POSITION PAPER

Greenhouse gases from pastoral farming – a New Zealand perspective

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1 Introduction

New Zealand has a unique greenhouse gas (GHG) profile amongst developed countries in that around half of the emissions in carbon dioxide equivalents (CO_2-eq), some 38 Mt, consist of methane and nitrous oxide (N_2O) originating from agriculture. Since 1990, farming has undergone significant changes with sheep numbers more than halving (now 27 million) and dairy cattle numbers doubling to 6.5 million (including young stock). The geography of New Zealand dictates farming systems. Much of the North Island is rolling to steep upland (known as hill country), suitable only for sheep and beef farming. Along its western side, a chain of mountains runs the length of the South Island. About one quarter of the total agricultural area is sufficiently flat and at a low enough altitude to allow pastoral dairy farming. Eastern areas of both islands are prone to summer drought. In recent years, much lowland has been converted from sheep and beef to dairy farming accompanied by irrigation and an intensive pastoral system utilising substantial fertiliser inputs. New Zealand exports 95 % of its dairy products which supply 30 % of those traded on the world market.

Average herd size is 430 milking cows per 150 ha (2.86 cows per ha). Total effective dairying area is 1.76 million ha with another 0.6 million ha devoted to dairy support, i.e. grazing of young stock, off-farm grazing of dry cows, and cropping. Approximately half the cow population is Holstein-Friesian/Jersey crossbred, one-third Holstein-Friesian and 10 % Jersey. Farmers are paid on kg of milk solids (MS). A separate dollar value is assigned to fat and protein with a minor penalty for milk volume. Most farms milk seasonally, with all cows calving in the spring (July, August, September) and being dried off by the end of May. Average production varies with seasonal weather patterns but is typically 380 kg MS per cow or 1,080 kg MS per ha (approximately equivalent to 9,800 kg fat and protein corrected (FPC) milk)[2]. DairyNZ defines farming systems by numbering from 1 to 5, with System 1 consisting of all-grass home-grown feed through to System 5, where 30 to 50 % of feed is grown off-farm (LIC and DairyNZ, 2018). The majority of farms fall somewhere between these two extremes, but there is a considerable year-to-year variation depending on weather and milk price.

Much sheep and beef farming is now carried out on poorer producing hill country in the North Island and sub-alpine areas in the South Island. These are the core breeding flocks and herds which provide young animals for finishing on better producing, lower altitude farms. Feedlots are rare; the vast majority of animals destined for the meat industry are finished on pasture. The total area used for grazing animals for meat industry is about three times that of dairying. Grain growing and horticulture are practiced only on a small scale, totaling some 70,000 ha.

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[2] Definition International Dairy Foods Association, Washington, D.C: Milk is approximately 87 % water and 13 % solids. As it comes from the cow, the solids portion of milk contains approximately 3.7 % fat and 9 % solids-not-fat.

The only government support of agriculture consists of a relatively small amount of funding for research. In 2003, the Pastoral Greenhouse Gas Research Consortium was established as a joint venture between research organisations, the government and farming groups, to determine practical methods of reducing agricultural emissions. Much research has concentrated on methane since it is the largest contributor to New Zealands agricultural greenhouse gas emissions. This also had a political objective as under terms of the Kyoto Protocol and Paris Agreement any decline in methane can be credited against CO_2 from fossil sources.

There have been no legislated controls on CO_2 emissions from the energy, industrial, and transport sectors. These sectors account for 70 % of the increase in national emissions since 1990, the remaining 30 % originating from agriculture. The growth in methane emissions since 1990 has been considerably smaller than the growth in CO_2 emissions from the energy sector. A reduction in methane emissions due to the decline in sheep numbers have partly compensated for the increased methane emissions related to the rise in dairy cattle numbers. It is N_2O, along with direct CO_2 emissions from the application of urea fertiliser, primarily by dairy farmers, that is the largest contributor to direct farm emissions growth from 1990 to 2017 (*Figure 1*; Ministry for the Environment, 2019). Emissions from on-farm fuel use and electricity consumption are insignificant.

The impact of methane emissions on warming has been the subject of some debate. Methane's short lifetime (some 12 years) means that stabilising emissions will result in a decline in atmospheric concentration. In contrast, the emission of long-lived gases such as CO_2 and N_2O need to be reduced to zero in order just to stabilise concentrations. Also subject to debate has been the reasons atmospheric methane concentration stabilised for a period in the early 2000s but has resumed an upward trend since 2009. Evidence suggests much of this additional methane is of fossil origin (Worden et al., 2017).

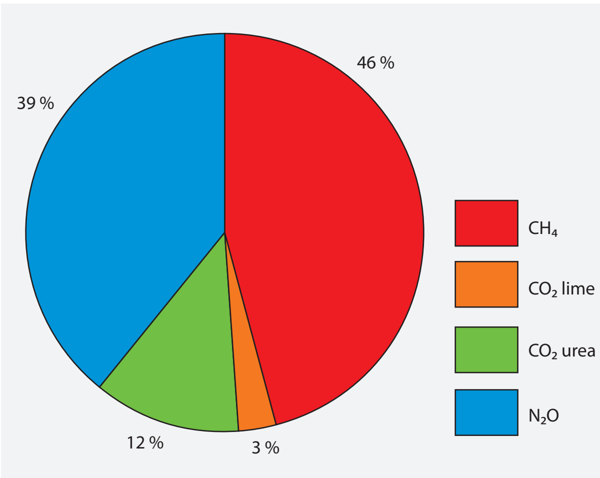

FIGURE 1

Growth in agricultural greenhouse gas emissions from New Zealand 1990–2017. Total growth is 600 kt CO_2-eq y^{-1} estimated by applying linear regression to annual data for each gas. CH_4: methane (Global Warming Potential, GWP 25).
CO_2 lime: direct emissions due to lime application.
CO_2 urea: direct emissions by soil organisms due to urea application. N_2O: nitrous oxide (GWP, 298).

2 Options for methane reduction

To date, no practical, cost-effective methods for reducing methane emissions from pasture-based systems have been developed. This is not surprising as enteric *Archaea* that produce methane (methanogens) have proved very resilient to attempts to manipulate their populations. The following is a summary of research findings.

Breeding

It has been determined that there is individual variation in ruminants in terms of their methane production in pastoral systems. In sheep, a flock reduction of 4 to 6 % can potentially be achieved by targeted breeding (Goopy et al., 2014). Currently, the Livestock Improvement Corporation is carrying out genetic screening for low emission traits in dairy cattle. However, populating a significant proportion of the national herd/flock with low emitters would be a long term process and may conflict with other breeding objectives.

Feed manipulation

Methane production is linked to the fibre content of the feed. Feeding a carbohydrate-rich, highly digestible diet results in a relatively low emissions intensity measured as kg CO_2-eq per kg FPC milk. However, the growing of crops necessary for the carbohydrate component of feed leads to a net increase in the GHG footprint (Williams et al., 2007), especially if feeding total mixed rations (Van der Nagel et al., 2003).

Feed additives under New Zealand conditions have so far been demonstrated either to have only temporary or no effect, or have turned out to be impractical to administer. Procedures have been developed to screen large numbers of compounds rapidly. The ideal compound (such as 3-nitroxypropanol) would inhibit the metabolic pathway for methane production rather than inhibiting the organism itself. The main issue remains administration in a pastoral situation. Although slow-release intraruminal mechanisms are available, they are not designed for long-term use.

Certain forages may have a significant effect, at least in sheep, e.g. forage rape (*Brassica napus*). Work in all these areas is ongoing.

Vaccination

Some progress has been made in developing a vaccine with antibodies being passed in saliva. So far, this has not resulted in significant inhibition of *Archaea* but work is continuing. Large scale clinical trials are still some time away (well into the 2020s), and although eventual efficacy is unknown, it seems unlikely to exceed a 20 % reduction (PCE, 2016).

Effect of stock numbers

The single most significant influence on national methane emissions is stock numbers. Sheep numbers have halved since 1990, and both beef cattle and deer populations have decreased substantially since 2004. Thus, a growing dairy cow population has largely driven the increase in emissions since 2008.

3 GHG reduction by farm management changes

A number of studies on how best management practices affect the environmental impact of pastoral farming have been published. There is an emerging consensus that, despite lower milk production per hectare, the reduction of cow numbers combined with nitrogen input limitation has a neutral to positive effect on farm profitability. Reliance on feed imported from off-farm, typically maize silage or palm kernel expeller, can have a serious negative effect on profitability at times of low milk prices. (Dewes and Death, 2015; Fraser et al., 2014).

It is becoming clear that maximising milk production is poorly correlated to maximising operating profit. Many farms reach a point where marginal costs of producing extra milk exceed marginal returns. After this point, profitability declines; however, this decline may not be obvious if a simplistic analysis which only averages costs and returns is carried out. A more sophisticated analysis, which allows identification of the point of maximum profitability for different levels of milk price, different management strategies, and associated risk, indicates the most resilient system. Evidence suggests the system most consistently profitable over a wide range of economic circumstances is one where stocking rates are low to moderate and cows are predominantly grass-fed with home-grown feed (Beukes et al., 2009; Anderson and Ridler, 2010; Anderson and Ridler, 2017; DairyNZ, 2019). A model constructed by Groot et al. (2012) has demonstrated similar findings on a largely pasture-based organic farm in the Netherlands where decreasing cow numbers and increasing forage intake results in improved environmental performance and profitability.

A significant influence on efficiency is the replacement rate of breeding stock. Animal wastage means both an expense to farmers and an unnecessary source of GHG emissions as it requires the rearing of an excessive number of young stock. A reduction of replacement rate should be achievable by combining better management with improved disease control.

There is a school of thought which proposes that since methane emissions are linked to dry matter intake, there will be little effect of reducing cow numbers if the same amount of feed is consumed. However, the data does not support this. Improved feed conversion efficiency and minimal cow wastage are characteristic of high-efficiency low-input farms, resulting in a lower proportion of consumed feed being devoted to maintenance of animals (Macdonald et al., 2014).

Currently, only around 5 % of dairy farmers operate a high-efficiency low-input system (Dewes and Death, 2015). If such strategies were applied nationwide, reductions in cow numbers and nitrogen usage would likely have a substantial effect on agricultural emissions. However, efficacy is highly dependent on the quality of management, and a proportion of farmers will not be capable of taking advantage of changes without training.

Modelling

Measuring changes at the farm level is not straightforward. Overseer® is a software package most commonly used by farmers and advisors for tracking nutrient flows and losses. Although it can also track GHGs, it is not primarily set up to do so. DairyNZ's Whole Farm Model can be linked to more sophisticated models in order to provide a more accurate picture of emissions for various scenarios at the farm level. However, like most international models, it is primarily used for research purposes. Dynes et al. (2018) have carried out a review of available emission models, many of which are limited in scope.

Soil carbon

There is increasing global interest in the potential for grassland soils to absorb large quantities of carbon of atmospheric origin if managed appropriately. It is well documented that continuous cropping results in substantial carbon loss to the atmosphere (e.g. Sparling et al., 1992). Return to pasture allows recovery; however, unless there is just a single cropping event, this may take some time.

Careful pasture management can build soil carbon, especially in degraded areas. There have been sizeable losses from some New Zealand soil types (peat, allophanic, gley), but many lowland soils have a high carbon content by international measures (Schipper et al., 2017). New Zealand does not report soil carbon losses except for those arising from changes in land use. Consequently, there is a paucity of data.

The role of nitrogen

The use of nitrogen (N) fertilisers has largely driven the intensification of dairying. N not only accounts for the increase in dry matter production of pasture but also the protein content of grass. Bacterial degradation of urine in the top layer of soil is the prime source of both leached nitrate and N_2O emissions, the amounts depending on a product of dry matter consumed and its protein percentage. The rise in N_2O emissions has paralleled the increase in the application of synthetic urea since 1990 (*Figure 2*).

4 Options for nitrous oxide reduction

4.1 Management changes

Reduction of N inputs is an obvious practical strategy. Before 1990, the nitrogen cycle of dairy pasture was driven by atmospheric fixation by clover. Studies have shown a marked reduction in N leached from farms where fertiliser N inputs have been reduced or eliminated. In parallel, reductions in the quantity and concentration of urea excreted in urine and thus N_2O formation can be expected (e.g. Thatcher et al., 2017).

Managing effects of cropping and pasture renewal can have a significant influence on N_2O. Herbicide use speeds up denitrification processes, and soil disturbance affects the potential for both N_2O and CO_2 emissions (Luo et al., 2017). Compaction of soils in wet conditions as a result of high

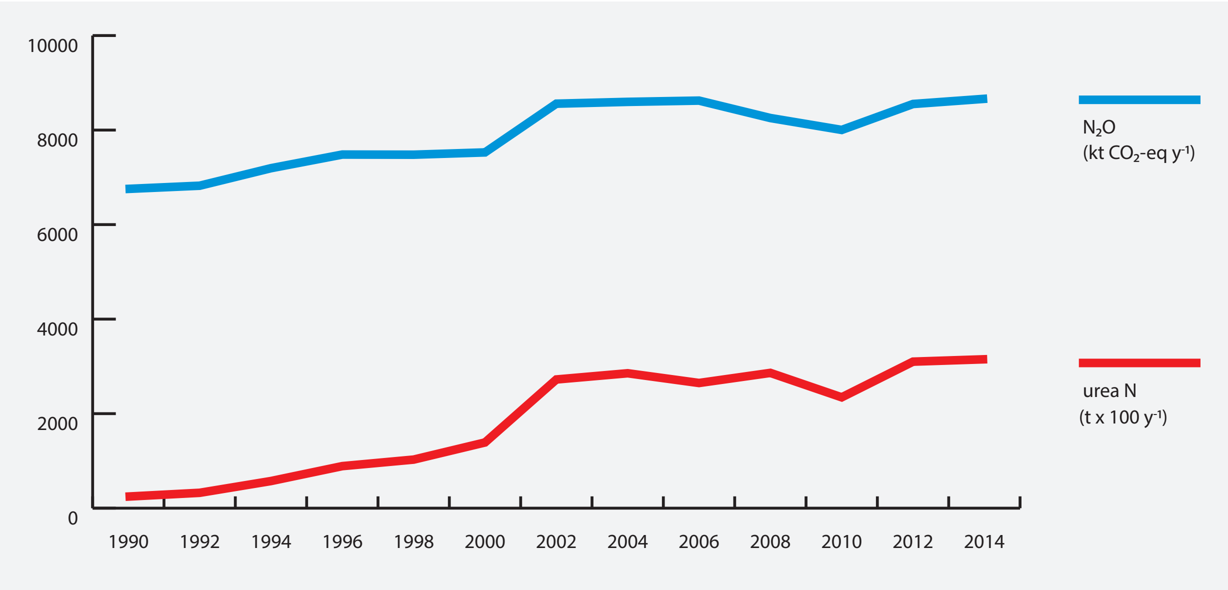

FIGURE 2
N_2O emissions from New Zealand agriculture and the use of urea N fertiliser 1990–2015. The dip of 2007–2009 was due to a spike in the price of urea (Data source: Ministry for Primary Industries; Ministry for the Environment)

stocking rates combined with concentrated deposition of urine and dung can lead to very high rates of N_2O production (Bhandral et al., 2007). Reduced stocking rates, smaller cows, maintenance of soil carbon, and better management of pastures can all help address this issue.

Manure management

On most dairy farms, over 90 % of manure is deposited directly on paddocks. Effluent is only generated when cows are yarded for milking. The housing of dairy cattle is rare in New Zealand and, except at shearing time, non-existent on sheep farms. More common are open concrete yards used for 'standing off' dairy cows temporarily during wet weather in order to prevent pasture damage. Such yards may also be used for feeding supplement. Manure is regularly scraped off and typically stockpiled before being returned to paddocks. Although emissions from this source are relatively minor, simple measures, such as covering stored solid manure to prevent water entry, can make a difference.

Raw effluent washed off milking yards is usually returned to paddocks by spraying. Emissions depend on prior storage and soil conditions at the time of dispersal. Additionally, most farms have 'hot spots' (gateways, troughs, laneways) where dung and urine concentrate, leading to a higher risk of N_2O formation. Ammonia volatilisation is a minor issue and only of any significance when urine or N fertilisers are applied to very dry soils.

Whatever methods of effluent collection and dispersal are employed, the potential amount of N_2O released is linked to the total amount of N cycling through the farm system. Precision testing would allow farmers to make better decisions as to timing and the amounts of N fertilizer to apply, but the most practical option for reducing emissions is to simply apply less.

4.2 Dietary manipulation

There is evidence that the addition of herbs such as chicory (Cichorium intybus) and plantain (cultivars of *Plantago lanceolata*) to pastures substantially reduces urinary urea (Box et al., 2016) and may also reduce methane with no effect on milk production. Plantain, in particular, seems to have an additional diuretic effect, and its roots exude a compound, yet to be identified, which appears to further limit nitrate leaching (DairyNZ, 2019). The effect on N_2O production has yet to be quantified, and work in this area is ongoing.

Reducing the protein intake of cows can be achieved by increasing the carbohydrate content of the diet, typically by supplementing it with a harvested crop such as maize, which reduces grass intake by substitution. As mentioned above, this increases the GHG footprint. High-sugar ryegrasses have been shown to be ineffective at reducing urine urea levels.

4.3 Soil amendments

Dicyandiamide (DCD, in the form of coated urea pellets) was introduced primarily to reduce nitrate leaching with the added effect of reducing N_2O emissions. However, it was withdrawn from the market in 2013 when residues were detected in milk. The urease inhibitor n-butylthiophosphoric triamide (nBTPT) reduces the conversion of urea to NH_3 gas, especially under dry conditions. Currently being spread on some 200,000 ha, its effect on N_2O production is minor (< 1 %).

5 Resource efficiency – comparing sheep and cows

Emissions intensity, expressed as kg CO_2-eq emitted per unit of product, is commonly quoted as a means of assessing the efficiency of a process and may be used to justify an increase in emissions. Thus, unless emissions actually decline, such figures can be misleading when considering the overall environmental impact.

Despite the marked drop in sheep numbers, from 1990 to 2016 total sheep meat exports declined by only 2 %. These figures reflect improved breeding, management, and feeding of a reduced number of animals. Total emissions from the sheep sector fell by 6 Mt CO_2-eq from 1990 to 2015. Emissions intensity at the farm gate fell from 45.2 to 26.6 kg CO_2-eq per kg meat exported. Farm profitability increased during this time in real terms by 110 % (Beef+Lamb NZ, 2018).

Over the same period, national MS production per cow increased by 41 % and production per ha by 72 %, largely as a result of improved genetics and feeding (LIC and DairyNZ, 2018). Methane emissions rose by 7.7 Mt CO_2-eq (129 %; Ministry for the Environment, 2019). The change in emissions intensity from 12.2 to 10.5 kg CO_2-eq per kg MS was relatively modest. Comparisons with international figures are difficult due to the variety of assumptions across different systems and significant uncertainties in the measurement of gases, although it appears New Zealand is likely to be at the lower end of the range of intensities.

Thus, although both the sheep meat and dairy sectors have shown an improvement in emissions intensity, only the production of sheep meat has shown an actual decline in emissions. In contrast, the rise in emissions from dairying has been substantial despite the modest decline in emissions intensity.

6 Conclusions

The most substantial growth in agricultural emissions from New Zealand since 1990 has been due to N_2O plus associated CO_2 released as a result of soil hydrolysis of urea. This is closely tied to the growth in the application of N fertilisers to dairy pastures, which in turn has allowed increased stocking rates. The most practical options currently available for reducing overall agricultural emissions involve a combination of dairy farm management strategies to tackle all three GHGs, particularly focusing on N_2O. A programme including a financial incentive to reduce the use of N fertilisers combined with farmer education would seem the most likely to produce results.

Unless a practical feed additive is developed, the only likely option for reducing methane emissions from ruminants on pasture in the long term is vaccination (PCE, 2016). The success of such interventions and the extent to which they may reduce overall emissions is by no means guaranteed. However, what is certain is that reducing stock numbers will reduce methane emissions. The sheep meat sector has demonstrated that productivity can be maintained despite a dramatic decline in stock numbers, and there is increasing evidence that the profitability of dairy farming can be sustained while reducing stocking rates and N inputs. If widely adopted, such strategies could produce a significant reduction in emissions. A conservative analysis suggests this would come at a zero cost to farmers, but for many it may lead to improved profitability.

6.1 International implications

Pasture-based dairy farming has a number of advantages over total-mixed-ration feeding of permanently housed cows:

- Grass is always the cheapest feed and, if well managed, the most profitable.
- In comparison to other feedstuffs, grazing has the least greenhouse gas emissions if nitrogen inputs are kept to a minimum. Appropriate management of legumes is important to maintain the nitrogen cycle.
- Pastures have the potential to convert atmospheric CO_2 to soil carbon, if well managed.
- Mixed pastures that include herb species appear to have some environmental advantages over a pure grass sward.

Cropping for animal feed as an adjunct to grazing may have a place if the following considerations are taken into account.

- Minimising soil disturbance
- Minimising herbicide use
- Cropping an area once then regrassing immediately after harvest will rebuild soil carbon. It is important not to leave a field bare of vegetation over winter.

Since a considerable fraction of dairy production in the northern hemisphere is not required for the fresh milk market, it would seem likely to be profitable for a proportion of farmers to switch to a seasonal pasture-based system in climatically suitable areas. If these farmers were paid on a milk solids basis, it would promote a diversity of breeds more suited to both a grazing system and the manufacture of butter and cheese.

REFERENCES

Anderson WJ, Ridler BJ (2010) The effect of increasing per cow production and changing herd structure on economic and environmental outcomes within a farm system using optimal resource allocation. Proceedings of the 4th Australasian Dairy Science Symposium, Lincoln University, New Zealand, 31 Aug–2 Sept 2010, 215–219

Anderson WJ, Ridler BJ (2017) The effect of dairy farm intensification on farm operation, economics and risk: a marginal analysis. Anim Prod Sci 57(7):1350–1356, doi:10.1071/AN16457

Bhandral R, Saggar S, Bolan N, Hedley MJ (2007) Transformation of nitrogen and nitrous oxide emission from grassland soils as affected by compaction. Soil Till Res 94(2):482–492, doi:10.1016/j.still.2006.10.006

Beef+Lamb NZ (2018) How are we going to mitigate emissions in the sheep and beef sector? Presentation at ETS Forum Wellington NZIAHS [online]. Retrieved from <www.agscience.org.nz/wp-content/uploads/2018/10/BLNZ-NZIAHS.pdf> [at 20 June 2019]

Beukes P, Gregorini P, Romera A, Levy G, Waghorn G (2009) Modelling the efficacy and profitability of mitigation strategies for greenhouse gas emissions on pastoral dairy farms in New Zealand. Proceedings of the 18th World IMACS/MODSIM Congress, Cairn, Australia, 13–17 Jul 2009, 215–220

Box LA, Edwards GR, Bryant RH (2016) Milk production and urinary nitrogen excretion of dairy cows grazing perennial ryegrass-white clover and pure plantain pastures. Proceedings of the New Zealand Society of Animal Production, Adelaide, Australia, 76:18–21

DairyNZ (2019) Partnership farm trials show GHG possibilities [online]. Retrieved from <www.dairynz.co.nz/news/latest-news/partnership-farm-trials-show-ghg-possibilities> [at 20 June 2019]

Dewes A, Death R (2015) Getting ahead of the game. Maximising profit and environmental protection on 21st century dairy farms. Proceedings of the Society of Dairy Cattle Veterinarians of the NZVA Annual Conference, 3–24

Dynes RA, Vogeler I, Ledgard S, Wall A, Dennis S, Vibart R, White T, Brown M, Beukes P, Adler A, et al. (2018) Systems analysis to quantify the role of farm management in GHG emissions and sinks for pastoral sector. Wellington: Ministry of Primary Industries, 24p, MPI Technical Paper 2018/18

Fraser PJ, Ridler BJ, Anderson WJ (2014) The intensification of the NZ dairy Industry – Ferrari cows being run on two-stroke fuel on a road to nowhere? New Zealand Agricultural and Resource Economics Society (NZARES), Aug 28–29, 2014, Nelson, New Zealand, doi:10.22004/ag.econ.187491

Groot J, Oomen G, Rossing W (2012) Multi-objective optimization and design of farming systems. Agri Syst 110:63–77, doi:10.1016/j.agsy.2012.03.012

LIC, DairyNZ (2018) New Zealand Dairy Statistics 2017–18 [online]. Retrieved from <www.lic.co.nz/about/dairy-statistics> [at 10 Dec 2019]

Macdonald KA, Waghorn GC, Pryce JE, Spelman RJ, Williams Y, Wales WJ, Davis SR, Green TC (2014) An overview of the feed conversion efficiency trial for dairy cows – getting more from less. Proceedings of the 5th Australasian Dairy Science Symposium 2014

Ministry for the Environment (2019) New Zealand's greenhouse gas inventory 1990–2017. New Zealand Government, ME1411

PCE (2016) Climate change and agriculture: Understanding the biological greenhouse gases. Parliamentary Commissioner for the Environment, New Zealand Government, 100p

Schipper LA, Mudge PL, Kirschbaum MUF, Hedley CB, Golubiewski NE, Smaill SJ, Kelliher FM (2017) A review of soil carbon change in New Zealand's grazed grasslands. New Zeal J Agr Res (NZJAR) 60(2):93-118, doi:10.1080/00288233.2017.1284134

Thatcher A, Horne D, Brookes I (2017) A comparison of the impacts of organic and conventional dairying on the aquatic environment. Proceedings of the scientific track at the 19th Organic World Congress: ISOFAR, NCOF, TIPI, Delhi, India, 9–11 Nov 2017, Thünen Rep 54 (1):174-177, doi:10.3220/REP1510907717000

Williams ID, Ledgard SF, Edmeades GO, Densley RJ (2007) Comparative environmental impacts of intensive all-grass and maize silage-supplemented dairy farm systems: a review. Proceedings of the New Zealand Grassland Association 69:137–143

Worden JR, Bloom AA, Pandey S, Jiang Z, Worden HM, Walker TW, Houweling S, Röckmann T (2017) Reduced biomass burning emissions reconcile conflicting estimates of the post–2006 atmospheric methane budget. Nat Commun 8:2227, doi:10.1038/s41467-017-02246-0.