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INCLUSION OF NON-PASTURE FEED IN THE AGRICULTURAL INVENTORY MODEL FOR DAIRY, SHEEP AND BEEF

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Abstract

The quality of pasture and other feeds consumed by livestock has a significant effect on the quantity of greenhouse gas (GHG) emissions generated by New Zealand agriculture. Despite the increasing use of non-pasture feed in New Zealand (particularly for dairy cattle), the agriculture (GHG) inventory has assumed up until 2022 that livestock are entirely pasture fed. In 2023 the inventory methodology will for the first-time account for non-pasture feed. This improvement will significantly increase the accuracy of emissions reporting.

For dairy cattle, the estimated proportion of non-pasture feed consumed increased from 4.0% of total dietary intake in 1990-91 to 18.8% in 2017-18. Non-pasture feed usage in beef and sheep has remained relatively constant at 5-7% of total dietary intake between 1990 and 2015.

The estimated effect of non-pasture feed was included in the model by changing the pasture values for metabolisable energy (ME) content of feed (expressed as MJ-kg), nitrogen content (N%), and digestibility (DMD) to weighted averages based on the total diet of each livestock type. This methodology assumes the methane yield (amount of methane produced per unit of feed) for all feed types is identical to pasture.

Reported agricultural emissions when including non-pasture feed are consistently lower than emissions using pasture values for all livestock. The decreased emissions estimates reflect the higher metabolisable energy, lower nitrogen content, and higher digestibility of non-pasture feed compared to pasture. For sheep and beef, fluctuations over the time series were small, reflecting the consistent use of non-pasture feed. For dairy, there is a proportionally larger difference in later years, reflecting the changing composition of dairy cattle diet.

Introduction

The Agricultural Inventory Model (AIM) requires feed quality data to calculate methane and nitrous oxide emissions from dairy cattle, beef cattle, sheep, and deer. These emissions are expressed as carbon dioxide equivalents (CO2-e). For inventory purposes, there are three key components of feed quality:

a. Metabolisable energy (ME), used to calculate dry matter intake (DMI), and nitrogen intake.
b. Nitrogen (N%) content, used to calculate nitrogen intake and excretion.
c. Digestibility, digestible organic matter expressed as a percentage of the dry matter (DMD%), used to calculate faecal dry matter.

ME represents the energy that is available to an animal through absorption of nutrients. Lower ME feed requires increased dry matter consumption to reach the same level of productivity.

Increased dry matter consumption leads to increased methane emissions through enteric fermentation. The nitrogen content of livestock diet determines nitrogen excretion. A higher N content will lead to higher N intake and excretion, resulting in higher nitrous oxide emissions. A higher DMD value would lead to lower amounts of faecal dry matter and lower energy expenditure from livestock digestion, resulting in lower emissions.

In New Zealand dairy cattle, beef cattle, sheep and deer are grazed outside on pasture all year round. The 2022 inventory model assumed that dairy cattle, beef cattle, sheep and deer consume only pasture to satisfy their energy requirements and that no non-pasture feed is used. However, non-pasture feed is used to fill deficits in livestock diet.

The aim of this work is to incorporate non-pasture feed into the AIM without altering the model equations. Updating the methodology to account for non-pasture feed will increase the accuracy of emissions reporting.

Methods

Data collection

Data on non-pasture feed consumed by dairy cattle was sourced from the report Feed Consumed by NZ Dairy Cows: An update of feed volumes consumed by New Zealand dairy cows nationally and regionally since 1990-91 prepared by Dairy NZ in 2019 (DairyNZ Economics Group, 2019). Non-pasture feeds increased from 4.0% to 18.8% of total dairy cattle diet between 1990-91 and 2017-18. Primarily maize silage, swedes, turnips, and kale were consumed in the 1990's and early 2000's. Maize silage increased the most, from 0.5% in 1990-91 to 6.2% in 2007-08. Palm kernel extract (PKE) increased significantly from 1.6% in 2006-07 to 6.3% in 2019-20f. Fodder beet use increased significantly from 0.4% in 2010-11 to 2.6% in 2019-20f (Figure 1).

Data on non-pasture feed consumed by beef cattle was sourced from the report Supplementary feed use in the beef industry prepared by AbacusBio in 2018 (Sise, et al., 2018). Non-pasture feed usage in beef has remained relatively constant at 5-7% of total dietary intake between 1990 and 2015. The key feed types are swede, kale and baleage. The proportions of feed eaten are stable between years. The most used non-pasture feed is swede making up 3-4% of total diet.

Data on non-pasture feed consumed by sheep was sourced from the report Analysis of supplemental feed use in the new zealand sheep industry prepared by AbacusBio in 2017 (Sise, et al., 2017). Non-pasture feed usage in sheep has also remained relatively constant at approximately 5-7 % of total demand between 1990 and 2015. The key feed types are swede, turnip, sheep nuts (other supplements) and baleage. The proportions of feed eaten are stable between years. The most used non-pasture feeds are sheep nuts and swede making up 3-4% of total diet each.

Feed quality data for non-pasture feeds was obtained from Provision of Laboratory Data on Feed Quality prepared by Hill Laboratories (Calvert, 2020) and subsequent updates. Data included ME content (MJ/kg), nitrogen content (N%), and digestibility (DOMD%) for most feed types. Those not included were assumed to be the same as pasture. The data provided for this project relates to customer samples as submitted to the laboratory from January 2015 to March 2020 across 16 regions. The feed quality varies significantly within each feed type. The error bars in figures 2-4 show one standard deviation.

The AIM is designed to use DMD as opposed DOMD. DOMD values were converted to DMD using equations published in the Australian Fodder Industry Association (AFIA) test methods manual.

Pasture quality data was sourced from the AIM (Giltrap, et al., 2020). The characteristics of pasture change monthly and are the same each year. The characteristics of the feed are assumed fixed.

Figure 1: Proportion of different feeds eaten by dairy cows 1990-2018.

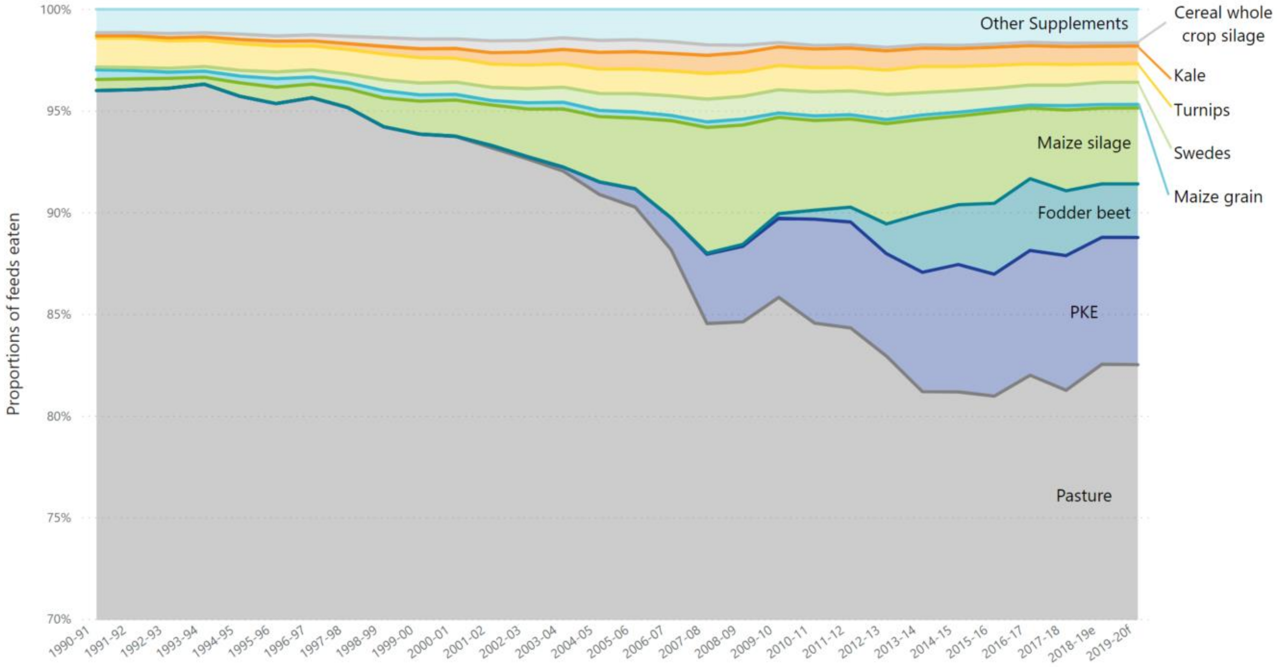


Figure 2: Metabolisable energy for different feed types compared to pasture, error bars show one standard deviation of Hill Laboratories data.

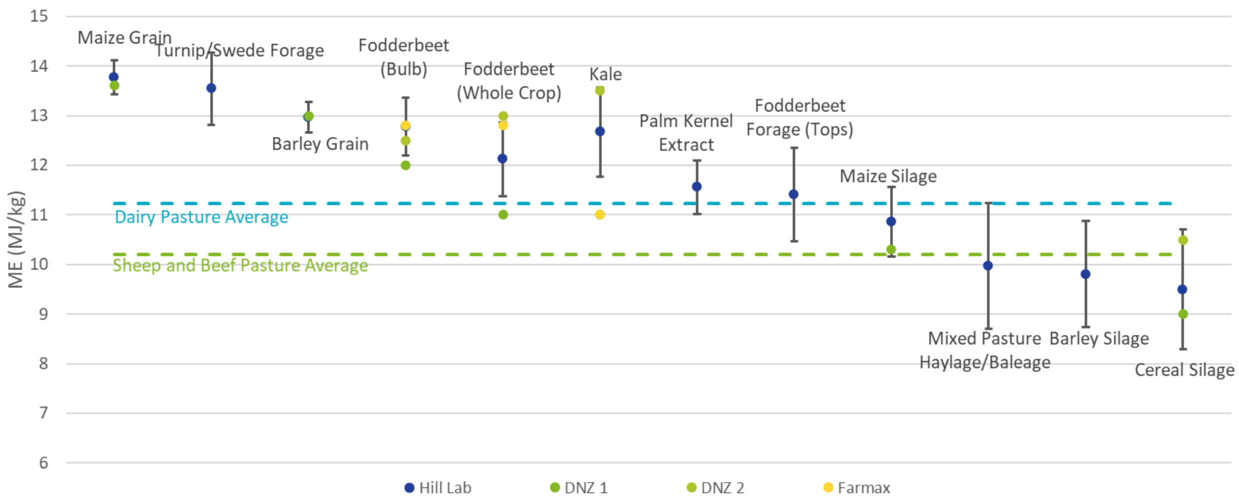


Figure 3: Nitrogen content for different feed types compared to pasture, error bars show one standard deviation of Hill Laboratories data.

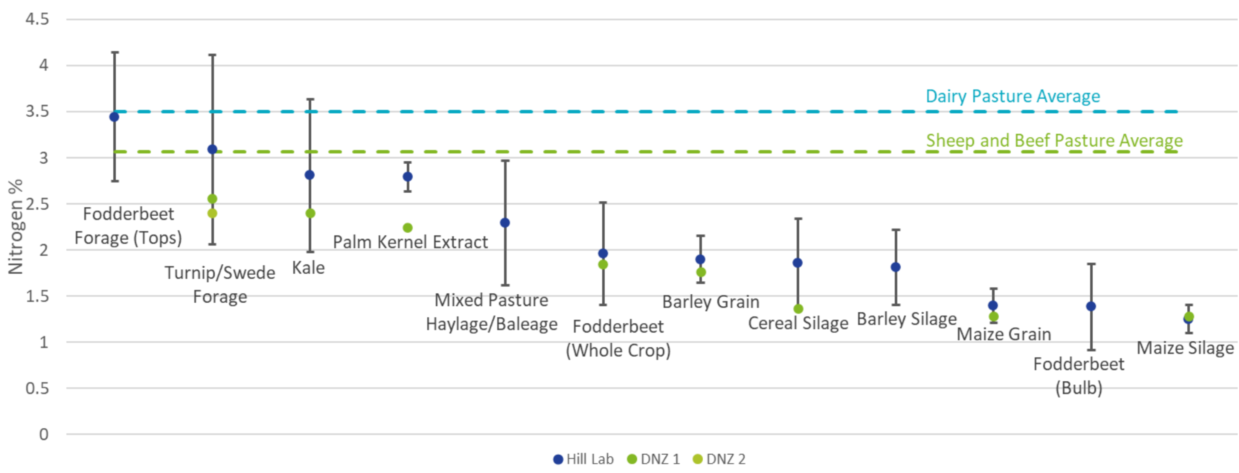
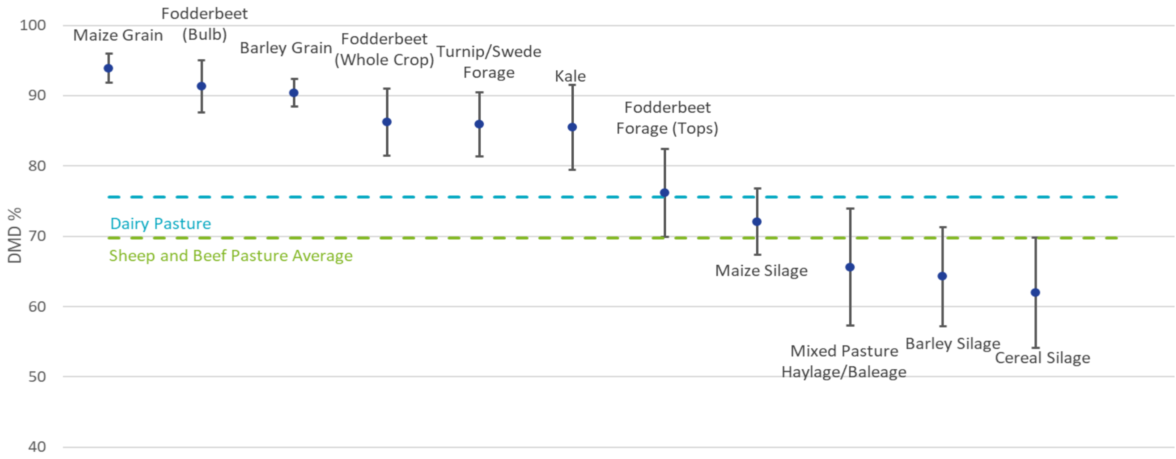


Figure 4: Digestibility for different feed types compared to pasture, error bars show one standard deviation of Hill Laboratories data.



Calculating new feed quality inputs

The revised feed quality input values were calculated using a weighted average.

For example:

$$ME = \sum ME_{feed} \times \%Diet_{feed}$$

The DOMD% for PKE was not included in the Hill Laboratory report so the value used is based on the average digestibility of pasture.

Data for sheep and beef are available every four years. The calculated ME, N% and DMD% were linearly interpolated to estimate missing value.

After the last year of data available (2019 for dairy cattle and 2014 for sheep and beef cattle) the ME, N% and DMD% in subsequent years were assumed to have the same values as the last available year.

Calculating impact on emissions

The revised monthly values for ME, N% and DMD% were tested in the 2022 Enhanced Livestock Model and Tier 1 inventory (AIM). The AIM was run on national mode. This methodology assumes the methane yield (amount of methane produced per unit of feed) for all feed types is identical to pasture.

Results

Feed quality inputs

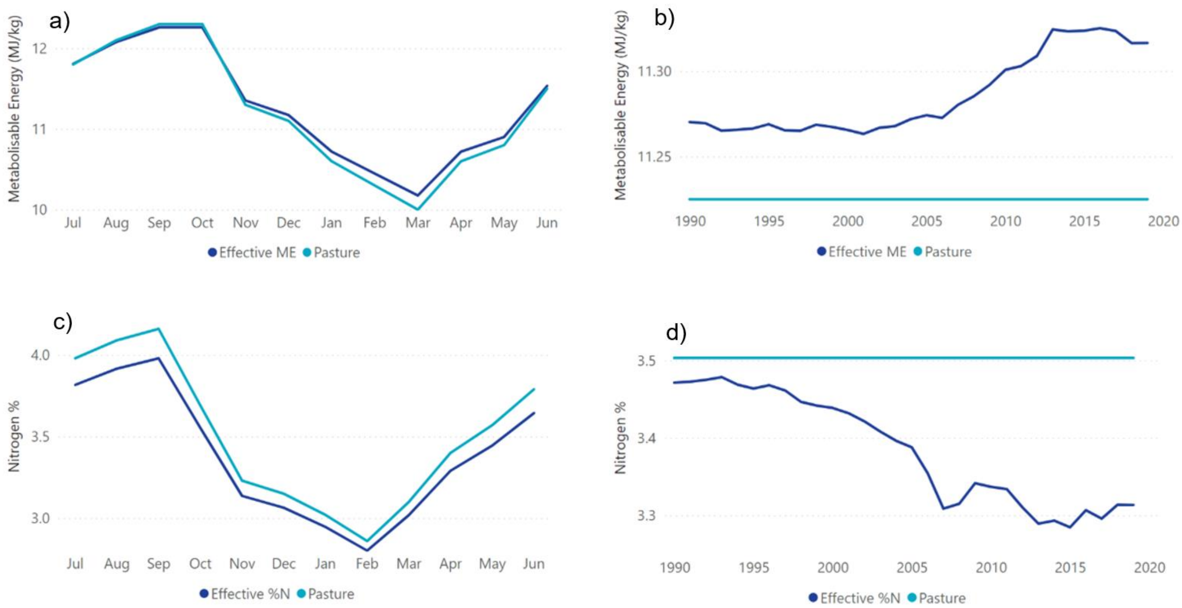
For dairy, the inclusion of non-pasture feed increases average ME content between November and July. Nitrogen content is reduced year-round but more so in the winter and spring. The seasonal variations are due to the pasture values changing by month. The magnitude of the difference increases as non-pasture feed becomes more widely used.

The effective monthly ME of feed is between 0.31 MJ/kg (3.1%) more and 0.09 MJ/kg (0.7%) less than pasture. The average difference from the pasture value is 0.061 MJ/kg (0.5%).

Between 1990 and 2006 the difference between effective feed and pasture average annual ME is between 0.04 and 0.05 MJ/kg (0.4-0.5%). The difference increases significantly from 2006 (0.5%) to 2015 (1.0 %). The difference then remains between 1.0% and 0.9% for the next four years (Figure 5b). This reflects the increase in the proportion of dairy cattle diet made up by non-pasture feed, especially fodder beet, which has a higher ME than pasture.

The N% of effective feed is lower than that of pasture across the year (Figure 5c). The largest difference is in September when pasture N% is highest. The N% of effective feed decreased rapidly between 1993 and 2006 (Figure 5d), reflecting the increase in the proportion of a cow's diet made up by maize silage. Maize silage has a similar ME to pasture but a much lower N%. Therefore, its influence is seen more clearly in in the N% of the effective feed than the ME.

Figure 5: Monthly (a, c) and yearly (b, d) average effective feed quality for dairy, 1990-2019

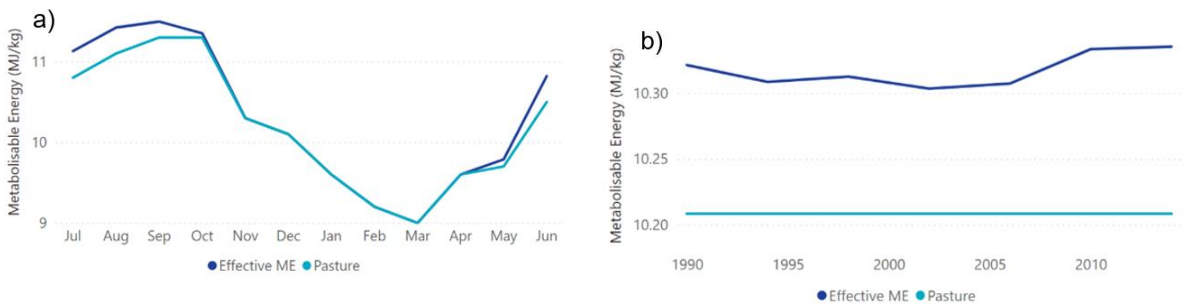


Beef cattle only received non-pasture feed May-October, so there is no change to the summer feed quality. The monthly ME of the effective feed is up to 0.45 MJ/kg (4.2%) more than pasture. The average difference from pasture (including the summer months where no non-pasture feed is used) is 0.11 MJ/kg (1.1%).

The inclusion of non-pasture feed in beef cattle diet increases the ME available in winter (Figure 6a). The months in which this has the most effect have changed over time. For 1990, the inclusion of non-pasture feed made the most difference to the effective ME in June, July, and August. In 2014 the peak difference between pasture ME and the effective ME was in September.

The difference between the average monthly ME of effective feed and pasture is relatively stable over time. The yearly average effective ME is between 0.9% and 1.2% higher that pasture for any year (Figure 6b). Similar trends are seen in digestibility. N% is decreased across the year, with the largest average decrease in August.

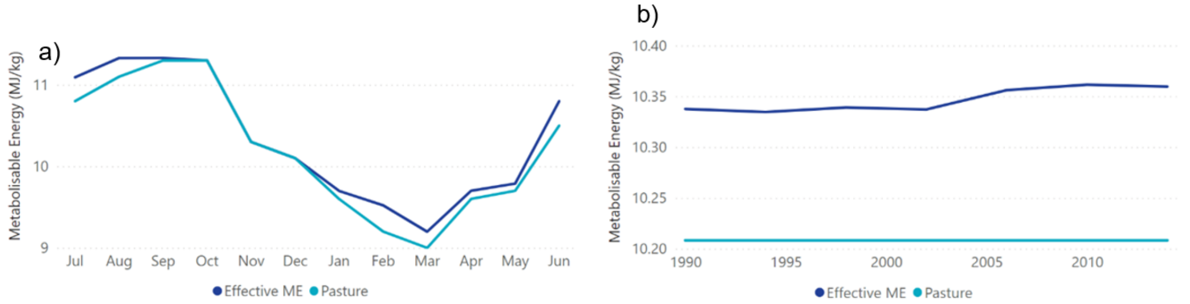
Figure 6: Average monthly (a) and yearly (b) effective feed quality for beef, 1990-2014



In sheep the monthly ME of the effective feed is up to 0.42 MJ/kg (4.6%) higher than for pasture alone. In 2014 the average ME was 0.14 MJ/kg (1.4%) higher than pasture. The difference between the ME of pasture and effective feed was greatest in February, aligning with the peak of summer non-pasture feed and low pasture ME (Figure 7a). There was another peak in June aligning with the use of winter non-pasture feed. Summer feed has a higher ME than winter feed due to the high proportion of leafy turnip and the low proportion of baleage.

Nitrogen content is decreased in winter (May-September) and increased in summer (January-April). This reflects the seasonal change in pasture quality and non-pasture feed types. Between years the N% is relatively stable.

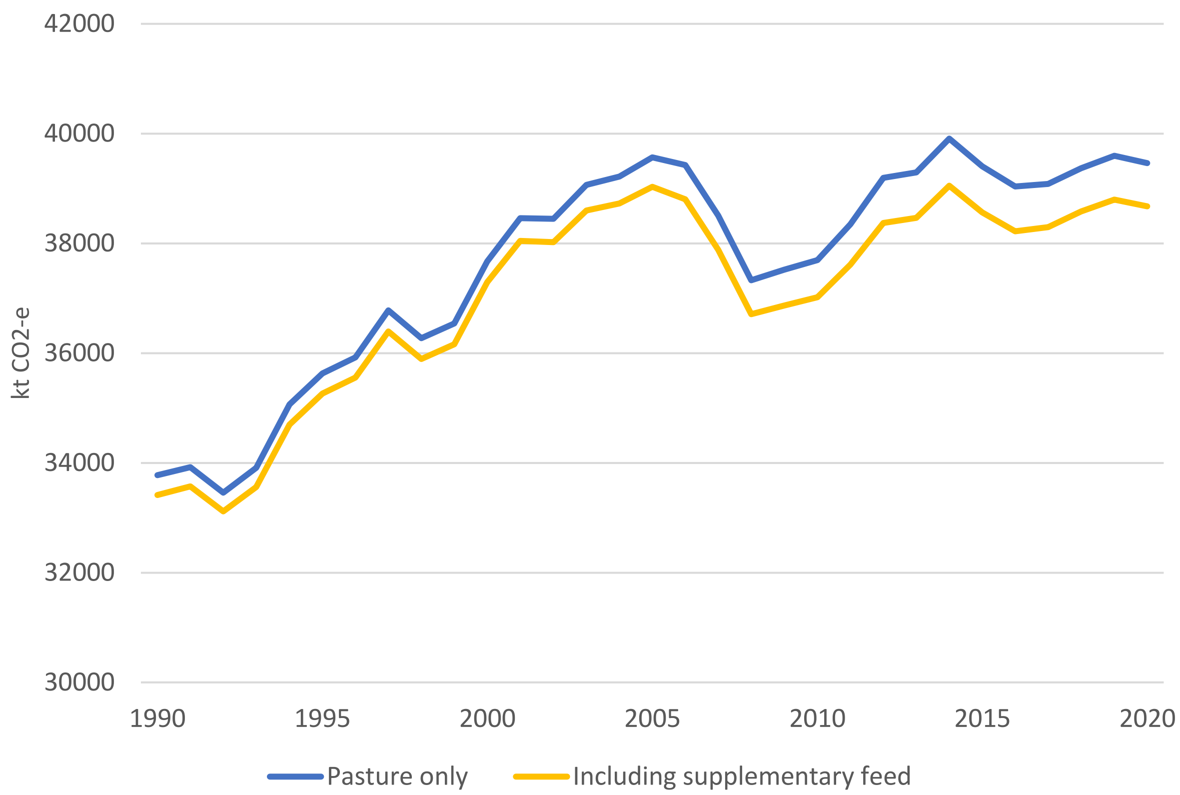
Figure 7: Average monthly (a) and yearly (b) effective feed quality for sheep, 1990-2014



Impact on emissions

For all years the inclusion on non-pasture feed reduced total agricultural emissions (Figure 8).

Figure 8: Total agricultural emissions using all pasture (dark blue) and effective feed (green) in the AIM 1990-2020 (AR4)



For the year 2020, the inclusion of non-pasture feed in addition to pasture for dairy, beef, and sheep reduced the overall agriculture emissions by 791 kt CO2-e (2.0%). Dairy cattle made up most of this change (-501 kt CO2-e), with total emissions from dairy cattle decreasing 2.7%. Emissions from beef decreased by 141 kt CO2-e (2.0%). Emissions from sheep were reduced by 149 kt CO2-e (1.6%).

Both methane and nitrous oxide emissions were decreased by including non-pasture feed. Methane (CH_4) emissions were reduced by 17.4 kt CH_4 (1.4%). Nitrous oxide (N_2O) emissions were reduced by 1.2 kt N_2O (4.5%). Carbon dioxide was not changed. For beef and sheep, the majority of total emission reductions came from methane. For dairy, the reduction in total emissions was relatively equally split (Figure 9).

Table 1: Emissions (kt CO2-e) by activity with and without non-pasture feed, 2020 (AR4)

	Pasture only	Non-pasture feed and pasture	Difference	Percent change
Dairy Cattle	18521	18020	-501	-2.7%
Beef Cattle	7102	6961	-141	-2.0%
Sheep	9308	9159	-149	-1.6%
Total	39465	38674	-791	-2.0%

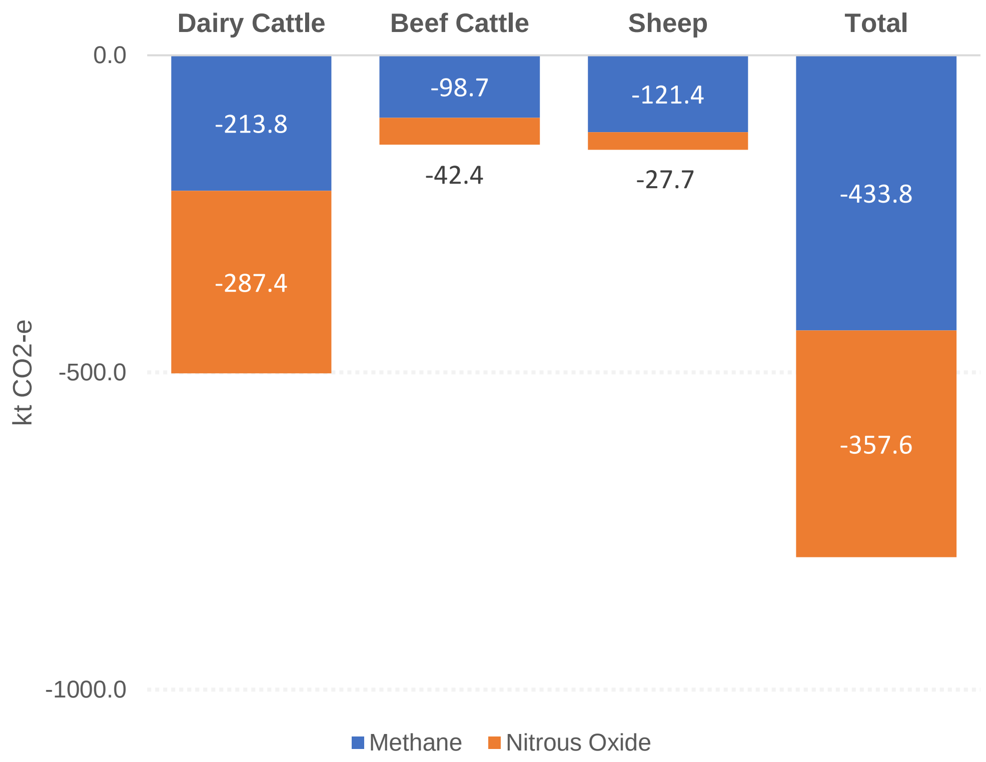
Table 2: Change in methane emissions (kt CH4) by activity from the inclusion of non-pasture feed in addition to pasture, 2020

	Pasture only	Non-pasture feed and pasture	Difference	Percent change
Dairy Cattle	618	610	-8.6	-1.4%
Beef Cattle	243	239	-3.9	-1.6%
Sheep	335	330	-4.9	-1.5%
Total	1220	1203	-17.4	-1.4%

Table 3: Change in nitrous oxide emissions (kt N2O) by activity from the inclusion of non-pasture feed in addition to pasture, 2020

	Pasture only	Non-pasture feed and pasture	Difference	Percent change
Dairy Cattle	10.3	9.3	-1.0	-9.4%
Beef Cattle	3.5	3.3	-0.1	-4.1%
Sheep	3.2	3.1	-0.1	-2.9%
Total	26.9	25.7	-1.2	-4.5%

Figure 9: Change in Methane and Nitrous oxide emissions (kt CO2-e) by activity from the inclusion of non-pasture feed in addition to pasture, 2020 (AR4)

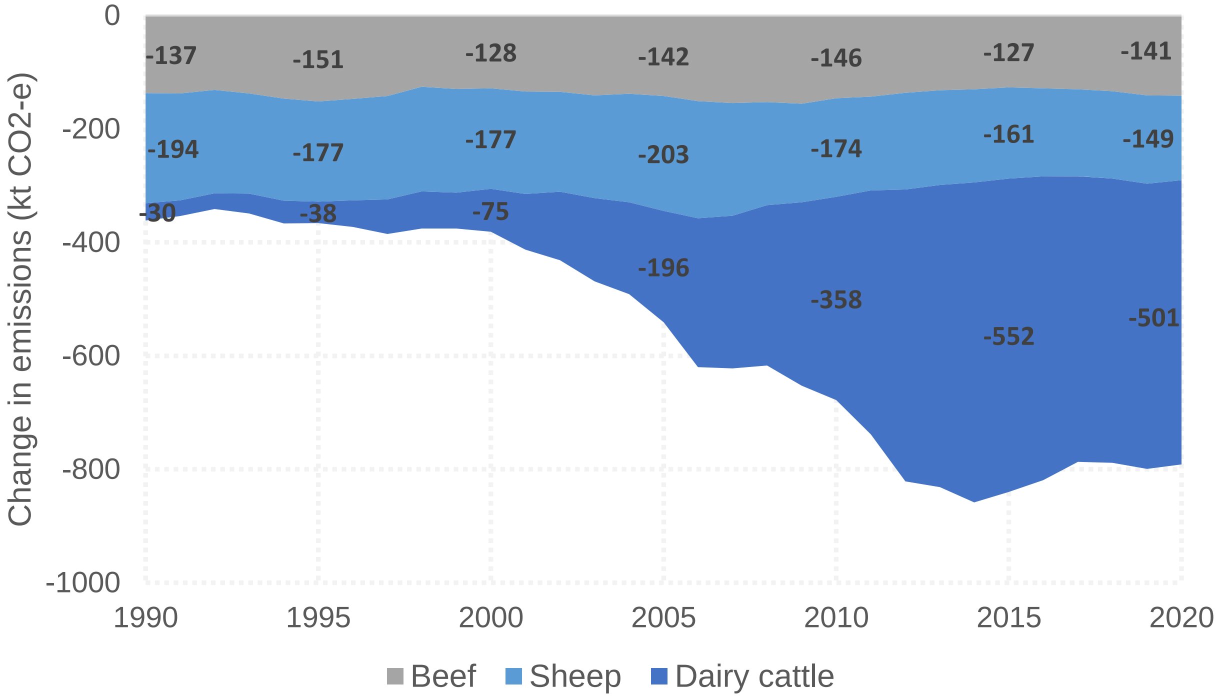


The difference between total agricultural emissions using all pasture and effective feed in the AIM for dairy, beef and sheep increased from -361 kt CO2-e (-1.1%) in 1990 to a maximum of

-858 kt CO2-e (-2.2%) in 2014. Between 2014 and 2020 the difference decreased slightly to -791 kt CO2-e (-2.0%).
For beef and sheep, the impact of including supplementary feed is relatively stable across the time series, between -155 and -126 kt CO2-e for beef and -206 and -149 kt CO2-e for sheep (Figure 10). For sheep, emissions using effective feed are 1.6% to 1.2% lower. For beef, emissions using effective feed are 2.1% to 1.6% lower than the emissions assuming all pasture.

The difference between total agricultural emissions using all pasture and effective feed for dairy increased from -30 kt CO2-e (-0.4%) in 1990 to -564 kt CO2-e (-3.0%) in 2014. Between 2014 and 2020 the difference decreased slightly to -501 kt CO2-e (-2.7%) (Figure 10).

Figure 10: Difference between total agricultural emissions by activity using all pasture and effective feed in the AIM 1990-2020. The trends relate to the amount of supplementary feed, the type of feed, and the size of the livestock population. (AR4)



Discussion

The reduced nitrous oxide emissions align with what other research suggests. Much of this research focuses on maize silage as it has a low nitrogen content and can be used to reduce dietary nitrogen concentrations. Reduced N consumption has been shown to reduce N concentration in urine patches (Jarvis et al. 1996; Oenema et al. 1997). Wilkinson & Waldron (2017) found that the output of N in milk as a proportion of total nitrogen intake increased when dairy cows were 5 kg of maize silage DM/head per day. This increased further when the crude protein of the pasture was reduced. Increases in the output of N in milk as a proportion of total nitrogen intake imply reduced N excretion in urine and manure.

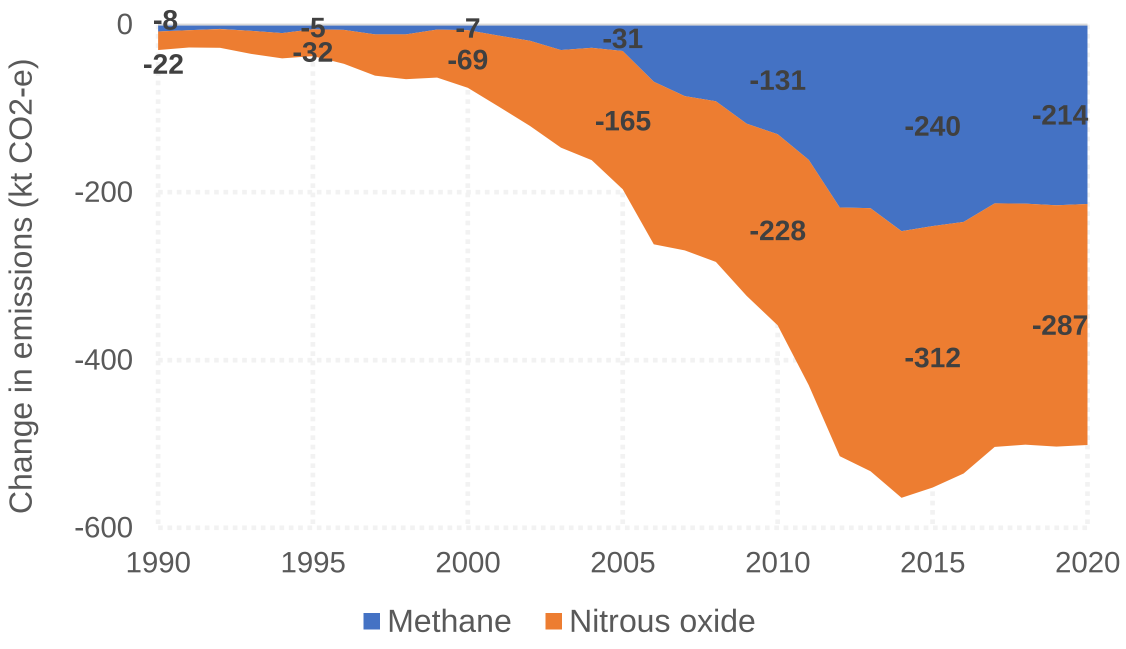
The reduced methane emissions are due to the reduced total DMI. When eating feeds with a higher ME, livestock need to eat less to meet their energy requirements. In the AIM enteric methane emissions are proportional to dry matter intake. This simplification is supported by Muetzel (2009) who found that in sheep, 86.3% of the variation in methane production is explained by DMI [kg/d]. Diet quality was not found to have a significant effect on methane yield.

The change in emissions from sheep and beef contribute a constant offset to the overall trend (Figure 10). The decreased emissions reflect the higher ME, lower nitrogen content, and higher digestibility of the effective feed compared to pasture. Fluctuations over time are small, reflecting the consistent supplementary feed use.

The change in emissions from using effective feed values for dairy increases over time (Figure 10). Rapid change occurs between 2000 and 2014. Between 2000 and 2005 the trend is mainly due to the decreasing nitrogen content of the effective feed as the ME is relatively stable. Between 2005 and 2014 the increasing ME of the feed also contributes. This reflects the change in the supplementary feeds used, with the increased use of fodder beet and PKE after 2007. The change in emissions from methane and nitrous oxide (Figure 11) support this interpretation, with the change in methane significantly increasing after 2005.

As well as feeding, changes in population influence the change in emissions. As the more supplemented dairy herd increases in size, the effect of dairy supplementation on emissions also increases.

Figure 11: Difference between dairy agricultural emissions by gas using all pasture and effective feed in the AIM 1990-2020 (AR4)



Benefits and limitations

Including non-pasture feeds in the AIM will more accurately reflect the feed quality of livestock. The change will also improve the accuracy of New Zealand's emissions estimates and can show the benefits of using supplementary feed in terms of controlling emissions

The method described can be implemented without changes to the methodology used to calculate DMI, nitrogen intake, enteric methane production, or any other existing part of the AIM. It can be implemented swiftly without further research (for example new emissions factors), or the methodological development required to incorporate these findings.

One of the limitations of this change is data availability. The estimates of supplementary feed consumed by sheep and beef cattle are only available every four years. These datapoints were linearly interpolated between for this analysis. The feed consumption data provided have not been independently verified.

Supplementation of lipids, addition of organic acids, and the use of halogenated compounds are also not covered by the methodology presented in this analysis.

This analysis does not consider effects on the wider system, such as the effect of growing feed crops on soil carbon or nitrogen in soils.

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