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METHODOLOGIES FOR GREENHOUSE GAS REPORTING AND IMPLICATIONS FOR FARMER INPUT REQUIREMENTS

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Abstract
He Waka Eke Noa is a partnership between primary sector bodies, Government, and Māori, to measure, manage and collectively reduce agricultural greenhouse gas (GHG) emissions, and recognise on-farm sequestration. The partnership is supported by technical expertise from research organisations. One of the aims of He Waka Eke Noa is to build a system for farmers and growers to calculate farm-scale GHG emissions. This system will be part of a pricing mechanism and will need to be available to farmers and growers by 2025.

Through discussions with farmers, industry representatives, agri-tech companies and members of the He Waka Eke Noa Emissions Reporting working group, two farm input methods have been developed for the emissions reporting system: 'simple' and 'detailed'. The methods are trying to achieve a balance between limiting input requirements (to minimise complexity) and providing enough detail so farmers can be rewarded for any on-farm efficiencies or adopted mitigation practices. The simple method is focusing more on minimising complexity, but the range of GHG mitigations captured is relatively small. The detailed method aims to captures more mitigations and, as a result, requires more inputs. The detailed method is only applicable to livestock farms; there is no difference between the simple and detailed methods for fruit and vegetable growers with no livestock.

The simple method applies industry averages for liveweight and age distribution to stock classes and combines these with actual farm production data. For livestock farms, the method requires four types of farm information: farm area, stock reconciliation, animal production, and synthetic fertiliser use. For hill country farms, slope class is included as an option if farmers want to be recognised for lower nitrous oxide emissions from medium and steep sloping land. Fruit and vegetable growers only require farm area and synthetic fertiliser type; fertiliser application method can be included but is not essential. Examples of mitigations included in the simple method are genetically-selected low methane sheep, reduced nitrogen (N) fertiliser use and N fertiliser incorporation.

The detailed method requires data relating to up to ten types of farm information and uses this data to determine energy and dry matter requirements for different stock classes at specific times of the year, based on body weights, animal reproduction data, farm production data and forage types. This gives a more accurate estimate of enteric methane and nitrous oxide emissions. The method allows businesses to capture the emissions reduction options offered in the simple method, plus additional mitigations and on-farm efficiencies (e.g. use of low GHG forages, low N supplements, high genetic merit livestock).

Background
It is in the interest of all agricultural sectors, government and iwi, that reporting of agricultural greenhouse gas (GHG) emissions by farmers is as simple but as accurate as possible. To provide farmers and growers with a choice for farm-level GHG emission reporting, two methods have been developed: 'simple' and 'detailed'. The methods aim to achieve a balance between limiting input requirements (to minimise complexity) and providing enough detail so farmers can be rewarded for any on-farm efficiencies or adopted mitigation practices. This paper provides a summary of the report on method specifications provided to He Waka Eke Noa (van der Weerden et al. 2021), which is available on-line: https://hewakaekenoa.nz/wp-content/uploads/2022/02/FINAL-He-Waka-Eke-Noa-Farmer-inputs-and-verification-report.pdf.

As part of the method development, we outlined the input information required to calculate the GHG emissions from each key source. We aligned current and future GHG mitigation options with each key source and ensured required inputs were able to capture these mitigation options. The New Zealand agricultural GHG inventory provided a useful reference point for developing the input specifications for the two methods, as it can be considered as a simple method for livestock-based emissions (Fig. 1).

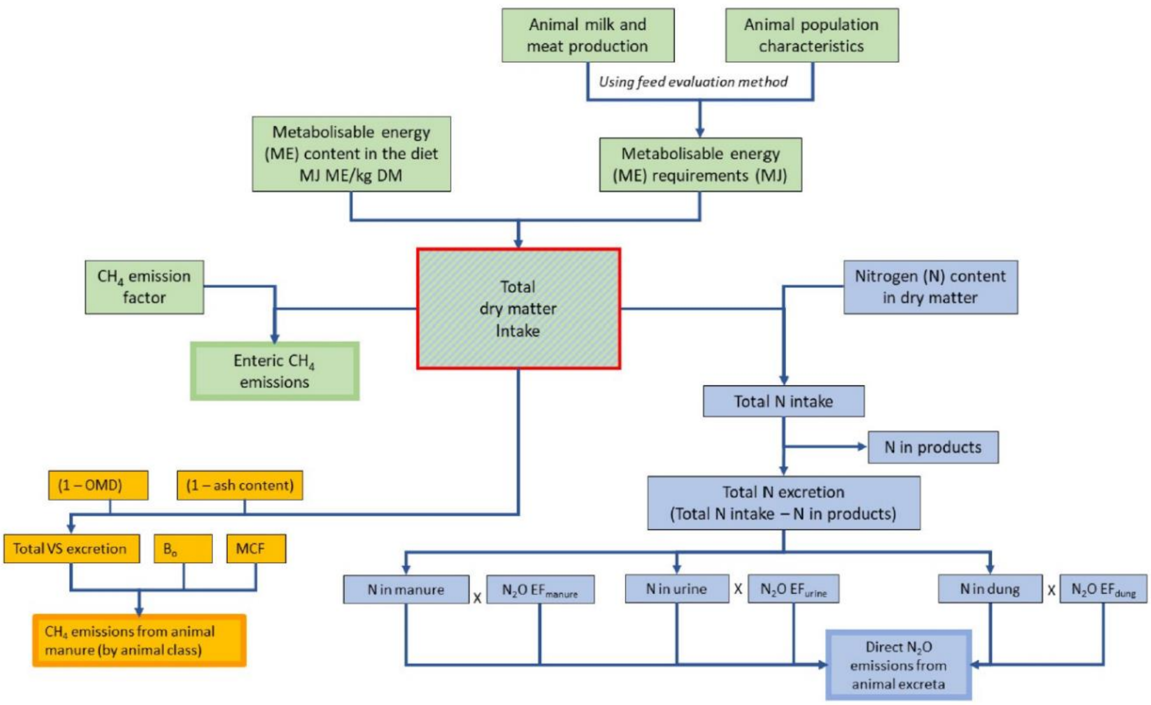

Figure 1. Schematic overview of the approach adopted by the New Zealand agricultural greenhouse gas inventory for estimating methane (CH_4) and nitrous oxide (N_2O) emissions from livestock production systems. Green boxes refer to enteric CH_4, orange boxes to manure CH_4, and blue boxes to N_2O. ME=metabolisable energy; MJ=mega joules; OMD=organic matter digestibility; VS=volatile solids; B_0=maximum CH_4 producing capacity of manure; MCF=CH_4 conversion factor; EF=emission factor. The efficiency of use of feed energy and protein modulate these fluxes. (source: Vibart et al. 2021).

Both the simple and detailed methods for calculating GHG emissions require a definition of the farm boundary. Based on discussions within He Waka Eke Noa, the farm boundary includes on-farm emissions from livestock and synthetic N fertiliser use, but excludes emissions associated with the production of bought-in supplements. Livestock emissions include enteric methane (CH_4) from ruminants, nitrous oxide (N_2O) from urine and dung deposited during grazing and land application of manure, and CH_4 and N_2O emissions from manure storage. Nitrous oxide can be emitted directly from N sources such as urine and N fertiliser, as well as indirectly via losses of N to water and ammonia emissions. Both direct and indirect N_2O emissions are included in the He Waka Eke Noa GHG reporting.

Simple Method

The simple method represents a basic method for estimating farm-scale GHG emissions. It was designed to require minimal inputs, however for livestock farms its simple structure means there is limited flexibility when attempting to represent farming practices that influence GHG emissions. This can lead to a less accurate GHG estimate with fewer mitigations able to be captured when compared with the detailed method. For many GHG sources, this method often aligns with New Zealand's agricultural inventory methodology (MfE, 2021).

The method applies industry-average liveweights to different stock classes and combines these with actual farm production data. For livestock farmers, inputs (Table 1) are limited to:

- farm area
- stock numbers and time on farm, split by stock class
- total synthetic nitrogen fertiliser used, split by type and tonnage,
- animal production data

Stock classes and breeds rely on default industry-average liveweights which are used for estimating annual energy consumption and therefore dry matter intake (DMI). This method assumes a single default forage type (pasture), with default feed quality and N content, where the latter is used for estimating urine and dung excretion.

Fruit and vegetable growers will require only two of these types of information: farm area and synthetic nitrogen fertiliser used.

Farm area
Area of farm will be required for calculating GHG emissions per hectare. 'Area' could relate to total or effective area; the definition has still to be determined at time of writing. If effective area is required, there will be a cost for some farms if a GPS map is required to determine the area of all the legal titles (total area) and area in pasture or crops (effective area).

Stock reconciliation split by stock class
Most if not all livestock farmers will have data on livestock numbers per class of animal, as this information is required for farm accounts and annual submission to the Inland Revenue Department as livestock reconciliations. For livestock on farm for less than 12 months, farmers will be required to include date of farm entry for mobs purchased and sales to allow a calculation of weighted annual averages. For red meat, stock sales and purchases, as well as kill sheets from meat processing companies will also provide information on timing and number of livestock slaughtered. Dairy farmers will be required to select the animal breed to determine average annual liveweights – six breed/crossbreed options have been proposed. Weights of replacements will not be required as these can be based on herd genetics. The time replacements are on farm may also need to be recorded if the responsibility for GHG emissions lies with the landowner. The GHG emissions from replacements can then be estimated using default energy requirements. For any breeds not included in a GHG emissions reporting system, farmers will need to select a proxy from one of three Jersey/Friesian crossbred options. Default pasture quality data (ME, N content) will be required to determine DM and N intake by grazing livestock.

Synthetic N fertiliser by type

Annual synthetic N fertiliser data is readily available through annual farm accounts and fertiliser suppliers. Synthetic N fertiliser will need to be split into standard urea, urease-inhibitor treated urea, and non-urea N fertiliser, due to different N emissions from each category. The recent N fertiliser cap for pastoral farms requires reporting of annual synthetic N fertiliser usage, this could be used for the GHG emission calculations. To simplify the data collation process for farmers, fertiliser companies could provide data on the amount of N sold to farmers on the basis of standard urea, urease-inhibitor treated urea, and non-urea N fertiliser.

Milk, meat, wool and velvet production per animal type and class

Production data is available from processors, stock sales records, grazing contracts and tax returns: this could be used as a data source. Livestock which increase in weight but are not sold or finished within a financial year will be counted in a livestock reconciliation, with industry average weight changes used for estimating energy requirements. However, wool is a product that can be carried over from one year to the next, which suggests there may be some error within a single year.

Optional inputs

The simple method includes two optional inputs (Table 1) that are not essential for calculating the GHG emissions but will help farmers and growers to be recognized for having lower emissions. The first relates to hill country farms, where urine deposited on steeper slopes generate lower N_2O emissions than on lower slopes. Recent research has shown that N_2O emissions from urine patches are lower from soils on steeper slopes compared to low slopes, and emission factors have been established for different slope classes for dairy and non-dairy cattle, sheep and deer (MfE, 2021). Farmers wanting to capture this slope class effect will require verified information on the proportion of the farm at different slopes (< 12°, 12 - 24°, > 24°). Farmers are unlikely to have information on slope classes across a farm, therefore this information may need to be purchased as a one-off cost from a suitable mapping company. Several fertiliser companies and farm management software companies can also provide this service.

The second option is whether N fertiliser is incorporated into soil at the time of application, which will reduce ammonia emissions from urea. This input is specific to cropping farmers and vegetable growers. It is unlikely that cropping farmers will maintain formal records on method of fertiliser application. However, this could be either sourced from own farm records or from information provided by contractors (e.g. type of drill used, such as Cross slot, where fertiliser is placed beneath the surface near the seed). If data is not available, the calculations assume synthetic fertiliser is surface applied.

Simple method mitigation options

Examples of mitigations included in the simple method (Fig. 2) are

- genetically-selected low methane sheep,
- reduced synthetic N fertiliser use,
- N fertiliser incorporation into soil following application (some farmers may already be practicing this, and so will have a slightly lower calculated GHG emissions).

Table 1: Farmer inputs requirements for simple GHG accounting method.

Method component	**Description of input**	**Comments**
Required inputs		
Farm area	Farm area	Required for determining GHG emissions per hectare. Total vs. effective area has yet to be determined by He Waka Eke Noa at the time of writing.
Livestock numbers	Stock reconciliation (animal numbers, time on farm, stock sales and purchases and stock deaths), split by stock class/breed[1]	The stock reconciliation requires the opening and closing numbers by stock class (e.g. hogget, two-tooth ewes, heifers R1), time on farm, weaning numbers, stock sales and purchases (numbers and weights), and stock deaths. Reproduction and liveweight gain will be derived from appropriate industry data[2]. For dairy, farmers will be required to select the animal breed to determine average annual liveweights. Farmers wishing to capture on-farm livestock efficiencies can use the Detailed method. GHG calculations will be required to determine weighted annual stock numbers using dates entering and exiting farm.
Fertiliser use	Total synthetic N (product tonnage) split into urea, non-urea, urea + urease inhibitor	
Animal production	Milk, meat, wool and velvet production per animal class[3]	
Optional inputs		
Topography	Area of farm in different slope classes (flat/low slope; medium; steep slopes)	Not essential; if not available, then assume flat/low slope. If available, GHG calculations must include modelling of nutrient transfer of urine-N from steep to lower slopes.
Fertiliser application method	Surface or incorporation	

[1] this requires knowing the number of livestock per class (sheep, beef and deer) or breed (dairy), including stock movements.
[2] sources for reproduction, liveweight gain and production data include Beef + Lamb New Zealand sheep and beef farm surveys and DairyNZ Facts and Figures. Methods of calculation (e.g. lambing/weaning percentages) should align with those used by industry bodies.
[3] Meat and wool production will be at lower granularity (e.g. meat from lambs, hoggets, mature ewes) compared to stock classes.

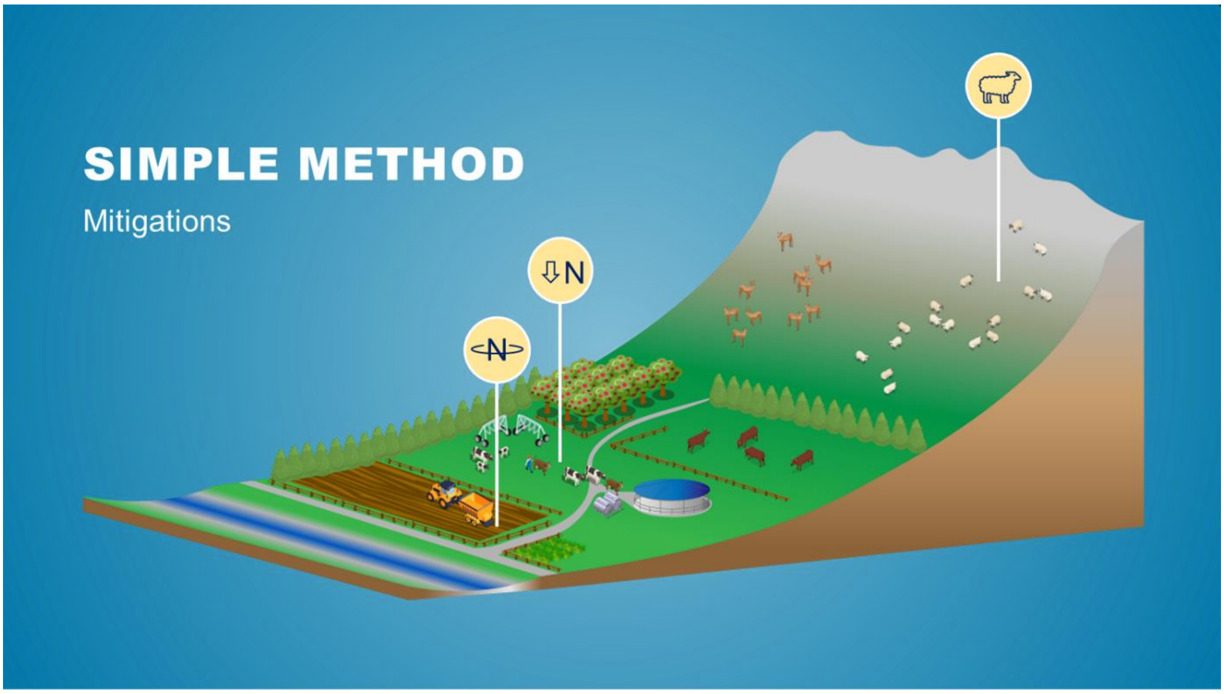

Figure 2. Mitigations available for farmers and growers adopting the simple method for calculating farm-level GHG emissions. From left to right: 1. N fertiliser incorporation into soil following application; 2. reduced nitrogen fertiliser use; 3. genetically-selected low methane sheep.

Detailed Method – farmer inputs

The detailed method allows substantial flexibility in livestock farming practices that influence GHG emissions and can capture more mitigation options compared to the simple method. For many GHG sources, this method often aligns with the more complex type of farm-scale GHG foot-printing models such as OverseerFM or FARMAX. For fruit and vegetable farms where no livestock is present, there is no difference between the simple and detailed methods as the only source of GHG emissions is synthetic N fertiliser use.

For livestock farms, this method will have the same inputs as the simple method (farm area, stock numbers and time on farm, synthetic N fertiliser use and production data), plus additional inputs (Table 2).

For dairying, additional inputs include:

- Animal liveweight and reproduction data
  - Average cow liveweight,
  - Number of dry cows and replacements,
  - Planned start of calving,
- Time and number of animals on off-paddock facilities,
- Feed type
  - Pastures and forage type and feed quality
  - Information on the start and end of grazing,
  - Type and amount of imported supplements, including the feeding method
- Effluent/slurry application method.

For sheep, beef and deer farms, the same four required inputs for the simple method, plus the following information:

- Animal liveweight and reproduction data

    - Average liveweight per stock class,
    - Planned start of mating,
    - Lamb, beef and deer weaning percentage,
    - Number of replacements retained post-weaning.
- Feed type
    - Pastures and forage type and feed quality
    - Information on the start and end of grazing, including stock type and number,

Animal liveweight and reproduction data
This data includes body weight of different livestock classes and age; planned start of mating; lamb, calf and fawn weaning percentage; number of replacements retained post-weaning, number of dry cows. Farmers will have most of these animal data on-hand at the stock class level, either captured in farm records or in farm management tools. Animal body weight values will be the most time-consuming data to obtain, but some farms will have weigh-scales to help measure this. For farms without weigh-scales, we propose to use default industry-average liveweights for each stock class. Given this will be less accurate than using actual data, it is recommended that farms achieving very high live weight gains would require weigh-scales to provide the most accurate data on body weight. Alternatively, farm data such as start of mating, weaning percentages, or the dates when stock enter and exit the farm, may be sufficient for estimating these emissions and capturing efficiency gains.

Time & animal numbers on off-paddock facilities
Farmers are currently unlikely to keep farm records of the number of animals and duration on off-paddock facilities (e.g. feed pads, stand-off pads, animal shelters, free-stall barns). However, for dairy, this information is being requested by most milk companies thus should be readily available.

Feed type, together with information on the start and end of grazing
The required feed type information includes date, number and class of stock entering and exiting different forage types bearing in mind that for some crops a transition period will be required. This information can then be integrated with animal liveweights to match energy requirements with energy supply from the different crop types to calculate DM intakes across the year. Records of crop feed quality will need to be documented. For farmers using imported supplements, the type, the amount of dry weight or fresh weight, and feeding method will be required. For dairy farmers, this information is captured by most milk companies and, for farmers using DairyBase, by DairyNZ.

Effluent/manure application method
This is specific to cropping farmers and vegetable growers where livestock manure can be incorporated at the time of application or immediately following surface application. It is unlikely that cropping farmers will maintain records on method of application per volume of manure. However, this may be relatively easy to collect, either calculated from own farm records or from information provided by contractors (e.g. proof of placement documentation, which will be influenced by the type of manure spreader and/or timing and type of cultivation). If data is not available, the calculations will assume effluent/manure is surface applied.

Table 2: Additional farmer inputs requirements for Detailed GHG accounting method (includes inputs for Simple method).

Method component	**Description of input**	**Comments**
Required inputs		
Animal liveweight and reproduction data	Dairy: Cow liveweight at 4-5 months after planned start of calving (most farms at 1 December); if unknown, then breed is required[1]. Proportion of year that young stock are on-farm. Time and number on off-paddock facilities. Sheep, beef and deer: Animal stock class[1] & body weight	Dairy: Class of young stock can align with liveweight of mature cow, with annual DM requirements calculated from the average annual liveweight of the dairy herd and proportioned for the number of months on farm after weaning. For young stock and dry cows the time on farm will be required if the responsibility for the GHG emissions sits with the landowner. If the obligation sits with business owner, this information is not required, as they will be responsible for any emissions from their livestock regardless of whether the animals are on or off farm.
	Planned start of mating; lamb, beef and deer weaning percentage; number of replacements retained post-weaning; number of other stock (carry-over/bulls etc)	Sheep, beef and deer farmers could plan to collect data at key farming operations (mating, scanning and weaning). Alternatively, stock class could be used to obtain regional industry averages for body weight. Body weight gain could be estimated from body weights and dates on/off farm within the GHG calculation.
Time & animal numbers on off-paddock facilities	Number of animals and duration on off-paddock facilities (e.g. feed pads, stand-off pads, animal shelters, free-stall barns).	Limited to dairy. This information is being requested by most milk companies therefore farmers are likely to be able to supply.
Feed type eaten	Date of start and end of grazing of different feed types. Data on imported supplements (type, amount, weight, feeding method).	Energy, DM and N intake from pasture, forages and supplements required to determine CH_4 emissions and N excretion. The GHG calculations need to include supplement database and percent utilisation for feeding method. Energy calculations should include default change in body condition score over lactation season.
Effluent/manure application method	Surface or incorporation	

[1] this requires knowing the number of stock per class (sheep, beef and deer) or breed (dairy), including stock movements.

The detailed method will calculate the energy and DM demands for different stock classes across seasons, resulting in a more accurate estimate, which better represents the actual farm emissions. Supplying liveweights, animal reproduction data, farm production data and forage types will lead to a more accurate estimate of DMI and urine and dung excretion, which in turn will provide more accurate estimates of CH_4 and N_2O emissions.

It is important to note that there are some farmers already measuring and recording many or all these inputs using tools and services such as OverseerFM, FARMIQ, FARMAX and other similar tools. In these cases, the extra time required for measurement and recording will be minimal. Within He Waka Eke Noa, there have also been discussions regarding direct links between these commercial tools and a proposed centralised GHG reporting system, which has yet to be built. However, for many farmers, some of these inputs will be new activities to measure and formally record.

Detailed method mitigation options
The detailed method will be able to capture the mitigations available for the simple method, plus additional mitigations and on-farm efficiencies (Fig. 3) such as:

- use of low GHG forages,
- low N supplements,
- high genetic merit livestock, which needs to be combined with reduced animal numbers.

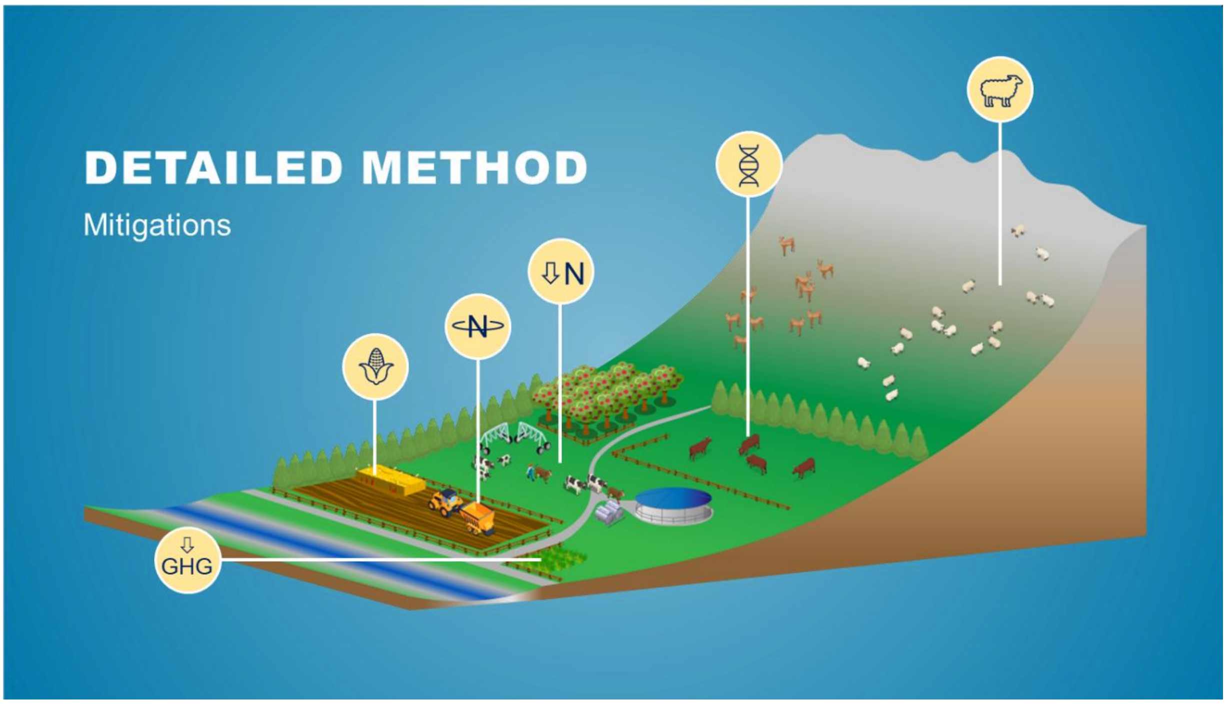

Figure 3. Mitigations available for farmers and growers adopting the detailed method for calculating farm-level GHG emissions. From left to right: 1. use of low GHG forages; 2. low N supplements (e.g. maize); 3. N fertiliser incorporation into soil following application; 4. reduced N fertiliser use; 5. high genetic merit livestock, combined with reduced animal numbers, and 6. genetically-selected low methane sheep.

Future work

We have described two methods for farmers to calculate farm-level GHG emissions. These methods will require further refinement and detail. To aid the refinement process, we have suggested further research including sensitivity analyses on the effect of using (i) livestock body weights based on an annual average vs. quarterly (or similar) body weights on GHG emissions and (ii) the planned start of mating to the average breeding date, given the potential variation in the spread of lambing. These and other areas of farm system analyses will help provide useful data to inform the right balance between limiting input requirements (minimise complexity) and providing enough detail so farmers can be rewarded for any on-farm efficiencies or adopted mitigation practices.

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