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Incorporation of GHG Management Options into MPI's Agricultural Inventory Model

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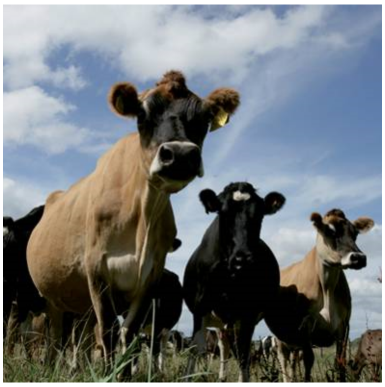

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Incorporation of GHG Management Options into MPI's Agricultural Inventory Model

Ministry for Primary Industries

June 2016

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1. Executive summary

This project aimed to:

a) Identify key current, emerging or next generation Greenhouse Gas (GHG) management options for agriculture,

b) Assess their feasibility on farm and likelihood of adoption,

c) Assess the feasibility of incorporation into MPI's Agricultural GHG Inventory model.

A workshop of scientific, industry, farm systems and policy experts was held to identify and assess potential GHG management options for agriculture, with a focus on options expected to reduce absolute GHG emissions. No judgement of their scientific validity, or expected effect on emission intensities (emissions per unit of product) was made.

Four key management options were identified,

a) Inhibitors (natural) e.g. nitrification and urease,

b) Inhibitors (artificial) and vaccines,

c) Animal selection,

d) Low GHG feeds.

Options were considered in terms of what change would be required to incorporate them into the inventory, including the inventory software model. Those that could be specified by changing annual emission factor (EF) or fraction values would require no change to the inventory software. Others might require more complex changes (i.e. calculation methodologies), and/or require additional activity data (AD). Incorporation into the inventory had to be assessed in terms of:

a) Ability to incorporate into the existing inventory structure,

b) Activity data:

    a. What data are needed,

    b. Availability to calculate the inventory from 1990,

    c. Future security of data.

Activity data requirements may be the biggest challenge when considering options for inclusion in the inventory. Some options (e.g. irrigation) may require activity data (or EFs) specific to relevant regions, while for others, sensitivity of the data could be an issue (e.g. fertiliser). To realise the full effect of some options in the inventory, a change to the Tier 1 methodology to use monthly emission factors and fraction values for nitrogen excreta calculations would be required.

The adoption rates for an option will be influenced by its effect on animal productivity and health, and economic considerations. These considerations may not be well understood, and were outside the scope of the workshop.

2. Introduction

2.1 Workshop goals

Incorporation of GHG management options into the inventory are expected to improve the accuracy of the Ministry for Primary Industries (MPI) emission reporting. A workshop was held to:

a) Identify key current, emerging or next generation GHG management options for agriculture,
b) Assess their feasibility on farm and likelihood of adoption,
c) Assess the feasibility of incorporating into MPI's Agricultural GHG Inventory model.

Workshop participants (Appendix 1) included scientific, industry, farm systems and policy experts. The focus was on management options expected to reduce absolute emissions, with no judgement of their scientific validity, or expected effect on emission intensities (emissions per unit of product).

Management options considered included use of forage crops, housing, feed pads, supplementary feeds, gibberellic acid (GA), among other options.

2.2 Background

Previous efforts to assess inclusion of mitigation technologies in New Zealand's (NZ) inventory include Kelliher *et al*. (2008) and de Klein *et al*. (2012). The latter examined the effect of a range of GHG mitigation technologies for NZ pastoral systems on inventories of enteric methane and agricultural soils nitrous oxide emissions. The impact of each technology was assessed individually by directly using the Inventory model to calculate emissions using specified adjustments to emission factors (EFs) or fraction (e.g. $Frac_{Leach}$) values, and expected adoption rates based on a survey of expert opinions. The mitigation options assessed by de Klein *et al*. (2012) were circulated to participants prior to the workshop (Appendix 2, Table 9.1). The workshop extended the results from de Klein *et al*. (2012). Results were used as a starting point if no better information was available e.g. expected adoption rate.

2.3 Report structure

Each management option identified is discussed with consideration for inclusion in the inventory (§3), and key options identified. No ranking is implied in the listing of the options. An overview of issues for incorporating options into the inventory software is given in §4. A glossary of common abbreviations and terms used when discussing the agricultural GHG inventory is provided in Appendix 4 (Table 11.1).

2.4 Assessment criteria

Options were assessed using the expert opinion of workshop participants on the basis of their potential to reduce emissions, likely adoption rate, anticipated overall impact on emissions, time frame for availability, and feasibility for incorporation into the current inventory methodology and software. For many options, the AD likely to be required could be identified, but participants were unsure if it was available. Two sample calculations follow that show how the impact on emissions of a management option could be assessed. These calculations are not made for each option discussed.

2.4.1 Examples of the effect of assumptions on overall GHG emissions

To show the effect of assumptions about an option on overall emissions, calculations are shown for two examples using specified reductions in EF and an adoption rate. While the actual inventory is population based, and integrated at annual and national scales, these calculations help show how the effect on emissions can be reduced due to scaling.

2.4.2 Low GHG feeds (non-pasture forage)

These (see §3.1.4) are expected to reduce the emission of enteric methane (not N_2O), and would be fed as an alternative to complement pasture. There would still be some pasture in the diet. Total enteric CH_4 emissions from pasture and non-pasture forage can be calculated as follows

$$E = (1\text{-}a)EFCH_4 + a(1\text{-}d)EFCH_4 + adEFCH_4(1\text{-}r) \qquad \text{Equation 1a}$$

where

E = total enteric CH_4 emissions from pasture and non-pasture forage

$EFCH_4$ = EF for enteric CH_4 from pasture (i.e. the default EF CH_4)

a = proportion adopting use of non-pasture forages

d = for adopters, proportion of the diet made up of non-pasture forage (likely to be non-zero). A proportion (1-d) of the diet will be pasture

r = proportional reduction in $EFCH_4$ for non-pasture forage

Equation 1a can be simplified to give

$$E = EFCH_4\,(1 - adr) \qquad \text{Equation 1b}$$

e.g. using an $EFCH_4$ of 21.6 and 100% pasture (the default for the inventory), total enteric emissions (per unit of dry matter intake) is calculated as (equation 1b with a=0)

$$E_{default} = EFCH_4\ (= 21.6)$$

Expressing E as a fraction of $E_{default}$ allows the calculation of the proportion of total enteric CH_4 emissions for a given adoption rate (a), reduction in $EFCH_4$ (r), and where adopters feed a proportion (d) of the diet as low GHG feed

$$v^* = E/E_{default}$$
$$= 1 - adr$$

Hence the proportional reduction (v) in enteric CH_4 emissions is given by

$$v = 1 - E/E_{default}$$
$$= 1 - v^*$$
$$= adr \qquad \text{Equation 2}$$

e.g. for a low GHG feed with adoption rate of 20% (a=0.2), adopters using 20% (d=0.2) of the non-pasture forage in their diets (80% of diet is still pasture), and an expected reduction in EF for enteric CH_4 of 25% (r=0.25), a reduction in enteric CH_4 emissions of

$$v = 0.2 \times 0.2 \times 0.25$$
$$= 0.01 \text{ i.e. } 1\%$$

1% could be expected.

For given values of d and r, and with a ≤ 1 (maximum adoption rate of 100%), this gives us the maximum proportional reduction in enteric CH_4 emissions as

$$v \leq dr$$

e.g. for d=0.25, r=0.2, an adoption rate of 100% (a=1) means the maximum possible overall reduction in enteric CH_4 emissions is 0.25 x 0.2 = 0.05 i.e. 5%.

Equation 2 can be rearranged to calculate the required reduction in $EFCH_4$ for a given adoption rate and level of feeding (d), and target total reduction in enteric CH_4 emissions (Table 2.3.2.1) e.g. with an adoption rate of 20% (a=0.2) and diet proportion of 20% (d=0.2), to achieve a 1% reduction in total enteric CH_4 emissions would require a 25% reduction in the $EFCH_4$ for the low GHG feed. The importance of adoption rate is seen in the first row that shows a reduction in $EFCH_4$ of at least 100% is required to achieve a 4% reduction in total enteric CH_4 emissions. This can be interpreted as meaning the target reduction in total enteric CH_4 emissions is not achievable with such a low adoption rate. Table 2.3.2.2 is a rearrangement of Table 2.3.2.1 to show required adoption rates. Due to the symmetry of the variables a and r in equation 2, the numerical values in these tables are the same.

Table 2.3.2.1. Effect of adoption rate and targetted reduction in total enteric CH_4 emissions on the required reduction(%) in $EFCH_4$ for non-pasture forages. Adopters are assumed to feed 20% of non-pasture forage as part of overall diet.

Required reduction (%) in $EFCH_4$ (d = 20%)				
	Target reduction in total enteric CH_4 emissions			
Uptake rate	**1%**	**2%**	**3%**	**4%**
20%	25%	50%	75%	100%
40%	13%	25%	38%	50%
60%	8%	17%	25%	33%

Table 2.3.2.2. Effect of reduction in $EFCH_4$ and targeted reduction in total enteric CH_4 emissions on the required adoption rate (%) of non-pasture forages. Adopters are assumed to feed 20% of non-pasture forage as part of overall diet.

Required adoption rate (%) for non-pasture forage (d = 20%)				
	Target reduction in total enteric CH_4 emissions			
Reduction in $EFCH_4$ (%)	**1%**	**2%**	**3%**	**4%**
20%	25%	50%	75%	100%
40%	13%	25%	38%	50%
60%	8%	17%	25%	33%

2.4.3 Urease inhibitors

The 2016 NIR (MfE, 2016) provides full data for the use of urease treated urea fertiliser, including adoption rate (19.3%). This allows an exact calculation of the expected mitigation using urease inhibitor treated urea fertiliser (MfE, 2016).

The amount of carbon dioxide equivalent emissions (CO_2-e) from N volatilisation is calculated as

$$V = UFrac_{GasF}EF_4(44/28)/10^6*298 \text{ (kt } CO_2\text{-e)} \qquad \text{Equation 3}$$

where

V = N volatilised (kt CO_2-e)

U = urea fertiliser applied (kg)

$Frac_{GasF}$ = fraction of total synthetic fertiliser emitted as NO_x or NH_3

= 0.1 for non-urease treated urea fertiliser

= 0.055 for urease treated urea fertiliser

Nb: the default value of $Frac_{GasF}$ is scaled by 0.55 for urease treated urea fertiliser

EF_4 = EF for indirect emissions from volatilising N

= 0.01

44/28 is a molecular conversion factor to convert N_2O-N emissions to N_2O emissions

with

p = proportion of non-urease treated urea fertiliser. Nb: adoption rate of urease treated urea fertiliser = 1-p

Following a similar calculation regime as used in §2.3.2, the percentage reduction in volatilised N can be calculated as

$$\% \text{ reduction} = 0.45(1-p) \qquad \text{Equation 4}$$

From the 2016 NIR, for 2014 the

total synthetic N fertiliser applied = 376890000 kg (§5.5.2, pg. 169)

proportion of urea fertiliser = 89% of all synthetic N fertiliser (§5.5.2, pg. 170)

adoption rate (1-p) = 19.3% (MfE (2016) Table 5.5.6, pg. 180)

so

U = 376890000 x 0.89

= 335455825 kg

Using Equation 4 gives (0.45 * 0.193) an estimated percentage reduction of 8.7% (13.6kt CO_2-e), consistent with long-hand calculation of the difference using equation 3.

3. GHG management options

A brief description of each option considered is given, with comments on likely changes required for incorporation into the inventory. This may include EF or fraction values, methodologies and AD, and an assessment of the availability of any required data. For reference, the likely adoption rates used by de Klein *et al*. (2012) are quoted if they were assessed for an option, as is the expected percentage reduction in overall emissions (if non-zero) based on the likely adoption rate. These adoption rates are given as the estimated percentage adoption over a 10 year period for dairy, sheep, beef and deer.

3.1 Key options

Four key options were identified at the workshop for consideration for inclusion in the inventory. They are consistent with research priorities of both the Pastoral Greenhouse Gas Research Consortium (PGgRc, 2016), and the New Zealand Greenhouse Gas Research Centre (NZAGRC 2016a and 2016b).

3.1.1 Inhibitors – nitrification (not DCD) and non-urease

These were identified as key options for inclusion in the inventory, with little change required for incorporation. Nitrification inhibitors were expected to reduce total emissions by 2%. To estimate their full effect, the inventory would need to us monthly EF and fraction values for Tier 1 N_{EX} calculations. This caveat applying to several other options was discussed. High expected adoption rates, and likely reductions in emissions from N_{EX} made the use of nitrification inhibitors (with or without urease) a recommended option for inclusion in the inventory. Land based inhibitors would affect emissions from fertiliser and urine patches, the latter a large source of N_2O emissions.

Their use in the inventory would require specification of a percentage reduction based on the type of inhibitor (EF_1 and EF_3 for nitrification, $Frac_{GasF}$ and $Frac_{GasM}$ for urease), and AD on the amount used. This could be implemented in a similar way to how DCD was incorporated (amount and area applied to, and total area) at the Tier 1 level. DCD was voluntarily withdrawn from sale in New Zealand in September 2012. Urease inhibitor use (Saggar *et al*., 2013) has been already incorporated into the inventory (MfE, 2014). Incorporation of other inhibitors would likely follow methods used to incorporate DCD and urease inhibitors.

Likely adoption rates: (nitrification inhibitors): 35,12,15,12 for dairy, sheep, beef and deer respectively (de Klein *et al*., 2012).

3.1.2 Vaccines and inhibitors

Vaccines and inhibitors (artificial) to reduce enteric CH_4 emissions were identified as a key option with a high potential for adoption due to ease of implementation on-farm. Incorporation in the inventory would require an adjusted CH_4 yield factor, possibly by species and class. They were expected to reduce total emissions by 1%. AD required could be how many animals (by species and class) were vaccinated and timing (monthly, if not used throughout the year). Effects on N_{EX} are unknown, and productivity effects on the animal may not be accounted for. Calculation of the inventory back to 1990 is expected to be achievable and it was expected the AD required would be available for future calculation requirements e.g. possibly from veterinary product sales. These area both areas of active research by PGgRc and NZAGRC. As the technologies are still in development, this influenced the assessment of likely adoption rates.

Likely adoption rates: 15,15,15,15 for dairy, sheep, beef and deer respectively (de Klein *et al*., 2012).

3.1.3 Animal selection

Breeding animals for low CH_4 emissions was one of the most promising options explored by de Klein *et al*. (2012), and is recommended for inclusion in the inventory.

This is an area of active research by PGgRc (2016) and NZAGRC (2016a). The expected moderate impact on CH_4 yield per unit of intake, combined with high expected adoption rates, was expected to achieve reductions in enteric CH_4 (4%) and total agricultural emissions (3%) (de Klein *et al*., 2012). This option is the subject of much international research e.g. Bell *et al*. (2012).

Incorporation into the inventory would require an adjustment to the CH_4 yield factor (by species) and AD on the proportion of animals with the better genetics. PGgRc have funded research on identification of a genetic marker to help assess the heritability of the trait. Heritability for the national flock could then be calculated knowing the number of sires with the trait, and the proportion of animals slaughtered having the marker. This could be a challenge to calculate, but when completed, would be straightforward to include in the inventory. It was suggested that a “methane worth” of animals could be established, similar to the “breeding worth” for dairy cows (LIC and Dairy NZ, 2015). While this information may be some years away, it has the advantage that the effect of this option is expected to be permanent, and easy to implement on-farm given the widespread acceptance of breeding worth, particularly in the dairy industry (DairyNZ, 2015).

Likely adoption rates: 35,30,10,30 for dairy, sheep, beef and deer respectively (de Klein *et al*., 2012).

3.1.4 Low GHG feeds

The inventory currently assumes all Tier 2 species are fully grazed on pasture. This may no longer be valid for milking dairy cows based on the DairyNZ classification of dairy farms into five production systems that show only 5-10% of owner-operator herds grazing only pasture (DairyNZ, 2015). This observation also applies to feeding of supplements (§3.2.1).

A low GHG feed option would involve use of non-pasture feeds bred for low GHG emissions to meet a proportion of animal intake requirements. Possible feeds include some brassicas (Sun *et al*., 2012), forage crops (e.g. fodder beet), and some improved pastures. Incorporation in the inventory would require an adjusted CH_4 yield factor, while AD requirements would include the %DMI from the low GHG feed, and feed properties (ME, %N, and digestibility) which are likely to be seasonal. It is possible the information on feed properties could come from current research activities by PGgRc (2016) and NZAGRC (2016a). Effects on N_2O EFs are unknown, and may be influenced (for example) by soil type. It was suggested this option could be implemented as a lookup table similar to how changes to the Tier 2 methodology for deer were implemented (MfE, 2013). It is possible that the AD required could be sourced from seed sales (as forage crops are grown from seed), but this may have similar commercial sensitivity issues to sourcing AD for fertiliser sales.

3.2 Other options

The following options were considered at the workshop and assessed as lower priority for inclusion in the inventory based on the factors considered i.e. activity data, likely adoption rates, available methodology and ease of inclusion in current inventory structure.

3.2.1 Supplements

Incorporation of supplements (including feed additives) into the inventory would face the difficulty of getting accurate AD on seed sales and supplement use, analogous to getting fertiliser information (§3.2.6). The AD required would be the amount of supplements fed, with possibly animal classes and timing information, and properties (ME, %N, and digestibility). The annual DairyNZ Economic Survey (DairyNZ, 2015) breaks dairy farms into 5 categories based on levels of year round supplementary feeding for milking cows only, but this information is not available for other Tier 2 species, or replacement animals. While use of supplements is common in the dairy industry (DairyNZ, 2015) AD on actual usage can be difficult to obtain (MPI, 2012).

3.2.2 Housing animals

In NZ, housing animals would typically be a temporary measure, except possibly for dairy goats (§3.2.12). For Tier 2 species, AD required would be the number of animals housed (off pasture), their productivity and diet received while housed. The diet could be treated in a similar manner to the requirements of feeding low GHG feeds (§3.1.4). Additional requirements would be knowing how animal waste was treated, and CH_4 yield from the waste. It was suggested that more ammonia (NH_4) would be volatilised. Changes in $Frac_{GasM}$ would need to be known, and will depend on the type of system and bedding used. Housed animals are incorporated in the British inventory structure. It was suggested that this could be used as a model of how to incorporate this option in the NZ inventory structure, if this option is pursued. As animal health issues can be associated with housed animals, a possible source of AD could be veterinary services.

3.2.3 Methane capture

Effluent storage ponds can be covered to capture CH_4, which may be recovered as energy, or burnt ("flamed"). Changes required in the inventory would be the specification of, a percentage reduction in the amount of CH_4 emitted from effluent ponds, the percentage of ponds covered, and how much (and for how long) waste was stored. This is similar to how urease inhibitors are handled. Participants were unsure how the required AD would be obtained. This may be covered in a question in the Agricultural Production Survey by Statistics NZ, or possibly obtained using the proxy of product sales (e.g. pond covers).

3.2.4 Grinding forage

Grinding forage to smaller particle sizes for animal diets would increase the passage rate. This option was regarded as similar to using low GHG feeds (§3.1.4), with similar methodology changes required. It was suggested this could result in a 13% reduction of CH_4 yield compared to grazing a white clover ryegrass pasture. A question was raised as to whether we have knowledge of CH_4 yields for animals getting close to voluntary intake, which may be the case for animals consuming ground forage. This option was assessed as having likely adoption rates of zero for all species.

3.2.5 Breeding for high feed conversion efficiency

This involves breeding animals that are more efficient in terms of using DMI and N. Animals with higher feed conversion efficiency (FCE) use less energy for maintenance, while animals that are more efficient at using N result in less emissions from N_{EX} losses e.g. dung, urine, and leaching. Incorporation in the inventory would require an adjustment for the ME requirements calculation (as less DMI would be required to meet a given ME requirement) but this is predicated on understanding the effect. It is possible that this information could be obtained from a more detailed analysis of current data (which would need to be identified). This option would likely result in less N_2O emissions due to a lower amount of N_{EX} as more N is routed to animal product.

3.2.6 Variable rate and placement of nitrogen fertiliser

Variable application rate and placement (to avoid urine patches) of nitrogen fertiliser would require a change to EF_1 and changes to $Frac_{Leach}$ and $Frac_{GasF}$. De Klein *et al*. (2012) reported an expected reduction in these (EF_1, $Frac_{Leach}$ and $Frac_{GasF}$) of 40%. Activity data required would be the percentage of total nitrogen applied that follows best practice for variable rate application. Extensions could include specification of EFs for different fertilisers, the amount of each fertiliser applied, and the potential to specify these by stock class. It might be possible to estimate some of the required AD from industry sources e.g. Fertiliser Association of New Zealand (FANZ), and the Fertiliser Council, with the caveat that the fertiliser information currently in the inventory is only supplied as an annual national total, and was difficult to obtain due to commercial sensitivities. The level of detail required might move the inventory too far away from the national average level it was intended to operate at. This option was expected to have a good uptake rate, but as its effects are limited to N input from fertiliser at certain times of the year (much less than N input to soils from urine), the overall impact on N_2O and total emissions was expected to be low. This is another option where to realise its full effect in the inventory would require Tier1 emissions to be calculated using monthly EFs and fractions to reflect the impact of timing of application.

Likely adoption rates: 25,12,15,12 for dairy, sheep, beef and deer respectively (de Klein *et al*., 2012).

3.2.7 Irrigation

A separate MPI project is assessing incorporation of irrigation into the inventory, led by Plant and Food Research. This is likely to require regional information on the amount and timing of irrigation, N_{EX}, and the effects on EF_1 and EF_3, little of which is readily available. Current inventory calculations use an average calculation for leaching, with $Frac_{Leach}$ (7%) based on Thomas *et al*. (2005).

3.2.8 Fertigation

The practice of applying of fertiliser with irrigation ("fertigation") would have similar requirements to irrigation. Implementation in the inventory would require additional fertiliser data, and information on the effects on EF_1 and EF_3, and N_{EX}, which are currently unknown. This practice is suited to precision irrigation, but has limited uptake in New Zealand, and was thought likely to be limited to existing irrigation systems, with little expected effect on total emissions.

3.2.9 Gibberellic acid

Gibberellic acid (GA) is a plant growth promoter, naturally produced by plants in warmer weather, and is applied by some farmers in cooler months. Some studies (e.g. Matthew *et al*. 2009) suggest it is best applied with N fertiliser, but there are conflicting studies on its effectiveness. It's possible that the use of GA as an alternative to N fertiliser could have the effect of reducing N_2O emissions and nitrate leaching, particularly from N excreted in urine (Whitehead and Edwards, 2015). Incorporation into the inventory would require knowledge of changes to EF_1, EF_3 and $Frac_{Leach}$, the quantity sold, recommended application rate and area applied, and timing of application. This is similar to the requirements for dicyandiamide (DCD) which is already implemented in the inventory. Workshop discussion indicated mixed views on its effect on emission factors, and also questioned unknown interactions e.g. those affecting the level of N (and carbon) in the soil.

3.2.10 Pasture quality

Current inventory methodology assumes all Tier 2 animals are fully fed by grazing pasture. It was suggested that genetic modification (GM) can potentially change any pasture property. Concern was raised about the quality of the pasture metabolisable energy (ME) values currently used in the inventory (see also §5.3). Updated ME (or nitrogen (N) content) values can readily be incorporated into the inventory. This may require changes to disaggregate the pasture quality information, likely by species and class. The required activity data could include the percentage of pasture fed that has a higher ME or lower N content. It was not known how this could be obtained.

Changes made to the deer model (MfE, 2013) present deer with pasture ME, %N and digestibility values that are a weighted combination of values from dairy, sheep and beef pastures. Other Tier 2 stock could be fed pasture that was a mix of ME values in a similar way to the method now used for deer.

A combination of higher ME and low N pastures (no excess animal N intake) and an option (§3.3.2) to increase N partitioned to dung may make it possible to control partitioning of carbon (C) and N.

3.2.10.1 *Pasture with higher ME content*

Pasture with higher ME content would lower the DMI required to meet animal energy requirements, with consequent reduction in CH_4 emissions. Incorporating this in the inventory would require disaggregation of the ME content of animal feed (pasture), and the proportion of pasture that has higher ME. It would possibly also require disaggregation of species and classes, as not all would be fed the higher quality pasture. Use of higher ME pastures may allow animals to be finished earlier (see §3.2.11).

3.2.10.2 *Pasture with lower N content*

Feeding animals on pasture with lower N content would affect N_2O emissions, and would need changes similar to higher ME pasture for incorporation into the inventory.

3.2.11 Finishing animals, especially lambs, faster

Better genetics means lambs can reach slaughter weights faster, which would likely result in lower emissions as they spend less time grazing pasture. Published research focuses on breeding for performance with little reference to GHG emissions e.g. Kenyon *et al*. (2014).

Incorporation into the inventory could be a big job, likely requiring several changes:

a) More than one birth date, and use regional averages,
b) Number of lambs (regional),
c) Disaggregation of slaughter dates e.g. monthly average. These would need to be reconciled with lamb numbers and birth dates to assess animal age, which would need to be more precise.

It is possible this could be incorporated as a lookup table, but getting the required information back to 1990 would be a challenge. This option was not considered by de Klein *et al*. (2012).

3.2.12 Land use change – dairy sheep and dairy goats

Dairy sheep and dairy goats are two alternative land use systems that would likely result in lower GHG emissions than from dairy cows. This is because the feed conversion efficiency (FCE) of goats is greater than dairy cows, which is in turn is greater than sheep. Dairy goats would likely be housed which would lower their GHG emissions. Peterson and Prichard (2015) provide an overview of the current state of the NZ dairy sheep industry (currently there are only two sheep milk processors of any size) and reflect on its status since starting in the early 1990s. Anticipated to grow over the next 10 years, they caution that growth anticipated in the early 1990s didn't eventuate. Workshop opinion was that while neither industry is currently regarded as sufficiently developed for inclusion in the inventory, both warrant watching closely over the next 10 years.

Goats are currently only included in Tier 1 inventory calculations. Including dairy goats or sheep in the inventory would require adding a new Tier 2 species (for goats) or species class (for sheep). The inventory software reporting would need to be extended to include any changes to species or class information. While production of milk for raising lambs is already accounted for in the inventory, this would need to be increased if dairy sheep were included for commercial milk production. The change from production for meat to production for milk would likely increase emissions, and require activity data for the number of sheep used for milk production, and the amount of commercial milk production. Knowledge of differences in efficiency of converting feed between sheep for lamb production and dairy sheep would also be needed.

3.2.13 Biofilters

Biofiltration is a biological process to treat volatile organic and inorganic compounds. In agriculture, biofilters act through naturally occurring bacteria (methanotrophs) converting CH_4 to the less potent CO_2, and has the advantage of not producing N_2O during that process. Volcanic pumice soil has been demonstrated to be an effective biofilter material, but has limited availability. System interactions mean emissions (e.g. N_2O) may increase elsewhere.

3.3 Options discussed but not pursued at workshop

3.3.1 Ammonia capture

Comparable to the use of bio-filters (§3.2.13), required AD would likely be the percentage of farms using systems to capture ammonia (NH_4).

3.3.2 Increased Nitrogen partitioned to dung

This may be achieved by animals receiving some form of future intervention. Changes required in the inventory may include adjusting the digestibility N_{EX} factor, or the partitioning of N_{EX} to dung and urine. AD required would be the percentage of the population receiving the intervention.

3.3.3 Early life intervention

The possibility of early life interventions, e.g. vaccinations, may change the rumen development and could require an adjustment of the CH_4 yield factor. Required AD would be the percentage of the population receiving the intervention, and the CH_4 yield factor for those animals.

3.3.4 Healthier animals

Healthier animals could be treated as animals with an adjusted FCE (§3.2.5) and/or grazing high ME pastures (§3.2.10.1). AD required would be the proportion of the population that was "healthier", and would be straightforward to implement in the inventory if the AD was available.

4. Changes required to inventory structure and software

The inventory is calculated using a mix of Tier 2 (for beef, dairy, deer and sheep) and Tier 1 approaches. Some outputs from the Tier 2 calculations (e.g. total CH_4 and total N_{EX}) are used as inputs for the Tier 1 model, which completes the calculation of total emissions using annual EF and fraction values. The Tier 1 totals are used for submission to the UNFCCC via MfE. Several options would require extensions to the reporting of calculations if implemented in the inventory e.g. §3.2.12.

4.1 Emission factors and fraction values

Management options that can be specified as changes in annual EF or fraction values can be incorporated without change to the inventory software. The Tier 2 model already allows specification of monthly N_2O EFs and fractions for each species, for urine and dung (Rollo and Kelliher 2010). Several of the management options discussed during the workshop (e.g. irrigation, precise fertiliser application) could require seasonal or monthly specification of EF and/or fraction values to be used for Tier 1 calculations.

Incorporating these into the existing Tier 2 inventory would extend what is already in place for urine and dung, and extension to use regional values is feasible. Monthly and regional EF and fraction values could help improve the accuracy of the inventory, if these become available. The biggest challenge is credible evidence to change from using constant (annual) EFs. Proposed changes should take into account current EF and fraction values (Appendix 3).

4.2 Methodology

Some management options would require methodological changes, and for some, the structure doesn't currently explicitly exist in the software to allow its incorporation. The flexibility of the software means it could readily be adapted for some options, e.g. land use change (§3.2.12), which would likely require specification of temporal population models.

A change to the current Tier 1 N_{EX} calculations would be required to see the full effect of incorporating options requiring monthly EFs and fractions (de Klein *et al*. 2012). These currently apply annual EF and fraction values and override the disaggregation that occurs in the Tier 2 N_{EX} calculations, which require monthly EF and fraction values. The changes required to the structure to allow use of monthly EF and fraction values for Tier 1 N_{EX} calculations could be made immediately, before the monthly values are available.

4.3 Activity data

For options requiring methodological changes or revised AD, the availability of suitable AD is the likely to be the biggest challenge. The AD needs to be available to allow recalculation of the inventory from 1990 (IPCC, 2006), and be expected to be available in the future. Relevant population and performance data for the existing model are available, but sourcing other AD can be a challenge e.g. MPI (2012).

5. Other considerations

5.1 Applying multiple management options

The study by de Klein *et al*. (2012) was limited to applying each mitigation technology one at a time. The effect of applying multiple GHG management options simultaneously was discussed in the workshop, and may require science to answer. This might be an adjustment factor for the combined effect if two or more options were applied simultaneously, and the percentage of the population receiving the multiple interventions.

Hristov *et al*. (2013) addressed the topic of interactions among multiple GHG management options at the farm level and states that while the effect of interactions is likely to be unknown, their effect is unlikely to be additive. For example, Eckard *et al*. (2010) compared hypothetical emissions from a dairy farm, estimating reductions in GHG emissions of 40% using a cumulative reduction of mitigation practices, compared with a reduction of 91% when the practices were considered to be mutually exclusive or additive.

5.2 Data considerations

A question was raised (§3.1.4) if there was better information available on pasture ME, and the conversion of DMI to enteric CH_4. Recent NZ research examining the production of enteric CH_4 from pasture shows that DMI is still the strongest predictor of enteric CH_4 production. An analysis of recent Australian pasture ME data by Charley *et al*. (2015) has shown the potential benefit of using an up to date data set. Using the pasture ME from their recent data set (< 10 years old), estimates of emissions from forage fed cattle are reduced by 24% in the Australian GHG inventory (Charmley *et al*., 2015).

One of six "cross-cutting" opportunity identified in the 2012 Farm Animal Integrated Research (FAIR) report (FASS, 2012) was the value of data-mining "to understand what is already known, to prevent unnecessary duplication, and to provide a better base on which to build future research". Data-mining uses improved computational and/or statistical analysis techniques to extract useful information from datasets e.g. Kelliher *et al*. (2014).

5.3 Nutrient cycle effects on farm

The management options considered are farm management options. Their use on farms to mitigate GHG emissions may alter other aspects of the nutrient cycle e.g. an option used to mitigate N_2O loss may cause an increase in NH_3 volatilisation or N leaching.

6. Summary and recommendations

6.1 Key GHG management options

Four key GHG management options were identified (§3.1) to be considered for inclusion in the inventory, based on expert opinion of their: assessed potential to reduce targeted emissions (e.g. enteric CH_4 emission factor), likelihood of adoption, anticipated overall impact on emissions, likely time horizon, and ability to incorporate the option into the existing inventory methodology. The four key management options are:

a) Inhibitors (natural) e.g. nitrification (not DCD) and non-urease (§3.1.1),
b) Inhibitors (artificial) and vaccines (§3.1.2),
c) Animal selection (§3.1.3),
d) Low GHG feeds (§3.1.4).

6.2 Suggested next steps

Collate results from current research activities supporting the key options identified (§6.1) to get a better estimate of their likely timeframe and help decisions to recommend their inclusion in the inventory.

The current inventory methodology would be improved by changing the existing Tier 1 N_{EX} calculations to use monthly EF and fraction values, as used for Tier 2 N_{EX} calculations. Monthly EF and fraction values are a likely requirement for several of the options considered. This could be implemented in the inventory software before credible data becomes available.

Sourcing the AD suggested for many options seems to be a challenge, potentially compromising their inclusion in the inventory. It could be useful to attempt to source anticipated AD required by one of the options (other than irrigation, §3.2.7) e.g. supplements for milking dairy cows, given the information on farms in each of DairyNZ's five classes of production systems (DairyNZ, 2015).

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8. Appendix 1 – Workshop participants

Table 8.1. Workshop participants - scientific, industry, farm systems and policy experts.

Name	Organisation	Expertise
Cecile de Klein	AgResearch	Scientific
Frank Kelliher	AgResearch	Scientific
David Pacheco	AgResearch	Scientific
Robyn Dynes	AgResearch	Scientific, farm systems
Mike Rollo	AgResearch	Scientific; Inventory software developer
Surinder Saggar	Landcare Research	Scientific
Mark Aspin	PGgRc[1]	Industry, farm systems
Greg Lambert	Private consultant	Industry, farm systems
Joel Gibbs[2]	MPI (observer)	Policy

[1] Pastoral Greenhouse Gas Research Consortium
[2] Inventory compiler

Apologies were received from James Fick (MPI) and Steve Thomas (Plant & Food Research). Steve contributed an outline of ideas for irrigation and some other options prior to the workshop.

9. Appendix 2 – Mitigation technologies assessed by de Klein *et al*. (2012)

Table 9.1. Mitigation (N_2O and CH_4) technologies assessed by de Klein et al. (2012).

Nitrous oxide (N2O) mitigation options	Methane (CH4) mitigation options
1. Animal supplementation DCD (12 months)	16. Rumen defaunation
2. Combined DCD and urease inhibitor (5 months)	17. Manipulation of feeding frequency
3. DCD applied to land (5 months)	18. Grinding forages
4. Animal supplementation DCD (5 months)	19. Animal selection for low methane
5. Double inhibitor fertiliser (12months)	20. Increase dietary fat
6. Urease inhibitors	21. Organic acids supplementation
7. Low protein/high sugar feed	22. Essential oil supplementation
8. Replacing grass silage with cereal silage	23. Fibrolytic enzymes supplementation
9. Increase concentrate in the diet	24. Monensin supplementation
10. Salt supplementation	25. Lower replacement rates
11. Improve N conversion efficiency in rumen	26. Use of yeast additives
12. Condensed tannin extract in diet	27. Increase feeding > maintenance
13. Restricted grazing during wet conditions	28. Small molecule inhibitors
14. Control timing and place of fertiliser	29. Anti-methanogen vaccine
15. Improve drainage of pasture soil	30. Feeding nitrate-containing diets

10. Appendix 3 – Recent changes to EF and fraction values in the inventory

Improvements in the inventory methodology can result from meta-analysis of research trials e.g. Kelliher *et al*. (2014) for EF_1-urea, or specific research e.g. Saggar *et al*. (2013) for $Frac_{GasF-UI}$. Proposed changes to EF and fraction values should note recent changes:

a) EF_1-urea (direct N_2O EF for urea N fertiliser applied to soils) from 0.01 to 0.0048. MfE (2015), Table A3.1.2.3, page 424,

b) EF_5 (indirect N_2O EF for N_{EX} and fertiliser which leach beyond soils) was reduced from 0.025 to 0.0075. MfE (2015), Table A3.1.2.3, page 424,

c) $Frac_{GasF-UI}$ (volatilisation of synthetic fertiliser including urease inhibitor (nBTPT) added as 0.045, implemented as a scalar (0.55). MfE (2015), Table 5.5.4, page 163.

11. Appendix 4 – Glossary

Table 11.1. Terms and abbreviations used in this report.

Term or abbreviation	Abbreviation for
AD	Activity data
CH_4	Methane. For the agriculture inventory, enteric or from animal waste
CO2-e	Carbon dioxide equivalent emissions
Data-mining	Computational and/or statistical techniques to help identify information in data sets
DCD	Dicyandiamide, a nitrification inhibitor
EF	Emission factor
Emission intensity	Emission per unit of product
Feed conversion efficiency (FCE)	Efficiency of use of feed for maintenance or production (milk, meat etc.)
$Frac_{GasF}$	fraction of total N fertiliser emitted as NH_3
$Frac_{GasM}$	fraction of total N from, animal manure and urine emitted as NH_3
GHG	Greenhouse Gas
GPG	IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Inhibitor	Reduces production of a GHG
Inventory	Estimation of national agricultural GHG emissions
IPCC	Intergovernmental Panel on Climate Change
kt	kilo tonnes (of emissions)
MfE	Ministry for the Environment
N	Nitrogen
N_2O	Nitrous oxide
N_{EX}	Nitrogen excreted (as urine and dung)
nBTPT	N-(n-butyl) thiophosphoric triamide, a urease inhibitor
NIR	National Inventory Report
NZAGRC	New Zealand Agricultural Greenhouse Gas Research Centre
PGgRc	Pastoral Greenhouse Gas Research Consortium
the inventory	NZ's Agricultural GHG Inventory

Term or abbreviation	Abbreviation for
Tier 1	Emissions estimated using GPG default methods and EFs
Tier 2	Emissions estimated using country specific methodologies and EFs
UNFCCC	United Nations Framework Convention on Climate Change