QUANTIFYING GREENHOUSE GAS LOSSES FROM TYPICAL MAIZE CROPPING SYSTEMS AND THE IMPACT OF POSSIBLE MITIGATION STRATEGIES USING OVERSEERFM

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Background

An analysis of New Zealand's greenhouse gas (GHG) emissions show that almost half come from agriculture (MfE, 2021). 'He Waka Eke Noa' (HWEN), a partnership between government, industry and Iwi/Māori, is focused on developing a framework to equip farmers and growers to understand the emissions from their farm enterprises and to identify how to reduce them. As part of the partnership, a pricing mechanism for agricultural greenhouse gases is also being developed. This will see farmers responsible for some of the cost of the GHG their farming enterprise produces.

There are several tools available to estimate GHG losses from cropping systems including OverseerFM[1], E-Check[2], Ministry for the Environment's Agricultural Emissions Calculator[3] and the Beef & Lamb GHG Calculator[4].

Maize is New Zealand's largest arable crop grown on around 74,000 hectares (AIMI, 2021). Of this total area, around 25% is harvested for grain. The remainder is harvested for maize silage, which is used as a supplementary feed mainly within the dairy industry. Few maize growers have modelled their GHG losses and therefore industry data is lacking. Coupled with this, there is limited grower understanding of how to decrease GHG emissions from maize cropping systems.

The aim of this paper was to model annual (1 October – 31 September) GHG emissions for twenty typical maize grain and silage production systems using OverseerFM. The impact of changes in maize crop and winter management on GHG losses were also investigated.

This information will provide much needed industry-wide data to guide arable farmers on the GHG emissions for their enterprises and how to mitigate these emissions on-farm.

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[1] https://www.overseer.org.nz/overseerfm

[2] https://www.far.org.nz/environment/greenhouse_gases

[3] https://environment.govt.nz/what-you-can-do/agricultural-emissions-calculator/

[4] https://beeflambnz.com/ghg-calculator-info

GHG Modelling and Reporting

OverseerFM (version 6.4.2) was used to estimate the biological GHG losses associated with 12 months of production (1 October 2020 – 30 September 2021) in twenty representative maize systems from Northland to Canterbury using yield data and maize crop and winter management information collected from maize growers.

OverseerFM was also used to model:

(i) The impact of different rates, formulations, and methods of nitrogen (N) fertiliser application on GHG losses from a typical Waikato maize silage and winter ryegrass silage system.
(ii) The impact of grazing the winter ryegrass planted after maize silage with dairy cows compared to harvesting it for silage.
(iii) The effect of using a fixed level of N-fertiliser input on the GHG losses of a maize plus annual ryegrass silage system where maize was planted into land which had been in long-term pasture vs a long-term cropping block.
(iv) The differences in GHG losses from a Northland maize grain crop established using conventional cultivation, minimum tillage or direct drill.

In this paper on-farm biological GHG losses from OverseerFM are reported as:

Biological GHG = methane + nitrous oxide + carbon dioxide (from N-fertiliser (urea) dissolution)

The OverseerFM value calculated is considered to provide a good indication of on-farm GHG emissions (Journeaux et al. 2021). It includes the main sources of biological GHG's that would be considered in agricultural emissions pricing: nitrous oxide (N_2O) released into the atmosphere, from dung and urine patches, and application of N fertilisers (the main driver of N_2O emissions from a cropping system). However, OverseerFM also calculates N_2O losses from crop residues and N fixation which are currently excluded from the proposed future agricultural GHG pricing framework.

Methane (CH_4) emissions are largely calculated from the required dry matter intake of a given livestock unit. The required intake depends on the energy in the feed, differing assumptions on feed metabolisable energy between emissions calculators can produce differences in the methane emission number.

Carbon dioxide (CO_2) emissions are calculated from dissolution resulting from application of nitrogen fertiliser as urea and lime. Carbon dioxide losses from the application of lime are currently excluded from the proposed future agricultural GHG pricing framework.

GHG Emissions from Representative Maize Grain and Silage Systems

Farm data for the 2020-21 growing season were collected for maize grain (n=8) and silage (n=12) systems located in the main growing areas of the country. An OverseerFM analysis was constructed for each farm and the maize and winter crop yields, N-fertiliser use, N-surplus (calculated as the sum of the nitrogen inputs used for production on the farm minus the total nitrogen that is removed from the farm as products) and annual GHG output summarised as shown in Tables 1 and 2.

Maize grain

Maize grain is typically grown as a monoculture on farms located in Northland, the Waikato, Bay of Plenty, Gisborne and the Manawatu. While historically the majority of paddocks were left fallow, in recent times there has been a move toward shorter maturity hybrid which allow the establishment of annual ryegrass (harvested for silage or winter grazed) or a green manure crop. The latter is either a single crop or a mix of species (e.g., oats, ryegrass, vetch, radish, mustard) which is sprayed out, ploughed in or crimped and rolled and left in the paddock to breakdown releasing nutrients for the next maize crop.

Most maize grain crops were grown in a continuous maize-on-maize system with many paddocks 20+ years in maize. Three growers left their land fallow during the winter whilst the others (5) planted cover crops (Table 1). Only one grower grazed their winter crop. Maize grain yields (14% moisture) ranged from 10.8 to 18.0 t/ha (average 14.6 t/ha).

N fertiliser application rate to the maize crop ranged from 59 to 358 kg N/ha (average 213 kg/ha). Only one grower applied N fertiliser to their winter crop. When considering the winter crop phase for the systems, total N fertiliser application rates for the 12-month period ranged from 59 to 368 kg N/ha. Total annual GHG emissions for the maize grain systems ranged from 1,114 to 2,873 kgCO2e/ha (average 2,036 kgCO2e/ha).

Maize silage

Maize silage is grown as part of a pasture renovation programme on dairy milking platforms and run-offs. There is also a significant amount of maize silage grown by contract growers who also either make ryegrass silage or graze dairy cattle on their land during the winter months (Table 2). With this in mind, maize silage systems ranged from crops grown on continuous cropping land (years in pasture = 0) right through to long-term pasture paddocks (years in pasture = 10). A winter crop of either annual or perennial ryegrass or oats was planted by every maize silage grower because the earlier harvest date for silage crops provides an effective window for these crops. Nine silage growers also wintered livestock but the type, duration on-farm and stocking rates varied significantly (see Table 2). Maize silage yields ranged from 15.0 to 26.8 tDM/ha (average 21.1 tDM/ha).

Nitrogen fertiliser application rate to the maize crop ranged from 131 to 310 kg/ha (average 220 kg/ha). Eight growers applied nitrogen to their winter crop at 30 to 92 kg/ha. When considering the winter crop phase for the systems, the total N fertiliser application rates for the 12-month period were 133 to 353 kg/ha.

Maize silage systems without livestock (n=3) had average biological GHG emissions of 1,850 kgCO2e/ha which was very close to that of maize grain systems without livestock (1,916 kgCO^2e/ha). The range of emissions from non-livestock silage systems was 1,697 to 2,096 kg CO^2e/ha. Maize silage systems which included winter livestock produced average biological GHG emissions of between 1,512 to 6135 kgCO^2e/ha (average 3,543 kgCO^2e/ha).

Table 1: Maize grain yield, crop management, rotation history and biological GHG emissions

Region	**Grain Yield (t/ha)**	**Fertiliser N Applied to Maize (kg/ha)**	**Fertiliser N Applied to Winter Crop (kg/ha)**	**N-Surplus (kg/ha)**	**Prior Years in Pasture**	**Winter Crop**	**Grazed**	**Methane**	**$N_2$0**	**CO_2 diss**	**Annual Biological GHG emissions**
								(kg CO_2e/ha)			
BOP	17.0	159	0	-46	8	Oats/annual ryegrass	N	0	1,836	183	2,019
BOP	15.3	307	61	-4	0	Annual ryegrass	N	0	1,701	536	2,237
East Coast	18.0	267	0	48	0	Annual ryegrass	Y	456	1,992	425	2,873
Manawatu	13.5	223	0	61	0	Fallow	N	0	1,550	284	1,834
Manawatu	14.0	175	0	7	0	Fallow	N	0	1,575	219	1,794
Northland	15.4	358	0	172	0	Fallow	N	0	2,364	454	2,818
Northland	10.8	156	0	39	0	Vetch, lupin & ryecorn	N	0	1,398	201	1,599
South Auckland	13.0	59	0	-97	3	Brassica	N	0	1,055	59	1,114
Averages	**14.6**	**213**						**57**	**1,684**	**295**	**2,036**

Table 2: Maize silage yield, crop management, rotation history and biological GHG emissions

Region	**Maize Silage Yield (tDM/ha)**	**Fertiliser N Applied to Maize (kg/ha)**	**Fertiliser N Applied to winter crop (kg N/ha)**	**Total Fertiliser N**	**N-Surplus (kg/ha)**	**Prior Years in Pasture**	**Winter Crop**	**Grazed (G) or Silage (S)**	**Methane**	**N_20**	**CO_2 diss**	**Annual Biological GHG emissions**
									kg CO_2e/ha			
BOP	26.8	228	62	290	-217	0	Annual ryegrass	G	2,245	1,824	293	4,362
Canterbury	20.0	231	69	300	26	10	Forage oats	S	0	1,619	477	2,096
Manawatu	23.0	131	46	177	-143	10	Perennial ryegrass	G	1,423	1,204	219	2,846
Manawatu	21.0	133	0	133	-162	5	Perennial ryegrass	G	1,455	1,076	164	2,695
Northland	15.0	193	0	193	-178	9	Perennial ryegrass	G	317	957	238	1,512
Northland	16.0	183	30	213	-12	10	Perennial ryegrass	G	2,357	1,967	268	4,592
Northland	16.0	183	30	213	37	9	Annual ryegrass	G	2,596	1,853	268	4,717
Taranaki	26.0	292	0	292	-37	10	Annual ryegrass	G	1,050	1,439	220	2,709
Waikato	22.4	310	0	310	-2	0	Annual ryegrass	G	471	1,447	403	2,321
Waikato	22.0	268	69	337	-112	0	Perennial ryegrass	S	0	1,336	421	1,757
Waikato	24.5	261	92	353	-222	4	Annual ryegrass	S	0	1,205	492	1,697
Waikato	20.2	182	46	228	-76	0	Annual ryegrass	G	4,007	1,835	293	6,135
Average	**21.1**	**220**	**37**	**253**					**1,327**	**1,480**	**313**	**3,120**

Discussion

This analysis highlights significant differences between maize systems in winter livestock numbers, N surplus and N fertiliser application rates. These differences have an impact on emissions of methane, nitrous oxide and carbon dioxide from N fertiliser dissolution.

Overall, in maize grain systems there were moderate to high correlations between annual biological GHG emissions and N-surplus (R^2 =0.4876) and total fertiliser N applied (R^2 = 0.7761). On average, the highest GHG emission for grain systems was nitrous oxide (83%).

In contrast there were poor correlations between annual biological GHG emissions from maize silage systems and total fertiliser N applied (R^2 = 0.097) and N-surplus (R^2 = 0.068). This was likely due to the contribution of methane from winter grazing. Methane was on average 34% of the annual biological GHG emissions but there was a large range (0 to 65%). In contrast nitrous oxide was on average 53% of the annual biological GHG emissions but the range was narrower (30 to 77%). There was a moderate correlation between methane and nitrous oxide (R^2 = 0.4313) which was unsurprising given the contribution of dung and urine patches to nitrous oxide emissions.

When the data for grain and silage were combined (n=20) there was no correlation between annual biological GHG emissions and N-surplus (R^2 =0.002) or total fertiliser N applied (R^2 = 0.0077).

In this study, the maize systems with the highest GHG losses included a grazed winter crop. The farm with the lowest GHG losses (1,100 kgCO_2e/ha/year) utilised a winter brassica mix as a green manure crop and low (59 kg N/ha) fertiliser N inputs to grow a 13.0 t/ha maize grain crop. Further studies should investigate the impact of systems like these on profitability especially when the rising cost of N-fertiliser and GHG charges are considered.

Scenario Modelling

Nitrogen fertiliser management

The impact of N fertiliser management on GHG losses from a maize silage system was modelled in OverseerFM using a representative scenario of a Waikato maize silage grower using conventional cultivation to establish maize in a long-term cropping paddock (Years in pasture = 0). Maize silage was planted in October and harvested in March. The crop yielded 22 tDM/ha maize silage and was followed by a direct-drilled winter crop of 4 tDM/ha annual ryegrass silage. A total of 250 kg/ha DAP (45 kg N/ha) was applied to the maize crop as starter fertiliser. Side-dress N was then applied to the model at varying rates to give a total maize crop fertiliser N application of 100 - 350 kg N/ha. No fertiliser was applied to the annual ryegrass. The GHG emissions from these systems were calculated and compared.

The impact of different forms of N, application methods and single vs split dressing were also considered using the representative scenario as a comparator (Table 3).

Table 3: GHG emissions from a typical maize silage/annual ryegrass silage system in Waikato when a range of fertiliser N rates and management practices are applied.

		Urea, incorporated, November	**Urea, surface applied, November**	**Urea, incorporated split Nov/Dec**	**Urease-coated N[5] surface applied November**	**Urease-coated N surface applied, split Nov/Dec**
		Biological GHG emissions (kg CO2e/ha)				
Total fertiliser N applied (kg/ha)[6]	100	584	606	-	592	-
	150	820	875	-	840	-
	200	1,027	1,150	1,045	1,091	1,066
	250	1,312	1,448	1,296	1,363	1,327
	300	1,565	1,745	1,550	1,630	1,590
	350	1,837	2,062	1,819	1,921	1,870

N management was shown to strongly influence the GHG emissions from a maize crop (Table 3). For a given yield, the more nitrogen you apply, the higher the GHG emissions (Table 3). Broadcasting urea also results in higher N and GHG losses than incorporating it. The loss can be as much as 10% at higher rates (Table 3). In contrast, side dressing with urease-coated N reduced GHG emissions by 2-7% with higher reductions being made at higher N application rates (Table 3). Very modest (1-2%) further reductions in GHG emissions can be made by split-applying urea, however the economic implications and the opportunity to revise the total input should be considered.

Winter crop management

The impact of winter crop management on GHG losses from a maize silage system was modelled using the scenario described above, with a maize fertiliser N input of 200 kg/ha/year and no fertiliser N applied to ryegrass. Specifically, we investigated losses from harvesting annual ryegrass silage (4 tDM/ha) vs harvesting an equivalent amount of drymatter by grazing dairy cows (Table 4).

The cows were Friesian x Jersey (495 kg liveweight) and were grazed at 6.8 cows/ha for 2 months to replicate a typical dairy cow wintering system.

Table 4: Biological GHG losses from a representative maize silage system with and without livestock.

Wintering system	Biological GHG emissions (kg CO2e/ha)			
	CH_4	N_2O	CO_2 (N-fertiliser dissolution)	Total
Annual Ryegrass Silage	0	860	249	1,109
Grazed Dairy Cows	1,531	1,204	249	2,984

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[5] Coated urea products (e.g., SustaiN® or N-Protect®) contain a urease inhibitor

[6] Includes starter fertiliser

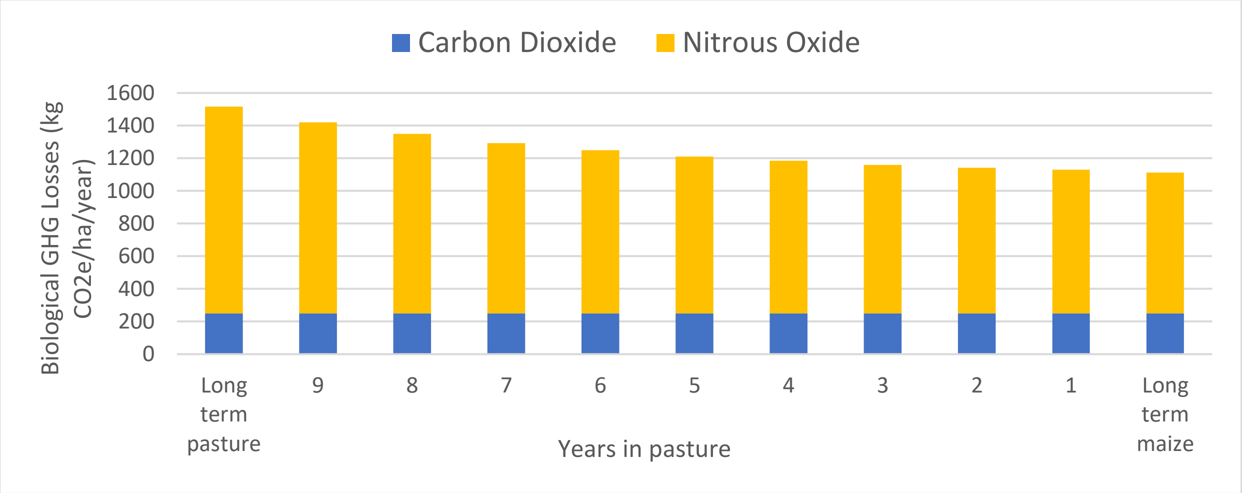
Wintering livestock increased total annual GHG emissions by 169% when compared to harvesting the equivalent amount of pasture as silage. The main contributors to the increase were methane, from rumen fermentation, and nitrous oxide from excreta deposited in the paddock (Table 4).

Years in pasture

While much of New Zealand's maize grain is grown on repeat cropping ground, maize silage is often grown in long-term pasture paddocks some of which have a history of dairy shed effluent application. Research has shown that these paddocks require no N fertiliser (base, starter, or side-dress) to achieve high crop yields (Johnstone et al, 2010). However, farmers commonly apply N fertiliser "just in case" the crop needs it.

To investigate the impact of 'flat rate' N-application on GHG losses from first year maize paddocks compared to those which had been long-term cropped, the scenario described above (conventional cultivation, 22 tDM/ha maize silage, 4 tDM/ha winter annual silage, 200 kg N/ha fertiliser input) was used, and the years in pasture modified from 10 (maize grown in a long term pasture paddock) to 0 (maize grown in a long term cropping paddock) in OverseerFM (Figure 1). Under this scenario, the N surplus remained stable at -243 kg/ha because N-surplus does not consider changes in soil N pool.

Figure 1. Modelled impact of 'flat rate' N-fertiliser application (200 kg N/ha) to biological GHG emissions for a maize silage crop following varying years in pasture.



When a flat rate of N fertiliser (200 kg/ha) was applied to all paddocks regardless of their history, biological GHG emissions were 36% higher for the long-term pasture paddocks. This was due to the soil N supply meeting crop requirements and the fertiliser N being surplus to requirements. Put simply, total N supply under these scenarios exceeded demand from the maize crop, resulting in N losses.

Crop establishment method

Globally, there is a trend to establish maize crops using reduced tillage methods. A growing number of maize crops are also established via direct drill or strip-till in New Zealand (a system where a narrow band, where the maize is planted, is cultivated and the remainder of the paddock is left undisturbed).

To investigate the impact of reduced tillage systems on maize crop GHG emissions, the annual GHG emissions from a Northland maize grain crop yielding 12 t/ha grown in a long-term cropping paddock (years in pasture = 0) was modelled. Maize was followed by a direct drilled winter brassica green manure crop. A total of 182 kg N/ha applied as 250 kg/ha DAP as a starter and 300 kg/ha coated urea as a side-dress was applied to the maize crop (Table 5). Different maize establishment techniques were applied to the model.

Table 5. Impact of maize crop establishment technique on biological GHG emissions from a maize grain and direct drilled brassica green manure crop system

	Biological GHG (kg CO_2e/ha)		
Maize Establishment Method	N_20	CO_2 dissolution	Total
Direct Drilled	1,461	219	1,680
Minimum Till	1,461	219	1,680
Conventional Cultivation (includes ploughing)	1,504	219	1,723

There were minimal differences in the GHG emissions from maize crops established using different practices, with crops established via conventional cultivation having only slightly higher modelled N_2O losses. This was likely due to a more rapid degradation of crop residues and/or an increase in mineralisation.

These OverseerFM calculations show changing maize establishment method makes little difference to on-farm biological GHG losses as modelled by OverseerFM.

Possible GHG mitigation strategies for maize growers

This analysis highlights a number of possible GHG mitigation strategies for New Zealand maize growers. The two main strategies are reducing nitrogen input and winter crop management.

Reducing nitrogen input

To reduce N input growers first need to set a realistic yield target, tools such as AmaizeN (www.amaizenlite.org.nz) can offer a guide of what to expect. Then growers need to consider what N can be contributed from the soil and preceding crop residues. The gap between what the crop requires to reach an average yield and what will be provided by soil and residue sources can then be filled with fertiliser N.

New Zealand agricultural soils contain relatively high organic matter levels with soil carbon stocks, averaging 100 t C/ha in the top 30 cm (Manaaki Whenua Landcare Research, 2020). The ability of these soils to mineralise a significant amount of N should therefore not be ignored when making N application rate decisions. The N contribution of preceding pasture or crops should also be considered. To assess soil N supply two measures need to be made, an assessment of soil mineral N and an assessment of potentially mineralisable N (Foundation for Arable Research, 2021).

The rate, timing and form of side-dress N is important. Soil mineral N testing prior to side dressing will allow growers to assess soil nitrogen levels so they can fine tune fertiliser inputs.

Precision agriculture technologies such as grid or zone soil mineral N sampling combined with variable rate fertiliser application can further decrease N-surplus thereby reducing GHG emissions. Ideally growers should incorporate urea or apply it immediately prior to rain to minimise ammonia volatilisation.

Coated urea products can also reduce volatilisation as these contain a urease inhibitor that slows down the conversion of nitrogen in urea to ammonia gas. The effectiveness of a urease inhibitor in reducing ammonia emissions depends on a range of factors, such as type of inhibitor, soil type, cultivation system, or climatic conditions (Klimczyk et al., 2021). Reductions as high as 50 – 60% in ammonia volatilisation have been reported (Cantarella et al., 2018; Modolo et al., 2018; Wang et al., 2020). Eight New Zealand trials compared urea and a urease inhibitor, SustaiN® as a broadcast fertiliser in maize. Benefits to SustaiN® were found only at two sites and the authors concluded that it may be a useful option where growers are broadcasting fertiliser N in dry conditions (FAR, 2008). It is important that an economic analysis is undertaken to ensure the benefit of using coated urea (lower N loss, less GHG) offsets the additional product cost.

Organic sources of nitrogen do not have the carbon dioxide emissions associated with fertiliser dissolution. Dairy effluents also have a lower emission factor than synthetic nitrogen sources, however, other organic N sources (poultry, pig, composts) have an equivalent emission factor to synthetic fertiliser. It must also be noted that application rates for effluents tend to be higher than those for synthetic products, this is because not all the nitrogen in an organic product is immediately available for plant uptake.

Winter crop management

Winter management has a significant impact on GHG losses from maize systems. When growing a non-legume, it is important that N fertiliser application rates match winter crop demand.

Finally, livestock make a significant contribution to GHG emissions. The data presented in this study suggest that those maize growers who do not winter graze animals are likely to lose around 2,000 kgCO_2e/ha/year, whilst systems incorporating livestock could expect to have losses closer to 3,500 kgCO_2e/ha/year and as high as 6,000 kg CO_2e/ha/year.

Summary

Some take home message for maize growers are:

(i) **Know your number**. Use one of the available tools to calculate the GHG loss for your farm. It is a step towards preparing for the future. Understanding where your emissions come from can help when considering what actions might be possible to manage or reduce them.

(ii) **Make sure your nitrogen application rate is appropriate**. Set realistic paddock yield expectations for your maize crop and consider paddock history and soil available nitrogen levels before determining crop nitrogen inputs.

(iii) **Consider the form, rate and timing of N application.** Incorporate urea or apply it prior to rain where possible. Alternatively consider the cost: benefit of using urease-coated N products. Consider organic sources of nitrogen including winter crop options which will help minimise N fertiliser inputs.

(iv) **Account for livestock**. If you want to reduce GHG losses from your farm, consider winter management options which do not include livestock. Alternatively take into consideration the GHG cost of animals as well as other potential co-benefits from livestock grazing when comparing gross margins and calculating grazing charges.

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