7% higher WSC levels than Impact and Bronsyn. AberAvon and AberMagic showed 13% higher WSC levels [Δ 20 g/kg] than Impact and Bronsyn at Palmerston North (190 *v.* 170 g/kg), except for autumn 2006 when there were no differences between cultivars. At Gore, AberAvon and AberMagic had similar WSC levels to Bronsyn but higher than Impact.

Taken together the European and New Zealand data imply that the increased WSC trait can be consistently expressed but the differences between the currently available HSG and standard cultivars are relatively small.

## SUMMARY AND CONCLUSIONS

The results summarised here do not in general substantiate the hypothesis that diets high in WSC increase animal productivity.

The only trial showing an increase in milk yield from a HSG diet (Miller et al. 2001a) occurred when there was a substantial difference in WSC content and where the protein content was lower than would be recommended for lactating dairy cows. Arguably this trial has little relevance to the New Zealand situation where CP concentrations are generally more than double those used in this study. The Dutch studies have more relevance since the diets used were both high in energy and protein and none of these trials showed a milk yield response to high-WSC diets. The single lamb trial reported in the literature does, on the face of it, look more promising since there was a significant increase in lamb liveweight gain when consuming forage with elevated WSC. The common factor in both of the studies where animal production responses were reported on high-WSC diets was that estimated DMD was also considerably higher; this alone could explain increased animal performance responses irrespective of whether HSG cultivars promote increases in microbial protein synthesis.

The data currently available in the literature do not provide conclusive evidence that HSG forages change N retention in product and N partitioning between dung and urine. The UK studies, which were conducted with diets generally low in protein, seem to support the hypothesis that high WSC will promote greater microbial protein synthesis, but the Dutch studies, which used diets higher in crude protein, do not. Edwards et al. (2007) in a comprehensive assessment of HSG argue that the differences in experimental results may arise because HSG cultivars work by improving the synchrony between WSC and N supply and hence there is a need to compare N use efficiency not for a range of WSC contents, or N intakes, but for a range of WSC:protein ratios. When compared in this way Edwards et al. (2007) argue that there may not be a conflict between the Dutch and UK data; an increase in WSC:CP ratio above c. 0.7 leads to a direct reduction in the proportion of N intake excreted in urine (and corresponding but much smaller increase in the proportion of N intake excreted in milk). This has important implications for the New Zealand situation since it implies that to achieve a given high-WSC:CP ratio, substantially more sugar is needed when the CP of the diet is high. New Zealand diets often contain > 20% CP, indicating that WSC concentrations would need to be > 300 g/kg; this is higher than anything reported in the studies reviewed here and it may prove challenging to consistently grow forages with WSC concentrations as high as this.

There are no data available in which $CH_4$ has been measured to support the notion that HSG forage cultivars can reduce $CH_4$ emissions per unit of feed ingested, and the indirect evidence is inconsistent. Thus at present any claims that HSG forage cultivars can reduce $CH_4$ emissions are premature.