Mitigation and Heterogeneity in Management Practices on New Zealand Dairy Farms

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Abstract

Pastoral farming can result in adverse environmental effects such as nitrogen leaching and greenhouse gas emissions. However, the cost of mitigation and hence the socially appropriate level of tolerance for environmental effects is still unclear. Research to date within New Zealand has either estimated the costs of specific mitigation technologies or used simulation modelling at a farm scale. This is limited for two key reasons: neither approach uses data from actual implementation of technologies and practices on real farms and hence costs are speculative; and both largely treat farms as homogenous when in reality they vary greatly. We use data on 264 farms to estimate a distribution of "farm management" residuals in how efficiently nitrogen leaching and greenhouse gas are used to generate production. We interpret this distribution as a measure of the potential for feasible, relatively low-cost mitigation to take place as less efficient farmers move toward existing best practice.

We can explain only 48% percent of the OVERSEER-modelled variation in New Zealand dairy farms' nitrogen use efficiency based on geophysical factors, specific mitigation technologies and practices that move emissions across farms such as wintering off animals. This suggests a potentially large role for management factors and farmer skill. In contrast, OVERSEER-modelled variation in greenhouse gas use efficiency is more easily explained by the observable factors (73%) but the potential for mitigation through management changes is still not insignificant. Using management practices that are already in commercial use, this first study using this approach suggests that improvements in nitrogen use efficiency may be able to reduce leaching by more than 30 percent, while improvements in greenhouse gas use efficiency may be able to reduce emissions by more than 15 percent; the potential varies considerably across farms.

JEL codes

Q53, Q57

Keywords

Marginal abatement cost curves, climate change, agriculture, greenhouse gas, heterogeneity, leaching, mitigation, nitrogen, use efficiency

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1. Introduction

Pastoral farming can result in adverse environmental effects such as nitrogen leaching and greenhouse gas emissions. Nutrient leaching from agricultural land is recognised as contributing to poor water quality in most developed catchments (Ministry for the Environment, 2007; Millennium Ecosystem Assessment, 2005). Greenhouse gas (GHG) emissions from agriculture are responsible for 48 percent of New Zealand's total emissions (Ministry for the Environment, 2009), and globally, about 50 and 60 percent of all anthropogenic methane and nitrous oxide emissions, respectively, are due to agriculture (Smith et al., 2007).

In New Zealand, there is a growing awareness among farmers, industry, government and consumers of these adverse environmental impacts. In some cases, regulatory intervention has imposed limits or costs on nutrient leaching and GHG emissions from farms. For example: a nitrogen trading scheme has been introduced for Lake Taupo (Young et al., 2010), nitrogen leaching in the Lake Rotorua catchment is capped under "Rule 11" (Environment Bay of Plenty, 2008), and, for GHGs, agriculture is being considered for entry into the New Zealand Emissions Trading Scheme (NZETS) after 2015. However, the cost of mitigation and hence the socially appropriate level of tolerance for adverse environmental effects is still unclear.

Estimation of mitigation costs requires an understanding of the environmental implications of specific actions and an estimation of the economic costs of those actions. We focus on the latter.[1] Research to date within New Zealand has either estimated the costs of specific mitigation technologies (e.g. Monaghan (2009) and Twaddle (2009)) or used simulation modelling at a farm scale. These are limited for two key reasons: neither approach uses data from actual implementation of technologies and practices on real farms and hence costs are speculative; and both largely treat farms as homogenous when in reality they vary greatly. In section 1.1 we briefly synthesise results from the simulation modelling literature and identify some key problems in using the collection of existing simulation studies to infer mitigation potential and costs.

This paper takes a different approach in response to these limitations; we focus on mitigation through improved management. There is evidence of a wide range of nitrogen (N) leaching and greenhouse gas (GHG) emissions use efficiency (how much product is produced

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[1] Syntheses and discussions of the effectiveness of mitigation actions have been carried out by Clark et al. (2011b), Eckard et al. (2010), Luo et al. (2010) and Robson and Edmeades (2010). Edmeades (2008) focuses on the effectiveness of nitrogen inhibitors. Grainger and Beauchemin (2011) discuss the use of different types of feed.

per unit of pollutant) in existing farming practice (Ledgard et al., 2011). Where differences in production efficiency between farms are driven by management, encouraging less efficient farmers to adopt farm management practices similar to those of the more efficient farmers is a potential mitigation strategy.

We use an unbalanced panel of 264 farms over three years to estimate a distribution of "farm management" residuals in how efficiently N leaching and GHG emissions are used to generate production. This is similar to the use of a Solow Residual to explore the role of total factor productivity in economic growth. We interpret this distribution as a measure of the potential for feasible, relatively low-cost mitigation to take place as less efficient farmers move toward existing best practice.[2] Jiang and Sharp (2013a and 2013b) have explored the technical and cost efficiency of New Zealand dairy farms, but have not explicitly considered leaching or emissions.

We can explain only 48% percent of the OVERSEER-modelled variation in New Zealand dairy farms' N use efficiency based on geophysical factors, specific mitigation technologies and practices that simply move emissions across farms such as wintering off animals. This suggests a potentially large role for management factors and farmer skill. In contrast, we can explain 73% of the OVERSEER-modelled variation in GHG use efficiency based on geophysical factors and specific practices. However, the potential for mitigation through management changes is still not insignificant. Using management practices that are already in commercial use, improvements in N use efficiency may be able to reduce leaching by more than 30 percent, while improvements in greenhouse gas use efficiency may be able to reduce emissions by more than 15 percent; the potential varies significantly across farms. These gains may be realised at relatively low cost given that improvements in use efficiency are associated with greater cash operating surplus per hectare for farms (Figure 28 and Figure 29), but adoption of N and GHG efficient practices will take time and may require training and other assistance.

1.1. Synthesis of On-farm Simulation Model Results

The use of computer simulation models is a well established approach to investigating the cost of on-farm mitigation. New Zealand models include Farmax (Bryant et al., 2010), the DairyNZ Whole Farm Model (Beukes et al., 2011), and the Waikato Multiple Agent Model (Doole et al., 2011).[3] Others use simple models based on farm budgets. N leaching and GHG emissions are frequently modelled using the OVERSEER model (AgResearch, 2010). Almost all of

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[2] Clark et al. (2011) also identify this as a mitigation option for greenhouse gas emissions.

[3] The states of nutrient leaching and land use modelling in New Zealand are summarised in Anastasiadis et al. (2013b) and Anastasiadis et al. (2013a).

these models were constructed as decision support tools and require the user to specify, and assess the feasibility of, every simulation.

Results from simulations using these models have been reported by AgriBusiness Group (2009), Anderson and Ridler (2010), Beukes et al. (2010), Beukes et al. (2011), Doole and Pannell (2009), Doole (2010), Doole et al. (2012), Dynes et al. (2011), Monaghan et al. (2008), Moyo and Yates (2010), Ridler et al. (2010), Smeaton and Blackman (2007), Smeaton and de Klein (2008), and Smeaton et al. (2011). Drawing from the results in these papers, we compiled a database of farm simulation results. Additional results were generously provided by Barrie Ridler.

Figure 1 and Figure 2 are constructed from our database of farm simulation results. Where possible for dairy farms, we have standardised the price of milk solids to \$6 per kg. However, no other standardisation was possible and hence we cannot identify how much of the observed variation is due to different modelling assumptions. Fitted trend lines are provided to give a general sense of the data.[4] Marginal abatement cost curves could in theory be constructed using the derivatives of these trend lines.

Figure 1: Nitrogen leaching and profit for Waikato dairy farms

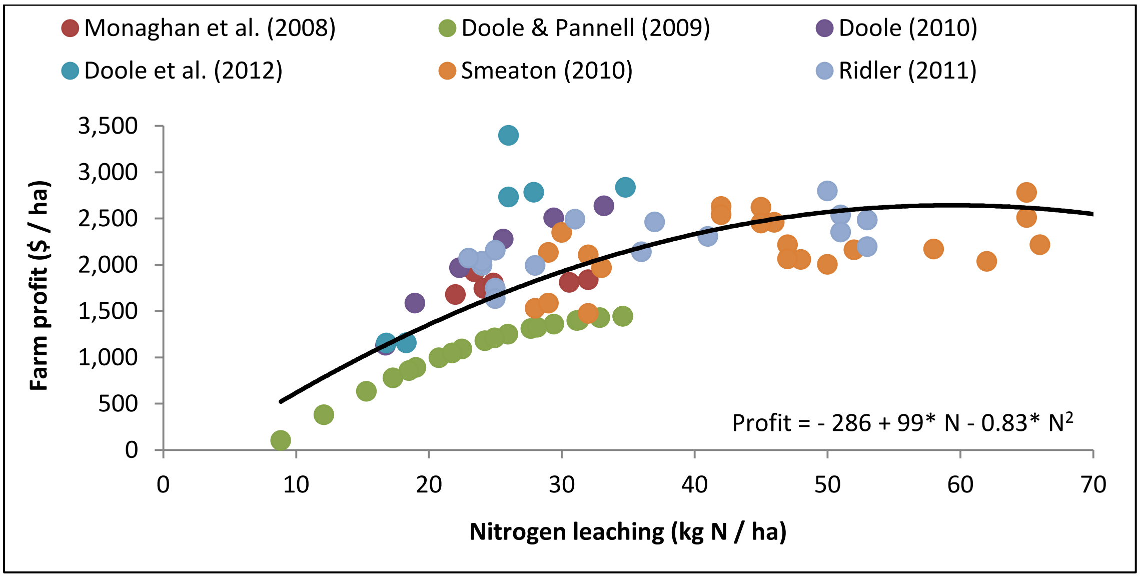

Figure 1 gives an overview of the relationship between N leaching and cash operating surplus for dairy farms in the Waikato region. This figure draws on 83 simulation results across 6 studies.

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[4] For all three figures: * indicates a coefficient is significant at the 1 percent level, otherwise the coefficient is not significant.

Figure 2: Greenhouse gas emissions and profit for Waikato dairy farms

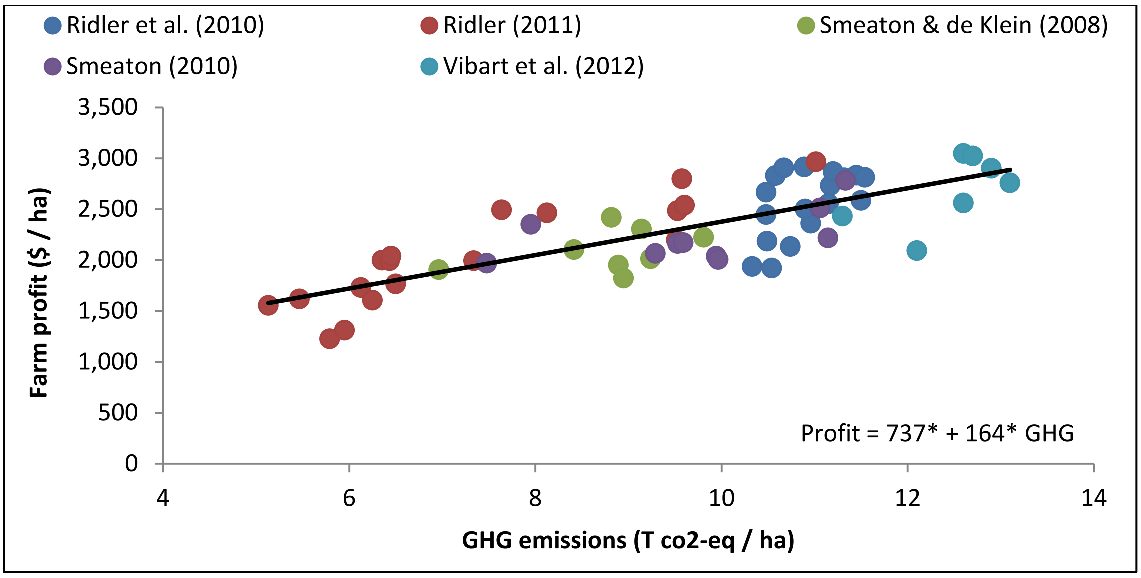

Figure 2 gives an overview of the relationship between GHG emissions and cash operating surplus for dairy farms in the Waikato region. This figure draws on 62 simulation results from 5 studies.

Figure 1 and Figure 2 highlight the general negative relationship between mitigation and farm profit.[5] We cannot combine the results shown in these figures to estimate mitigation cost curves as different authors have made different assumptions and insufficient information has been provided to standardise the results. Furthermore, it is not possible to use any individual study (other than the work using the optimisation model by Doole) for this purpose, as simulation results demonstrate possible farm systems, not optimal farm systems. Constructing marginal abatement cost curves using possible instead of optimal farm systems results in curves with both positive and negative costs mixed with both increasing and decreasing costs.[6] Such a marginal abatement cost curve is clearly absurd.

Furthermore, we identify the following limitations with the simulation results. While the underlying models have been compared to existing farms, the simulation results have not been systematically tested against real data, thus it is difficult to assess the feasibility or applicability of the results on a real farm. In addition, capital costs were sometimes ignored; difficulties in accessing credit were never accounted for; the costs to learn and implement new systems or technologies were ignored; and no allowance was made for risk management. Finally, the results

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[5] Some publications reported simulations where, by reducing overstocking, farms could both improve their profitability and reduce their environmental impact. Ackerman et al. (2009) and Barthel et al. (2006) consider why this may not occur in practice.

[6] For example we might observe that mitigating the first units of pollutant costs $30 per unit, mitigating the next few units results in revenues of $10 per unit, and mitigating the next few units costs $10 per unit.

are not representative of New Zealand dairy farms; the simulations focused almost exclusively on Waikato dairy farms and do not account for heterogeneity across farms in climate, land characteristics and existing farm infrastructure.[7]

This paper is set out as follows: in section 2 we discuss the data we use and show raw distributions of N leaching and greenhouse gas emissions use efficiency. We then estimate models of use efficiency and derive the residuals in section 3. Sections 4 and 5 present results on the residuals with regard to N and GHG use efficiency respectively. Section 6 concludes.

2. Data from MAF Monitor Farms

We use unit record annual farm level data collected as part of the Ministry of Agriculture and Forestry (MAF) monitor farm reporting, from 2008 to 2010 (Ministry of Agriculture and Forestry, dataset, 2010).[8] MAF combines these data by region and farm type to construct representative model farms, which are the focus of their monitor farm reports (see, for example, Ministry of Agriculture and Forestry (2011)).

Estimates of *Nitrogen leaching* (kg N/ha) and *GHG emissions* (T CO_2-eq/ha) for the farms were not measured on-farm but were calculated from reported farm characteristics and management practices using the OVERSEER model (AgResearch, 2010). AgFirst, an agricultural consulting firm who were involved in the collection of the unit record data, ran the OVERSEER model for each farm record.[9] The use of a model means that some variability in N leaching and greenhouse gas emissions is not captured.

Our final dataset is an unbalanced panel of 264 dairy farms over three years.[10] Out of a total of 443 observations, 127 farms were observed in only one year, 95 farms were observed in two years, and 42 farms were observed in all three years. The number of observations in each year also varied: 94 farms were observed in 2008, 192 farms were observed in 2009, and 157 farms were observed in 2010. The farms are well distributed across regions, with 15% of our

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[7] These issues are regularly encountered by consultants when providing advice to farmers. See for example work by AgFirst (2010). A notable exception is Doole (2010), who explicitly focuses on heterogeneity using data from dairy farms in the Upper Waikato.

[8] The Ministry of Agriculure and Forestry has since been merged with the Ministry of Fisheries to form the Ministry for Primary Industries (MPI).

[9] While monitor farm reports are produced for both dairy and sheep/beef farms, our analysis is limited to dairy farms. In order to consider use efficiency, a measure of on-farm production is required. For dairy farms it is straightforward to quantify production in kg milk solids. But for sheep/beef farms some composite measure of production would be needed, and constructing such a measure was beyond our expertise.

[10] Our initial dataset contained 461 observations. After cleaning we had 443 observations from 264 farms. Because we pool our data and do not account for clustering in errors, our standard errors are biased. This does not affect the residuals, which are the focus of the paper.

observations in Canterbury, 15% in the Lower North Island, 12% in Northland, 14% in Southland, 18% in Taranaki and 26% in Waikato.

For each farm in each year we observe *Total effective area*, the area used for milking and grazing the dairy herd (ha), and *Milk solids*, total milk solid production for the farm (kg MS).

Figure 3 and Figure 4 give the distributions for N and GHG use efficiency. They have been constructed such that the more efficient farms are to the right and the less efficient farms are to the left. For both figures we observe a skewed distribution with a large number of relatively less efficient farms and a longer tail of farms that are more efficient.

Figure 3: Distribution of N use efficiency

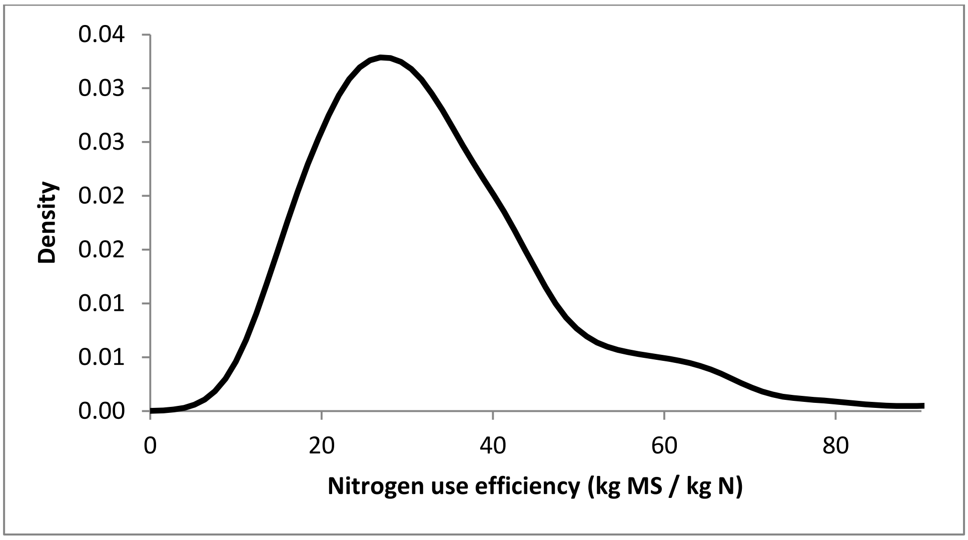
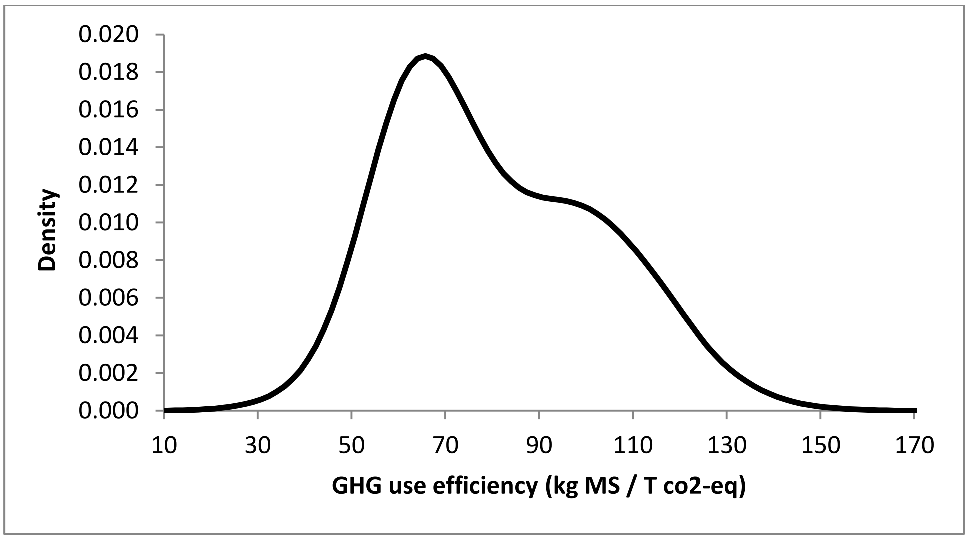


Figure 4: Distribution of GHG use efficiency



There is significant variation in use efficiency among farms. The most N efficient farms produce more than three times the amount of milk solids per kg N than the least efficient farms. The most GHG efficient farms produce more than twice the amount of milk solids per T GHG than the least efficient farms. How much of this variation is due to factors that can be managed on existing farms is the focus of our investigation.

We now describe the farm characteristics included in the monitor farm data that are used for our analysis. We group the farm characteristics into two categories: exogenous characteristics of the land and farming practices. Some descriptive statistics are reported in Table 1.

Some characteristics are out of the control of an existing farmer. We observe mean annual *Rainfall* (mm); mean annual *Temperature* (°C)[11]; *Topography*, classified as flat land (74%), rolling land (20%) or easy hill country (6%); *Soil type*, classified as peat (3%), pumice (5%), recent yellow-grey earth (YGE) (15%), sands (4%), sedimentary (42%) and volcanic soil (30%)[12]; and *Irrigated farm*, a binary variable indicating whether the farm is irrigated.[13] 17 percent of records were for irrigated farms.

Other characteristics are within the control of an existing farmer. We observe *Stocking rate*, the number of animals per hectare (animals / ha); *Young stock grazing*, classified as young stock on permanently (25%), young stock off until weaning (52%), young stock off for 9 months (23%) and young stock off permanently (1%)[14]; and indicators for the use of specific mitigation practices: the grazing of animals (other than young stock) off farm during winter, the use of a feed pad, the use of a wintering pad, and the application of nitrogen inhibitors. These practices were reported on 48%, 17%, 7% and 6% of farms respectively. For those farms that we observe in 2010, we also observe cash operating surplus.

Table 1: Summary table of variables

	Mean	Std. dev.	Median	Min	Max
Rainfall (mm)	1246	393	1200	450	2800
Temperature (°C)	13	1	13	10	18
Total effective area (ha)	156	94	131	35	795
Production(T MS)	147.7	101	121	27.5	735
N leaching (kg N/ha)	32	12	30	10	95
GHG emissions (T CO_2-eq/ha)	12.4	4.1	11.6	3.8	28.5
N use efficiency (kg MS/kg N)	34	15	31	10	105
GHG efficiency (kg MS/T CO_2-eq)	81	22	76	30	150
Stocking rate (cows/ha)	2.8	0.7	2.8	1.0	5.0

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[11] Where these data were missing, the mean temperature for farms in the same region was used.

[12] Soil type for some farms in 2008 was classified using an alternative set of definitions. Where these farms were observed in 2009, we use their recorded soil type in 2009 to help reclassify their soil type in 2008. Observations for which we could not reclassify the 2008 soil type were dropped.

[13] As this variable was not observed in 2008, we assume that farms that were irrigated in 2009 were also irrigated in 2008.

[14] Young stock grazing in 2008 was classified using only the descriptions young stock off and young stock on. We assume these are equivalent to young stock off until weaning, and young stock on permanently, respectively.

Production per animal (MS/cow)	345	67	338	175	765[15]
Production per hectare (MS/ha)	963	306	942	245	2035

We also observe measures of farm production, in particular *production per animal* and *production per hectare*. These two measures are linked via stocking rate and arise as a result of all the management choices that a farmer makes on-farm.

Distributions of stocking rate, production per animal and production per hectare are given in Figure 16, Figure 17 and Figure 18, respectively. There three measures are all associated with the intensity of the farm and exhibit moderate positive correlation with both N and GHG use efficiency. It follows that more efficient farms tend to be more intensive.

3. Estimating Distributions of Manageable N and GHG Use Efficiency

We use a regression model to separate use efficiency due to farmers' skill and farm management practices from use efficiency due to other factors. Given that we cannot observe farmer skill, we instead control for all other factors and allow farmer skill to be captured in the residual. Given that the residual contains all uncontrolled exogenous variation and model misspecification, interpreting the residual as a measure of farmer skill and choice of management practice will be overstating the influence of these. On the other hand, some of the exogenous variables will be correlated with farmer skill – e.g. the best farmers may have the better farms. This would lead to an understatement of the role of skill.

We control for variation in land and atmospheric conditions as these are given for existing farmers. Whether a farm is irrigated or not is also included. If farmers have access to irrigation it will generally be used and changes in irrigation infrastructure are slow.

In addition to these exogenous factors, we also control for the grazing of stock off the farm, as this only moves their emissions elsewhere. Further controls are included for the use of specific mitigation technologies (wintering pad, stand-off pad, and nitrogen inhibitors). While the use of such technologies is a farm management decision, they are not our focus. Our methodology is not appropriate for assessing their potential for wider use at low cost. Too few farms employ them to date, and those that do are not a random sample. We hence control for their sometimes-significant effects on nutrient and GHG use. As the effectiveness of nitrogen

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[15] This seems a very high level. However, it is a high-input, low-stocking rate farm with a Friesian herd, and the data providers believe this is not impossible. This extreme is only one data point and has no material impact on the results.

inhibitors is known to vary with rainfall and temperature (Kelliher et al., 2008; Menneer et al., 2008), an interaction effect is included.

The model is fitted using ordinary least squares. Thus we assume the effects of the different variables are both linear and additive. Given the complex chemical and biological processes that result in N leaching, GHG emissions and milk solids production, this is clearly a simplification and will generate model misspecification errors. These are a problem only if these errors are correlated with skill and management.

We first present results for the underlying variables, production, N leaching and GHG emissions, before presenting results for use efficiency. These help with the interpretation of the results in which we are most interested.

3.1. Determinants of Production, N Leaching and GHG Emissions

Table 2 shows that some characteristics have predictable relationships with milk solid production per ha. For example, sloped land and farms that graze young stock on produce less per ha. Irrigation and feed pads allow greater intensity. N leaching and GHG emissions are highly correlated with production (0.32 and 0.65), so it is unsurprising that topography, young stock management, irrigation and feed pads have the same relationships with them as with production. We can't tell whether land with these characteristics is good for milk production when leaching and emissions are a concern.

In other cases production and N leaching are opposite. For example high rainfall is associated with low production and high leaching. This clearly suggests that where nutrient pollution is a concern, it would be better if farms were on lower rainfall land. Other characteristics, for example pumice soil, appear to increase N leaching and GHG emissions with no significant effect on production. Again where land-use change is an option, moving farming away from pumice soil and avoiding new dairy farms on this land could be helpful. Finally, winter grazing off is associated with both increased production and lowered leaching – of course it is not possible for all farms to do this, but if animals can be moved to areas where there is less damage there can be a net gain.

Table 2: Regression results for production, N leaching and GHG emissions – do not interpret as causal relationships

	Production per hectare (kg MS / ha)			N leaching per hectare (kg N / ha)			GHG emissions per hectare (T co2-eq / ha)		
Explanatory variables	Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.	
Rainfall (mm)	-0.15	0.038	***	0.0040	0.0019	**	-0.0021	0.0004	***
Temperature (°C)	-35	9.5	***	0.81	0.47	*	-0.075	0.11	
Topography = easy hill	-180	45	***	-4.2	2.2	*	-0.95	0.51	*
Topography = flat	(Control)								
Topography = rolling hill	-120	28	***	-4.0	1.4	***	-0.88	0.32	***
Soil = peat	110	59	*	1.4	2.9		2.0	0.67	***
Soil = pumice	70	50		15	2.5	***	1.8	0.57	***
Soil = recent YGE	31	33		4.4	1. 7	***	0.89	0.38	**
Soil = sands	-77	57		-1.3	2.8		-0.79	0.65	
Soil = sedimentary	(Control)								
Soil = volcanic	200	27	***	9.3	1.3	***	2.2	0.30	***
Young stock off for 9 months	-59	28	**	-0.87	1.4		-0.31	0.32	
Young stock off permanently	-32	130		16	6.3	**	1.9	1.4	
Young stock on permanently	-17	33	***	-1.5	1.6		-0.74	0.37	**
Young stock off until weaning	(Control)								
Farm is irrigated	270	35	***	8.5	1.7	***	2.6	0.40	***
Winter grazing off	57	24	**	-2.3	1.2	*	-0.18	0.27	
Feed pad used	110	28	***	3.1	1.4	**	1.3	0.32	***
Wintering pad used	-1.6	40		-0.95	2.0		0.40	0.46	
N inhibitors used	240	720		-7.1	36		-6.9	8.3	
N inhibitors x Temperature	5.1	56		0.16	2.8		0.73	0.64	
N inhibitors x Rainfall	-0.25	0.24		0.002	0.012		-0.002	0.003	
Year effect 2010	(Control)								
Year effect 2009	-27	23		0.70	1.2		5.5	0.27	***
Year effect 2008	-34	36		2.4	1.8		0.52	0.41	
Constant	1550	117	***	12.1	5.85	**	12.5	1.34	***
No. observations	443			443			443		
R-squared	0.54			0.30			0.67		

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%. Unclustered standard errors

3.2. Determinants of N and GHG Use Efficiency

Our key focus, however, is on N and GHG use efficiency. Table 3 gives the regression results for use efficiency with respect to N leaching and GHG emissions. As expected from the dicussion above, higher rainfall and pumice soil implies lower N use efficiency. Although hilly topography lowers N and GHG, it also lowers production and this dominates especially for GHGs, leading to lower GHG use efficiency. In contrast for volcanic soils the positive production effect dominates the increase in GHGs but not that in N, leading to higher GHG use efficiency but lower N use efficiency. Winter grazing off raises N and GHG use-efficiencies but at unknown cost on other farms. Nitrogen inhibitors have the expected effects but only the direct effect on leaching is significant. Although our focus is not identifying the characteristics causally related with use efficiency, it is reassuring that these results seem reasonable.

Table 3: Regression results for use efficiency (do not interpret as causal relationships)

	N use efficiency (kg MS / kg N)		GHG use efficiency (kg MS / T co2-eq)	
Explanatory variables	Coef.	Std. Err.	Coef.	Std. Err.
Rainfall (mm)	-0.0097	0.0020 ***	0.0015	0.0021
Temperature (°C)	-2.8	0.50 ***	-3.0	0.53 ***
Topography = easy hill	-3.1	2.4	-12	2.5 ***
Topography = flat	(Control)			
Topography = rolling hill	0.073	1.5	-5.3	1.6 ***
Soil = peat	-0.38	3.1	-1.4	3.3
Soil = pumice	-9.9	2.6 ***	-4.5	2.8
Soil = recent YGE	-4.4	1.8 **	-2.1	1.9
Soil = sands	-3.5	3.0	-0.82	3.2
Soil = sedimentary	(Control)			
Soil = volcanic	-3.4	1.4 **	3.2	1.5 **
Young stock off for 9 months	-0.76	1.4	-3.8	1.5 **
Young stock off permanently	-10	6.6	-18	7.0 ***
Young stock on permanently	-5.0	1.7 ***	-8.2	1.8 ***
Young stock off until weaning	(Control)			
Farm is irrigated	0.095	1.8	2.8	1.9
Winter grazing off	4.8	1.3 ***	6.3	1.3 ***
Feed pad used	1.8	1.5	1.1	1.6
Wintering pad used	0.74	2.1	-2.5	2.2
N inhibitors used	69	38 *	62	40
N inhibitors x Temperature	-3.6	2.9	-4.7	3.1
N inhibitors x Rainfall	-0.021	0.013	-0.001	0.014
Fixed effect for 2010	(Control)			
Fixed effect for 2009	-2.3	1.2 *	-37	1.3 ***
Fixed effect for 2008	-2.9	1.9	-8.9	2.0 ***
Constant	86.5	6.15 ***	138	6.55 ***
Number of observations	443		443	
R-squared	0.4845		0.7260	

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%. Unclustered standard errors

48 percent of variation in farms' N use efficiency, and 73 percent of variation in farms' GHG use efficiency, can be explained by exogenous factors, movement of stock or specific mitigation technologies. This suggests a large role for management factors and farmer skill, particularly for N leaching but also for GHG emissions.

3.3. Interpreting Residuals

By controlling for observed factors, our intention is for the residuals to capture use efficiency due to farmer skill and farm management. There are two key reasons why this may not be true. First, the residuals may include the effect of factors that cannot be managed by farmers. This occurs where the relationship between use efficiency and the explanatory variables is misspecified and where exogenous drivers of use efficiency are omitted.

Second, some coefficients will be affected by omitted variable bias and this will affect the residuals. This occurs where there is correlation between the explanatory variables and farmer skill and management. For example, if more skilled farmers with better access to capital are more likely to be able to afford flat land, the coefficients relating GHG use efficiency to topography will be biased and may appear to explain more of the variability in use efficiency than they really do. If new, more sophisticated farms tend to be concentrated in the South Island where temperatures are lower, the temperature will appear to have a larger effect on use efficiency than is justified biophysically and the effect of the highly skilled and resourced farmers on that land will be underestimated.

We explore the potential for omitted variable bias to affect our results in the appendix. Although higher milk solid production per cow is predictably associated with higher N use efficiency, as the coefficients for N use efficiency do not differ significantly when explanatory variables for farmer skill and management are included, we can be confident that omitted variable bias is minimal with respect to N. In contrast, some coefficients relating to GHG use efficiency are significantly affected when explanatory variables for farmer skill and management are included. This suggests that our results contain omitted variable bias with respect to GHGs. Investigation of the distribution of residuals suggests we may underestimate the potential gains from improvements in farm management.

Two characteristics of our data also affect the interpretation of our results. First, as inclusion in the monitor farm reporting is voluntary, there is likely to be sampling bias in the data. We expect less efficient farmers to be underrepresented in our data and hence also in our results. Second, N leaching and GHG emissions are not measured on farm but are estimated using the OVERSEER model based on a combination of observed farm characteristics. Thus, true variation in N leaching and GHGs is likely to be underestimated. Also it means that we can pick up only variations in management that affect the input data used in OVERSEER. Together these probably lead us to underestimate the role of farmer skill and management in driving use efficiency.

4. Results: Nitrogen Leaching

We consider both the distribution of use efficiency that is due to observed factors and the distribution of residual use efficiency, which we interpret as farmer skill and management.

Figure 5: Observed and estimated distributions of N use efficiency

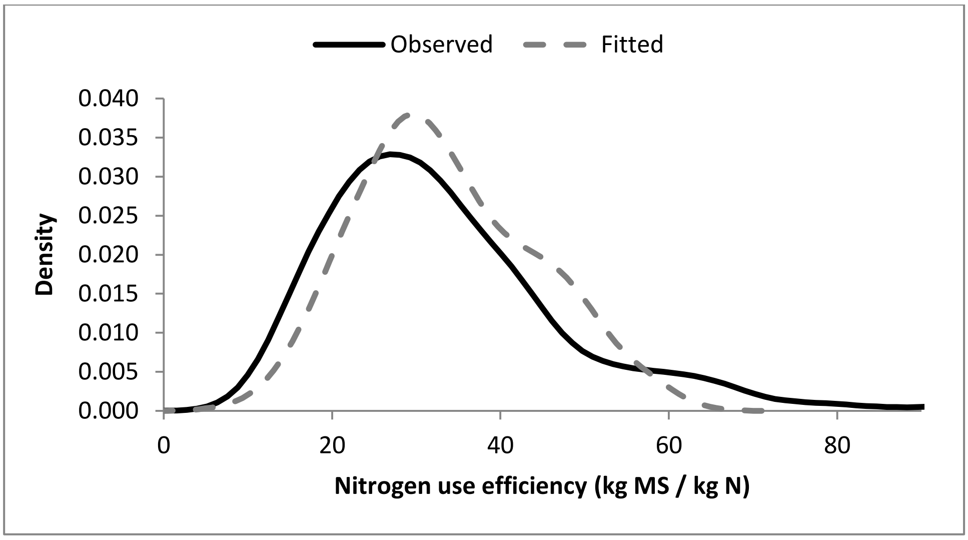

Figure 5 compares the fitted distribution of N use efficiency against the observed distribution of use efficiency. The most efficient farms are to the right. The fitted distribution underestimates the proportion of farms with the lowest, and with the highest, levels of efficiency.

Figure 6: The distribution of N use efficiency residuals

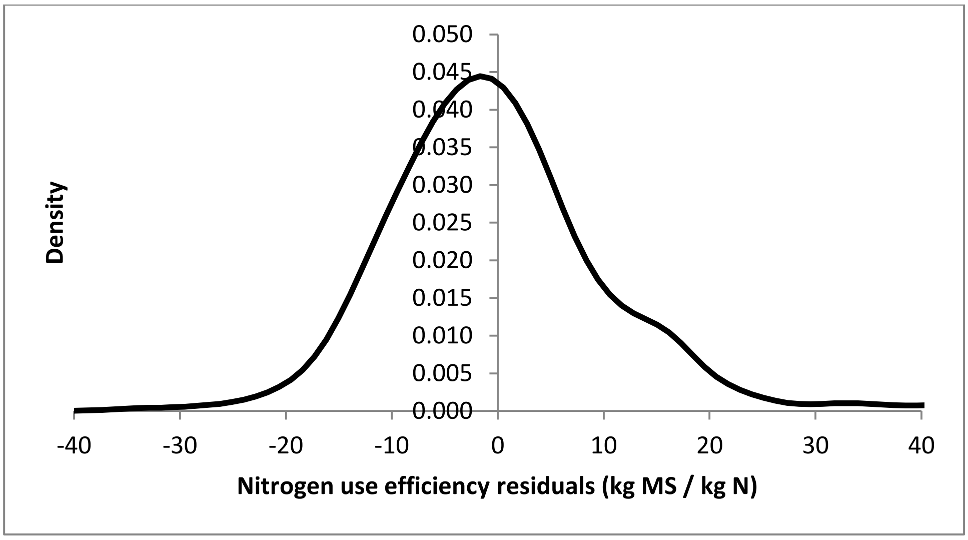

Figure 6 gives the distribution of N use efficiency that we attribute to farm management practices. We observe that the residual distribution is as dispersed as the fitted distribution. This suggests that factors within the control of the farmer are a significant determinant of the N use efficiency reported for a farm.

We use these results to quantify the mitigation that may be possible from the adoption of more N efficient farm management practices. Farms with low N efficiency may be able to mitigate by adopting similar management practices to existing farms with high N efficiency. We consider the following three scenarios for improvements in N efficiency:

1. *Conservative scenario*: all farms with efficiency due to farm management practices below the 50th percentile (the median) increase their efficiency by half the difference between their current efficiency and the 50th percentile by improving their farm management practices.
2. *Ambitious scenario*: all farms with efficiency due to farm management practices below the 95th percentile increase their efficiency by half the difference between their current efficiency and the 95th percentile by improving their farm management practices.
3. *Extreme scenario*: all farms with efficiency due to farm management practices below the 95th percentile increase their efficiency to the 95th percentile by improving their farm management practices.

Figure 7: Improvements in N use efficiency due to farm management

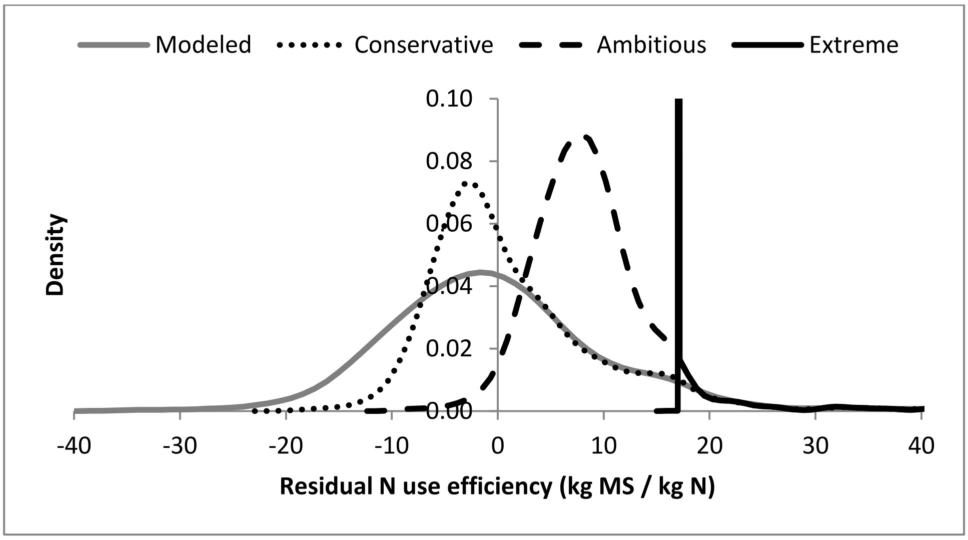

Figure 8: The gains in N efficiency due to improvements in farm management

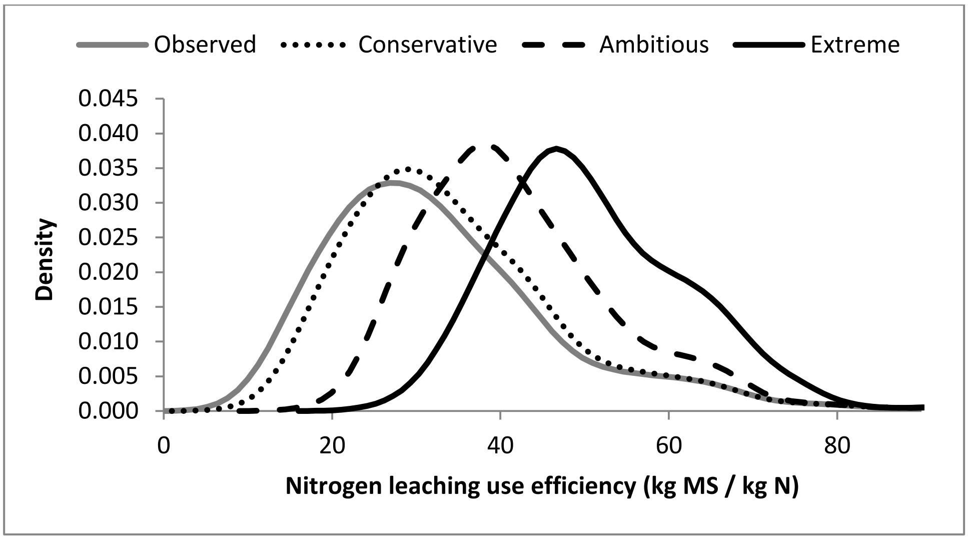

Figure 7 gives the improvements in N use efficiency due to farm management (the residual) under the three scenarios. The implications of these changes for the observed distribution of N use efficiency are given in Figure 8. The mean gain in efficiency over all farms and the implied mitigation of N leaching if production levels remain constant are given in Table 4.

Table 4: Mean efficiency gains and N mitigation

	Mean efficiency gain	Implied N mitigation
Conservative scenario	5.0%	4.8%
Ambitious scenario	26.3%	20.9%
Extreme scenario	52.7%	34.5%

If our sample is representative of New Zealand dairy farms and catchments, these results suggest that either production on existing farms can increase significantly even if total N leaching in a catchment is capped at current levels; or equivalently, that significant mitigation is possible if production growth is constrained. These results hold for the population of farms as a whole. Some individual farms are able to mitigate and increase production significantly, while others are already efficient and cannot make changes. To the extent that mitigation possibilities are driven by these distributions, this highlights the need for flexible regulation rather than requiring similar cuts by all farmers. The importance of factors that are outside of the control of existing farmers suggests that fixed levels of emissions per hectare would also not be efficient.

5. Results: Greenhouse Gases

Here we repeat the analysis for greenhouse gases.

Figure 9: Observed and estimated distributions of GHG use efficiency

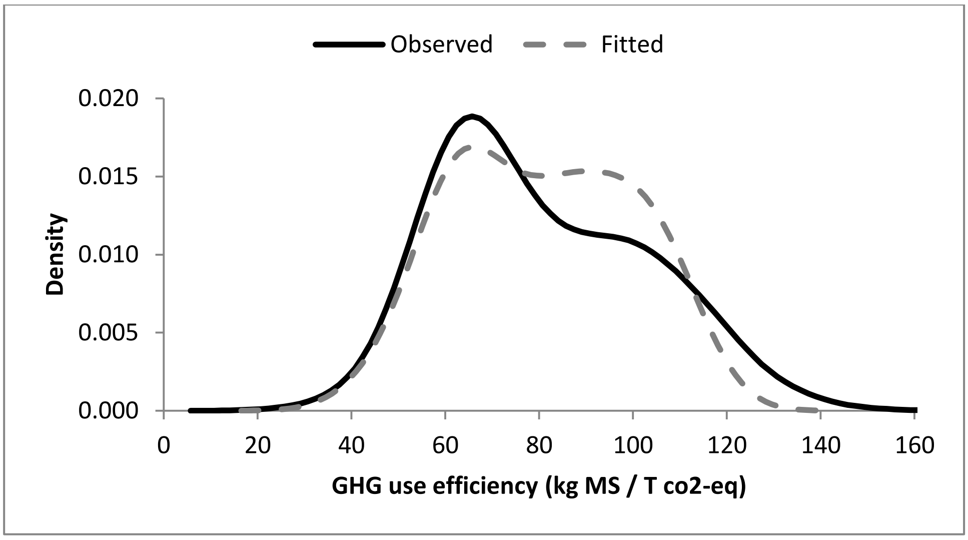

Figure 9 compares the fitted distribution of GHG use efficiency against the observed distribution of use efficiency. The most efficient farms are to the right. The fitted distribution underestimates the proportion of farms with the lowest, and, particularly, the highest, levels of efficiency.

Figure 10: The distribution of GHG efficiency due to farm management practices

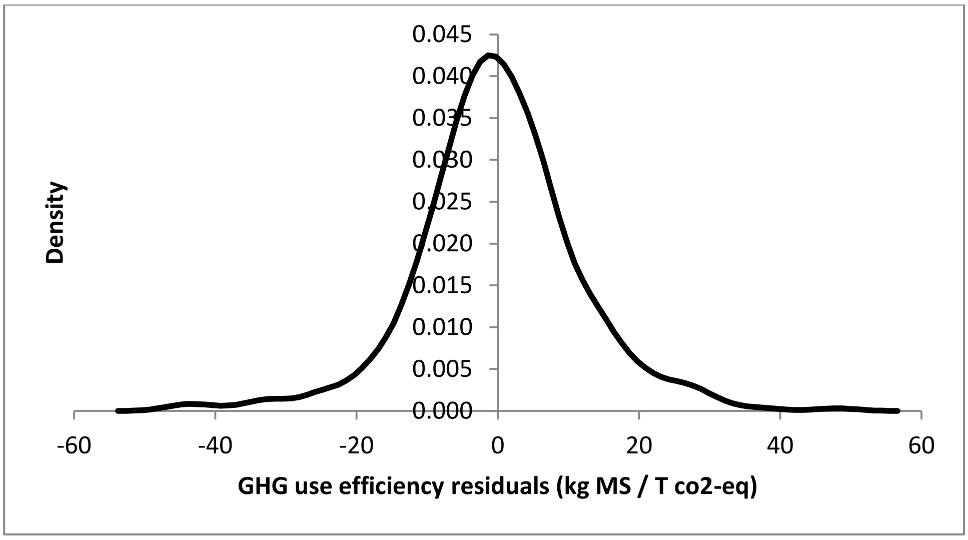

Figure 10 gives the distribution of GHG use efficiency residuals that we attribute to farmer skills and management practices. The dispersion of the distribution of residual use efficiency is around half that of the observed distribution. This suggests that management factors are a significant determinant of the GHG use efficiency reported for a farm, though less than for N leaching.

We then consider the same conservative, ambitious and extreme scenarios as specified for improvements in N use efficiency.

Figure 11: Improvements in GHG use efficiency due to farm management

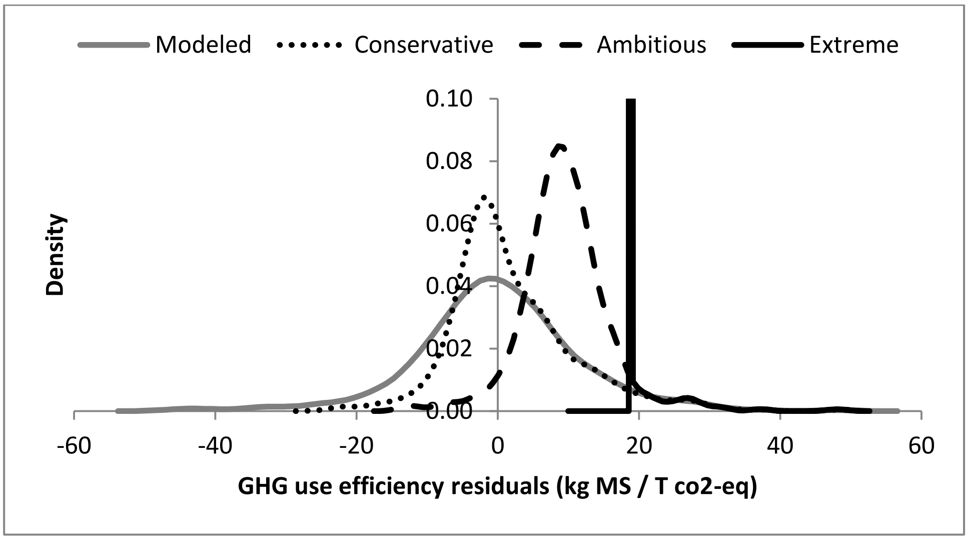

Figure 12: The gains in GHG efficiency due to improvements in farm management

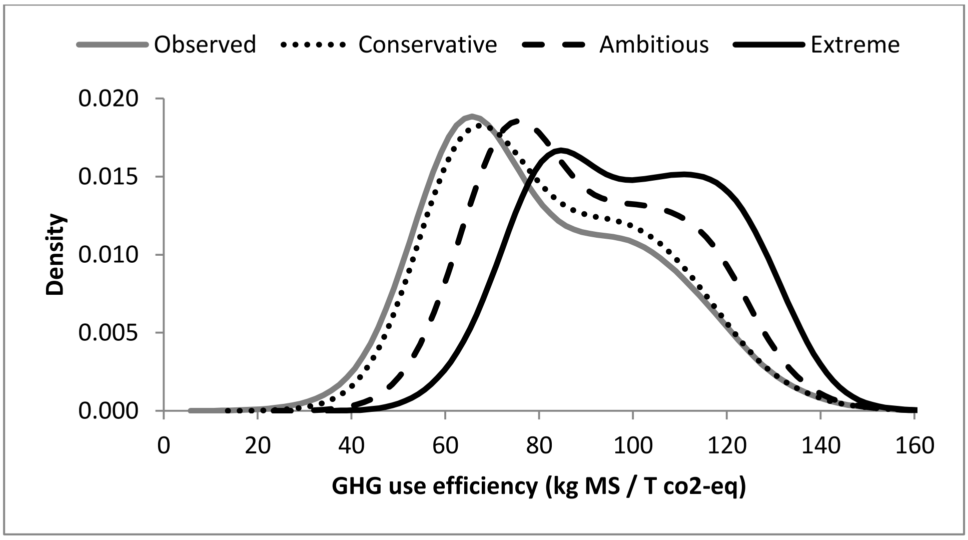

Figure 11 gives the improvements in GHG use efficiency due to farm management (the residual) under the three scenarios. The implications of these changes for the observed distribution of GHG efficiency (once factors outside the control of farmers are account for) are given in Figure 12. The mean gain in efficiency over all farms and the implied reduction in GHG emissions if production levels remain constant are given in Table 5.

Table 5: Mean efficiency gains and GHG mitigation

	Mean efficiency gain	Implied GHG mitigation
Conservative scenario	2.5%	2.4%
Ambitious scenario	11.8%	10.5%
Extreme scenario	23.6%	19.1%

Because greenhouse gases are global, not local, pollutants, the total level of agricultural emissions within New Zealand is not the primary concern. To the extent that we are able to influence our own and global diets, reduced production may result from efficient consumer-focused mitigation strategies but it will not be driven by on-farm policies. There is no point reducing production, and hence emissions, in New Zealand if that production simply moves off-shore. In contrast, improving emissions efficiency of production is always beneficial. Thus the key interpretation is that for a given level of production we may be able to reduce emissions by up to 19% without any new technology or even implementation of N inhibitors or other specific mitigation technologies. This supports the idea that we can continue the historical trend toward lower GHG-emission dairy products for a long time, and may be able to accelerate it. Further reductions in GHG emissions need not be dependent on new technology, but can be driven by greater diffusion of existing practices.

6. Discussions and Conclusions

Existing marginal abatement cost analysis is problematic. We take a different approach, considering the potential for changes in management that existing farmers have already achieved. First, by considering improvements in the distribution of existing farms' use efficiency, we explicitly incorporate heterogeneity among farmers into our analysis. Second, by suggesting that farmers with less efficient management practices adopt practices similar to those of the more efficient farmers, we are promoting credible practices that are already in use on existing farms.

Our results suggest that significant mitigation could be achieved by "bringing up the rear". That is, encouraging less use-efficient farmers to adopt management practices similar to those of the more efficient farmers. Our results can be interpreted in four ways, depending on the pollutant and circumstances. First, some farmers operate under a nitrogen cap at recent levels of leaching, such as that in Lake Taupo (Barns et al., 2013) or Lake Rotorua's Rule 11 (Foster et al., 2009). If land use were fixed, which it is not in the case of Taupo, our results suggest that production for the average farm could rise significantly (between roughly 25 and 50%) with no increase in leaching. However, using current practices, the best current farms would have no ability to increase production without purchasing extra nitrogen allowances. Second, when absolute reductions in leaching are sought, our results could be used to estimate part of the mitigation potential (where the other parts are derived from land-use change and new technology) – more than a 30% reduction could be possible. Third, in the case of greenhouse gases, where, holding global consumption of dairy products constant, the goal is to produce lower-emission dairy products, our results suggest that dairy products could be up to 19% more efficient with existing practices and no more use of specific mitigation technologies. Fourth, in the absence of regulation, increases in N use efficiency from improved management are likely to be associated with increased dairy profitability and hence increased land-use change pressure. It is unclear what the net effect on catchment scale leaching would be from a policy that simply improved dairy farm management practices.

All these consider the potential for mitigation only on existing farms. In a rapidly growing sector, those establishing new farms could choose to locate them in areas with lower emissions, as well as immediately adopting more efficient practices. We do not quantify this potential but given the strong role of geophysical factors in both N and GHG use efficiency, explaining 44% for N and 73% for GHG, it could be considerable.

The fact that high levels of efficiency are achieved on some farms, and that these farms may also have higher profitability, does not mean that turning these potential reductions into real reductions will be costless. Investments in the (unobservable) human capital of farmers and facilitation of adoption of high use-efficiency practices (possibly through access to knowledge and finance) will be required, and we need to better understand the resilience of these high use-efficiency practices to shocks. Changes in behaviour that are as complex as this involve uncertainty and will tend to diffuse slowly.

These are the first results that use this approach. There are limitations in the data set resulting from its small size, sample bias, and potential variability in application of OVERSEER, and our linear modelling is likely to be limiting. These results alone should not be taken too seriously but they do suggest that the better existing farmers have significant knowledge about how to reduce leaching and emissions even when they do not explicitly seek to do so. They also suggest the value of further, deeper exploration with a larger dataset and a multidisciplinary team.

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Appendix

Our analysis above has focused on N and GHG use efficiency. Many other farm characteristics exhibit heterogeneity that may be of interest. For completeness and future reference we give distributions and relationships for other variables of interest, including production per cow, production per hectare, stocking rate, N leaching per hectare, GHG emissions per hectare, and cash operating surplus.

Variable Distributions and Relationships

In addition to the description of the data in section 2, we provide distributions for some of the variables in our data. These are raw distributions and do not control for any underlying farm characteristics. Other than for the distribution of cash operating surplus per hectare, which only uses data for 2010, these distributions combine data from all three years (2008 to 2010).

Figure 13: Distribution of N leaching per ha

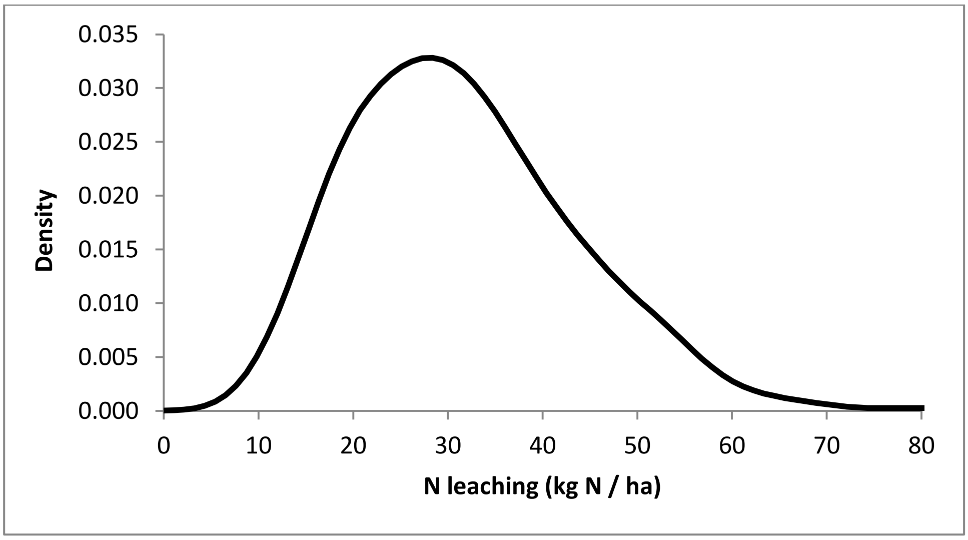


Figure 14: Distribution of GHG emissions per ha

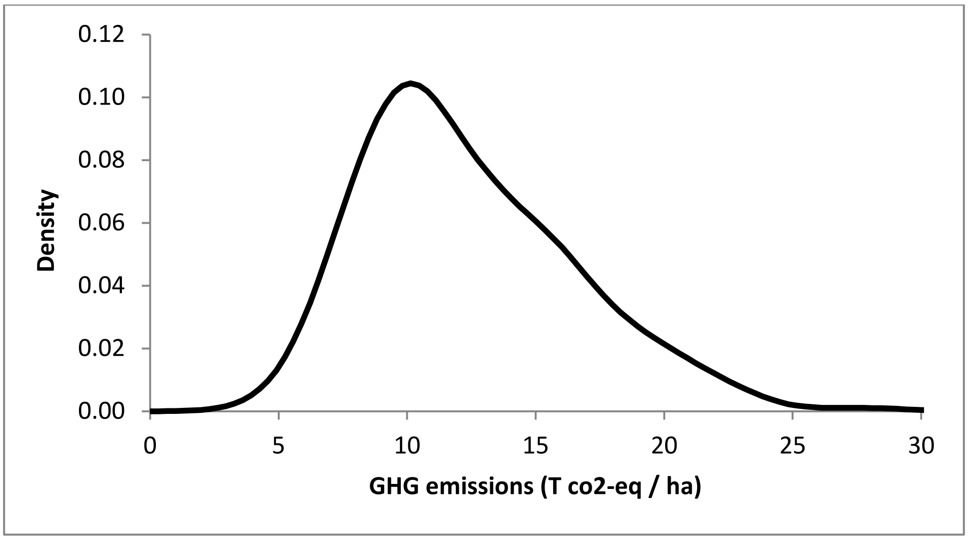


Figure 15: Distribution of farm size

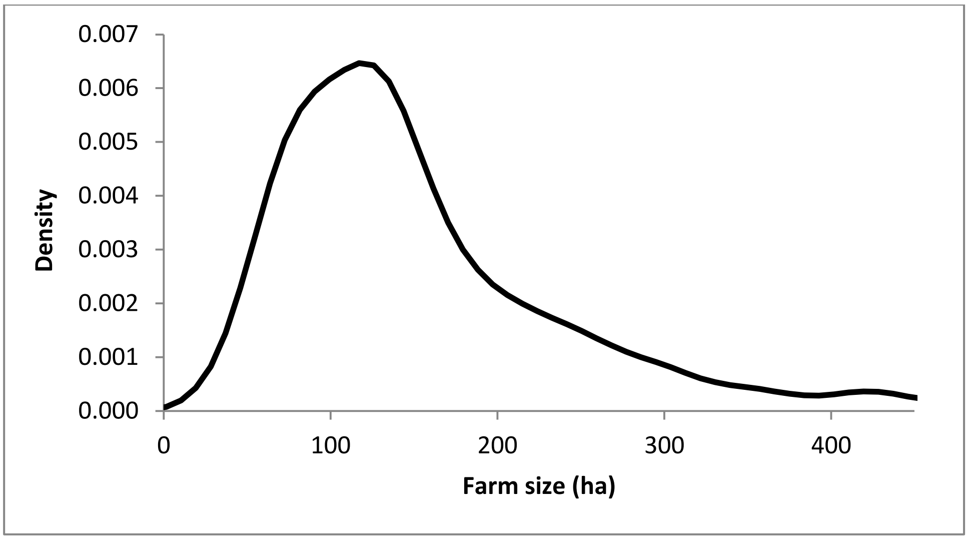


Figure 16: Distribution of stocking rate

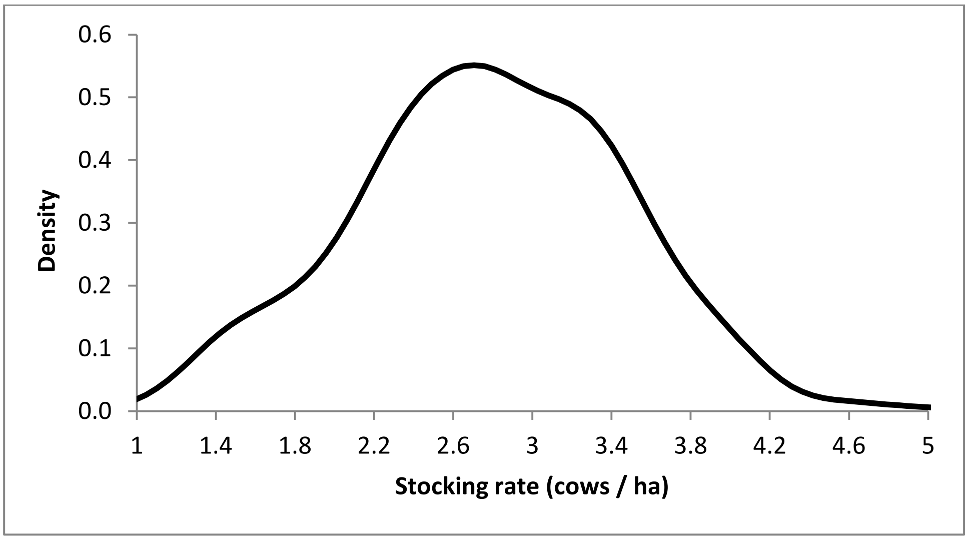


Figure 17: Distribution of production per animal

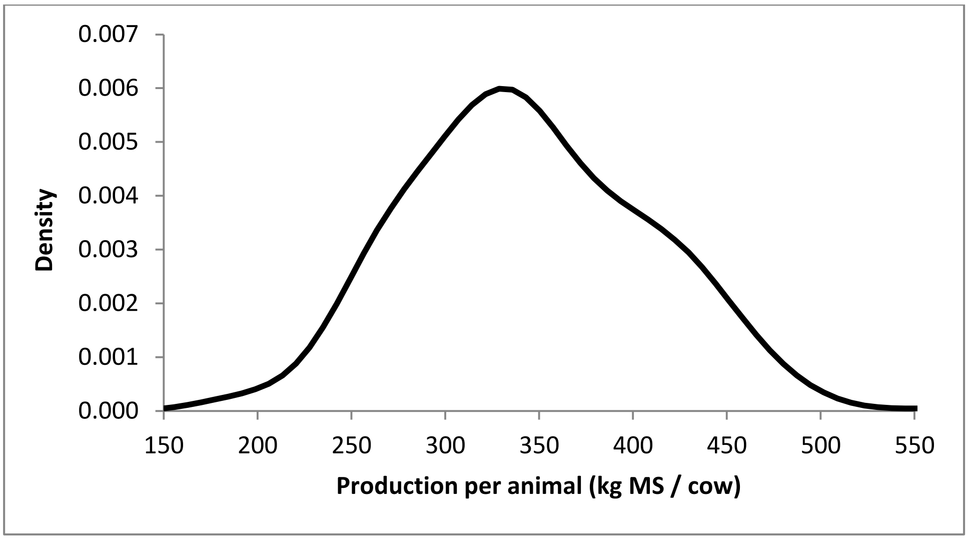


Figure 18: Distribution of production per hectare

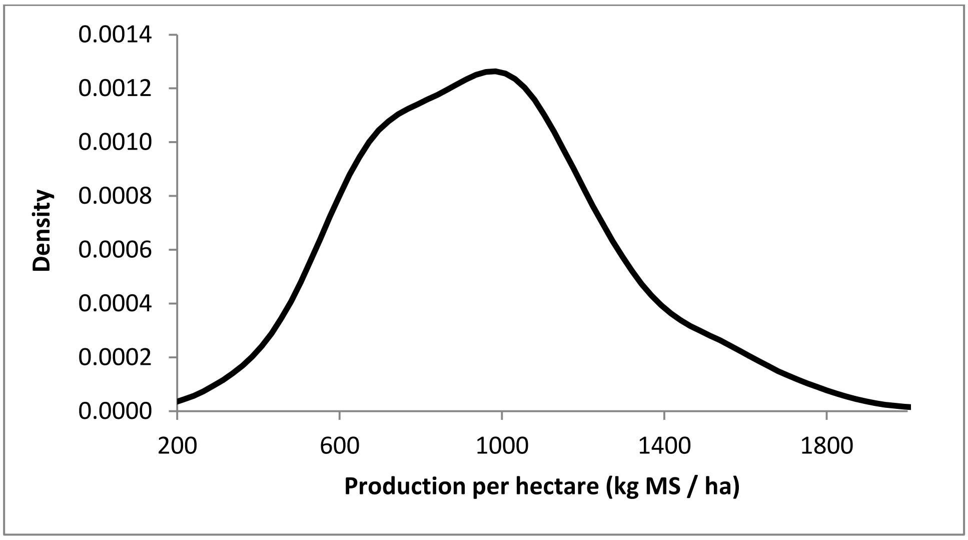
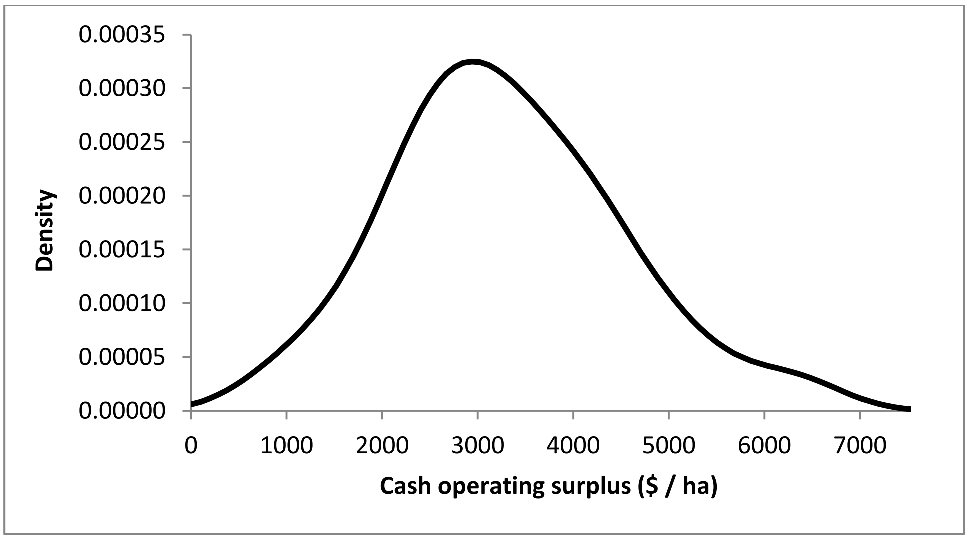


Figure 19: Distribution of cash operating surplus per hectare (2010 observations only)



The following figures give the relationship between selected pairs of variables. They have been constructed using only the observations from the 2010 monitor farm unit records. Figure 20 to Figure 23 focus on the interaction between emissions and use efficiency. Figure 24 to Figure 27 give production with respect to emissions and efficiency, and Figure 28 to Figure 31 do the same for cash operating surplus (as a proxy for profits). Trend lines and R-squared values are provided to illustrate the strength of the relationships. For all figures: * indicates a coefficient is significant at the 1 percent level, otherwise the coefficient is significant at the 10 percent level.

Figure 20: The relationship between N and GHG use efficiency

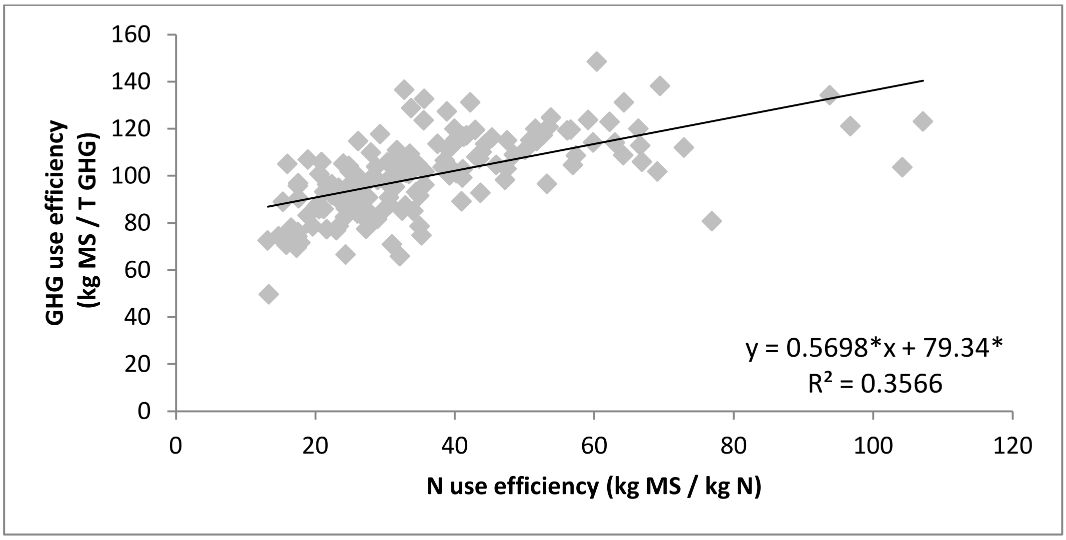


Figure 21: The relationship between N leaching and N use efficiency

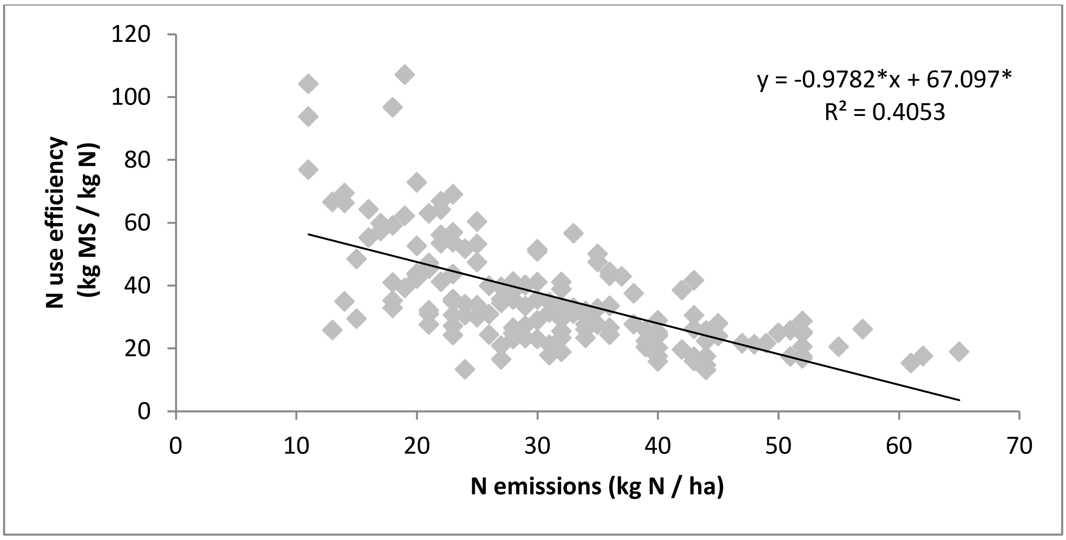


Figure 22: The relationship between GHG emissions and GHG use efficiency

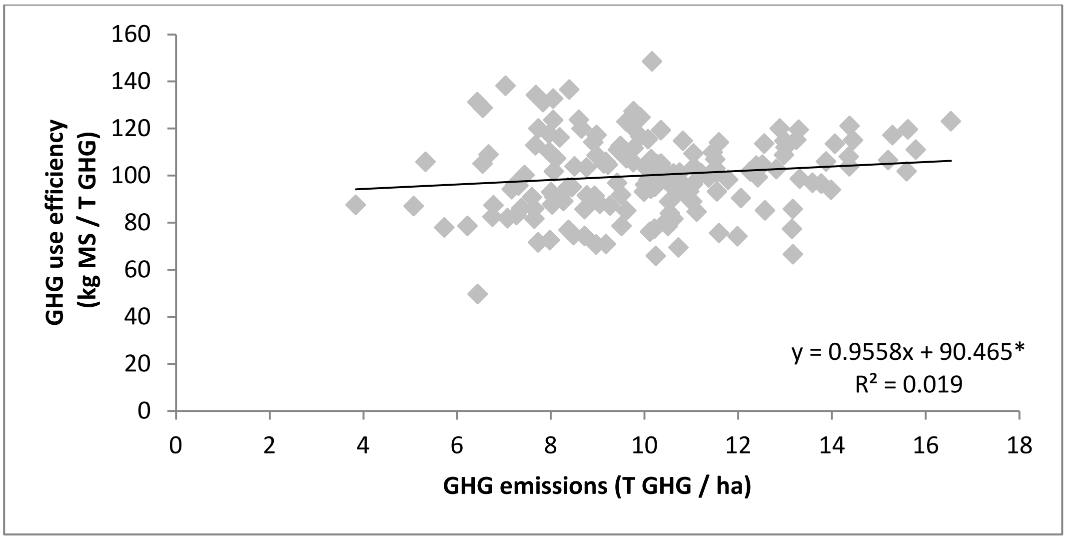


Figure 23: The relationship between N and GHG emissions

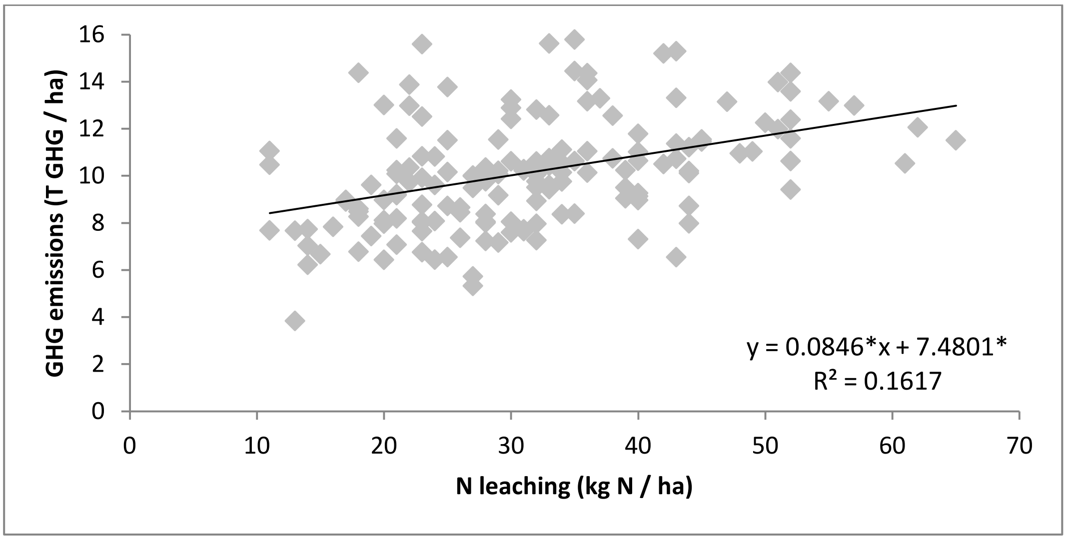


Figure 24: The relationship between production and N use efficiency

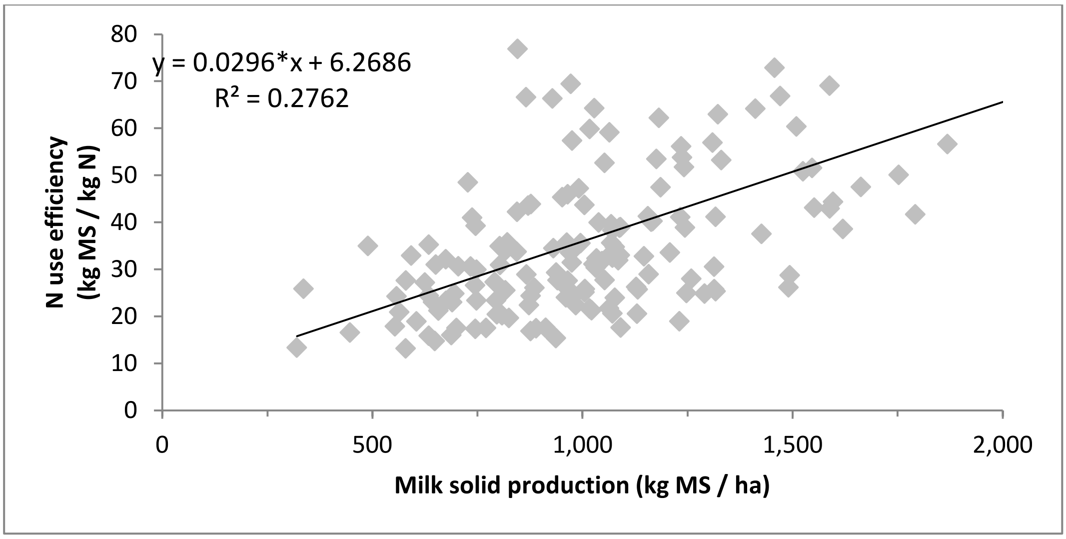


Figure 25: The relationship between production and GHG use efficiency

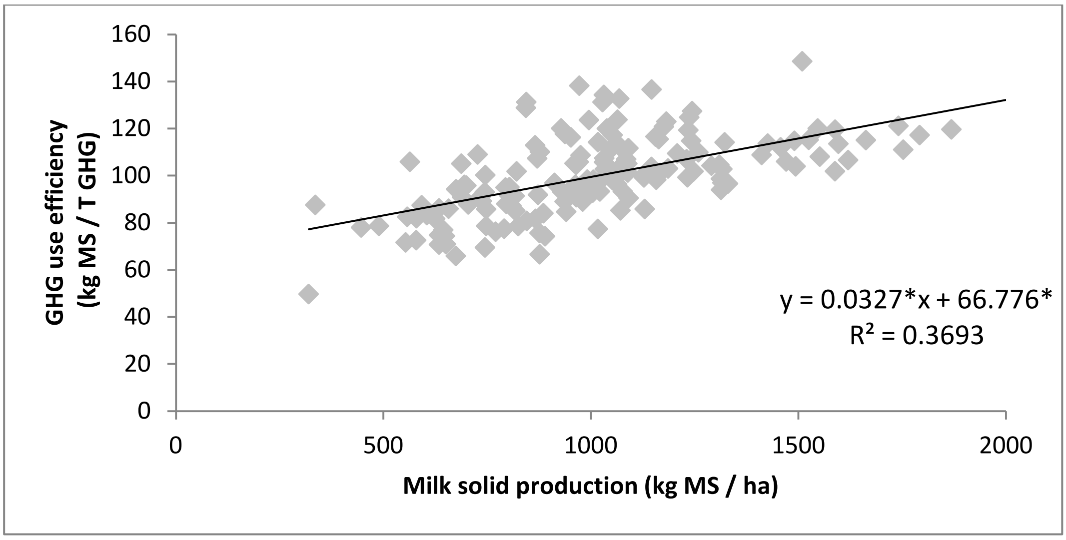


Figure 26: The relationship between production and N leaching

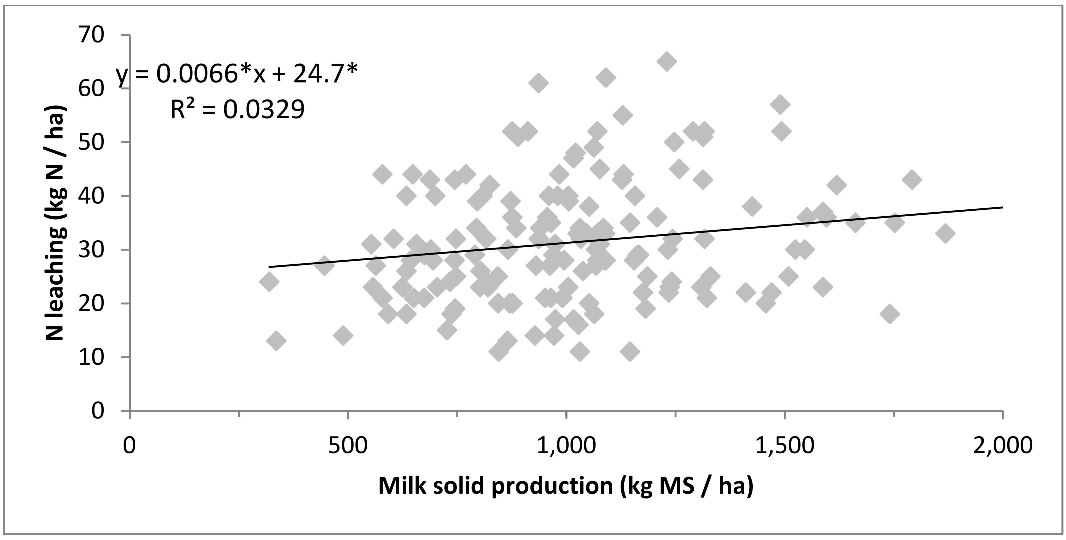


Figure 27: The relationship between production and GHG emissions

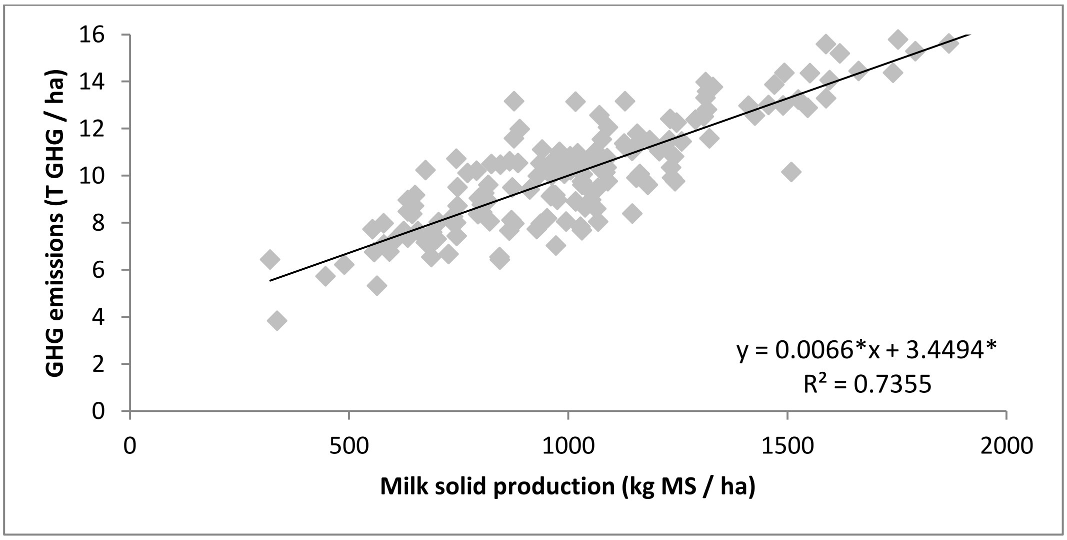


Figure 28: The relationship between cash operating surplus and N use efficiency

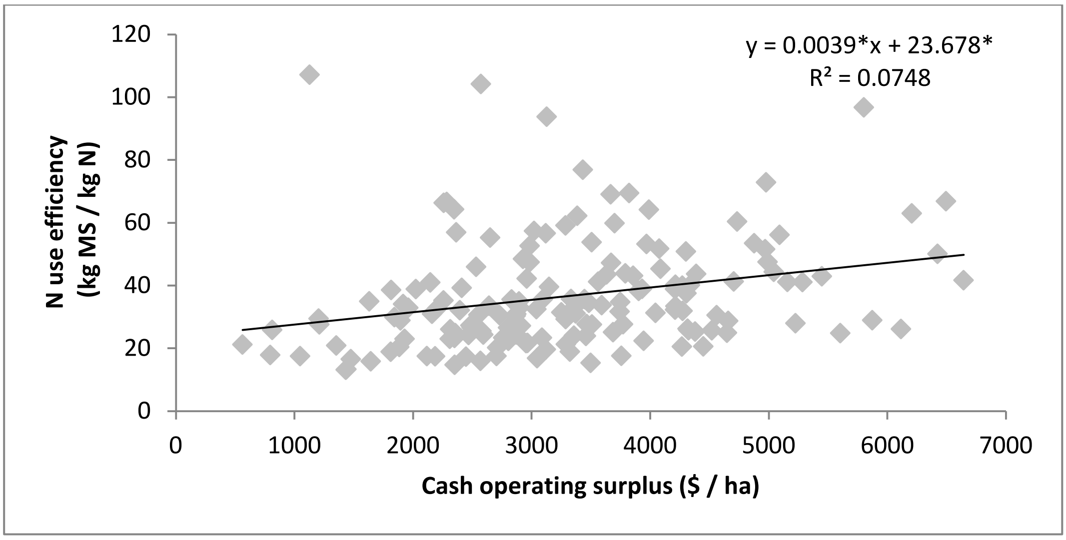


Figure 29: The relationship between cash operating surplus and GHG use efficiency

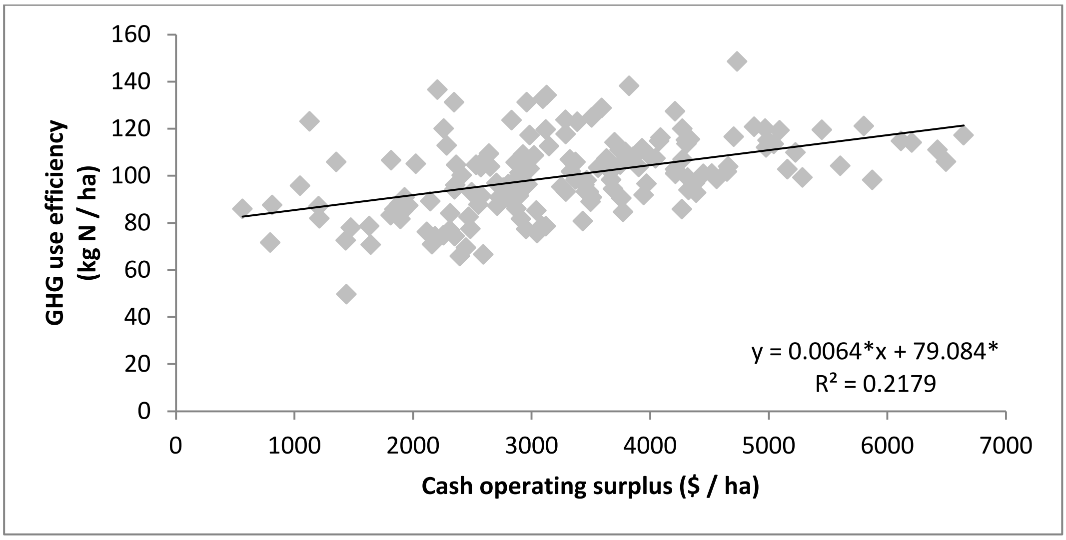


Figure 30: The relationship between cash operating surplus and N leaching

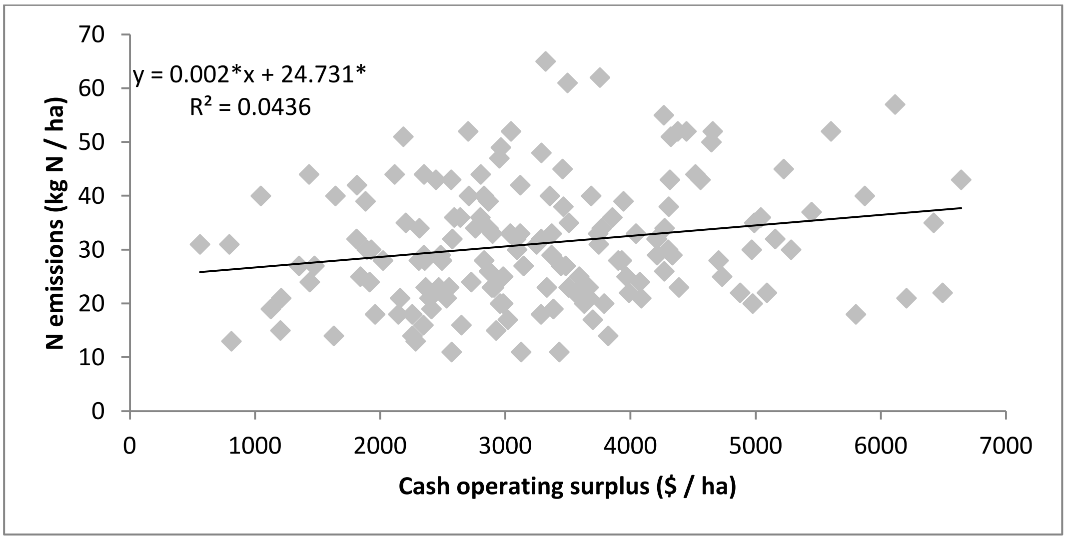
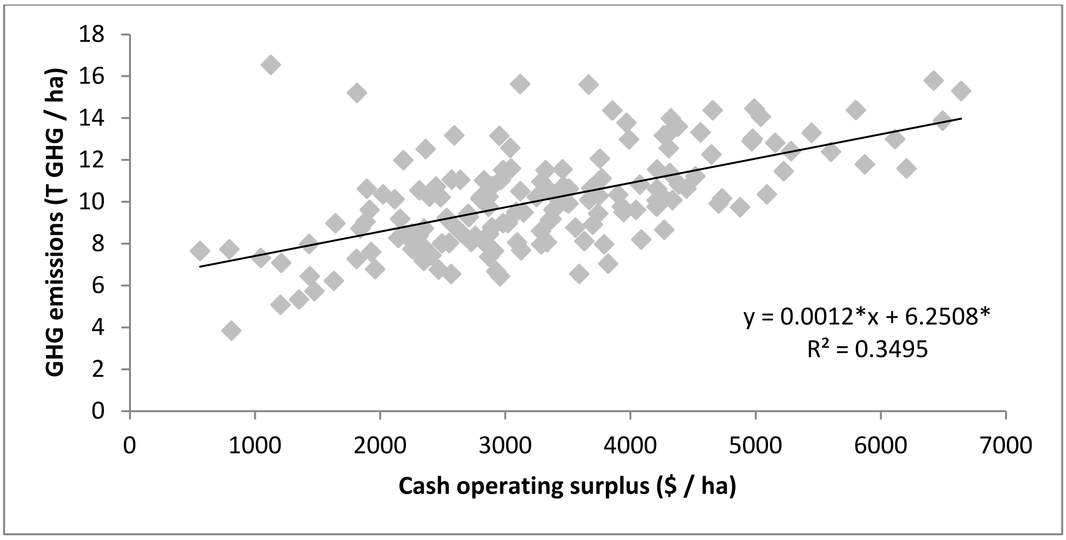


Figure 31: The relationship between cash operating surplus and GHG emissions



Omitted Variable Bias

To investigate the potential for omitted variable bias to affect our results, we repeated the regression analysis of N and GHG use efficiency including measures of farmer skill and farm management. Table 6 and Table 7 give the results for N and GHG use efficiency respectively.

Table 6: Regression results testing omitted variable bias for N use efficiency

	Original Regression			Expanded Regression			Difference
Explanatory variables	Coef.	Std. Err.		Coef.	Std. Err.		
Rainfall (mm)	-0.0097	0.0020	***	-0.0079	0.0020	***	
Temperature (°C)	-2.81	0.50	***	-2.36	0.51	***	
Topography = easy hill	-3.10	2.35		-0.72	2.37		
Topography = flat	(Control)						
Topography = rolling hill	0.073	1.5		1.7	1.5		
Soil = peat	-0.38	3.1		-1.7	3.0		
Soil = pumice	-9.9	2.6	***	-10.9	2.6	***	
Soil = recent YGE	-4.4	1.8	**	-4.9	1.7	***	
Soil = sands	-3.5	3.0		-2.6	3.0		
Soil = sedimentary	(Control)						
Soil = volcanic	-3.4	1.4	**	-5.4	1.5	***	
Young stock off for 9 months	-0.76	1.4		0.040	1.4		
Young stock off permanently	-10.4	6.6		-10.5	6.4		
Young stock on permanently	-5.0	1.7	***	-3.5	1.7	**	
Young stock off until weaning	(Control)						
Farm is irrigated	0.095	1.8		-2.4	1.9		
Winter grazing off	4.8	1.3	***	4.4	1.3	***	
Feed pad used	1.8	1.5		0.20	1.5		
Wintering pad used	0.74	2.1		0.87	2.0		
N inhibitors used	69	38	*	68	37	*	
N inhibitors x Temperature	-3.6	2.9		-3.7	2.9		
N inhibitors x Rainfall	-0.021	0.013		-0.020	0.012		
S1: no feed imported	(Control)						
S2: 4-14% of feed imported				-2.4	1.7		
S3: 10-20% of feed imported				-1.6	1.8		
S4: 20-30% of feed imported				-3.3	2.0	*	
S5: >30% of feed imported				1.2	2.7		
Milk solids per cow (kg)				0.031	0.011	***	
Stocking rate (cow/ha)				4.1	1.0	***	
Fixed effect for 2010	(Control)						
Fixed effect for 2009	-2.3	1.2	*	-2.2	1.2	*	
Fixed effect for 2008	-2.9	1.9		-2.0	1.9		
Constant	85.50	6.15	***	57.32	9.50	***	**
Number of observations	443			443			

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%. Unclustered standard errors

Table 7: Regression results testing omitted variable bias for GHG use efficiency

	Original Regression			Expanded Regression			Difference
Explanatory variables	Coef.	Std. Err.		Coef.	Std. Err.		
Rainfall (mm)	0.0015	0.0021		0.0056	0.0018	***	
Temperature (°C)	-3.0	0.53	***	-1.5	0.48	***	**
Topography = easy hill	-11.5	2.5	***	-5.3	2.2	**	*
Topography = flat	(Control)						
Topography = rolling hill	-5.3	1.6	***	-0.76	1.4		**
Soil = peat	-1.4	3.3		-4.8	2.8	*	
Soil = pumice	-4.5	2.8		-6.0	2.4	**	
Soil = recent YGE	-2.1	1.9		-3.0	1.6	*	
Soil = sands	-0.82	3.2		1.8	2.8		
Soil = sedimentary	(Control)						
Soil = volcanic	3.2	1.5	**	-1.5	1.4		**
Young stock off for 9 months	-3.8	1.5	**	-2.2	1.3	*	
Young stock off permanently	-18	7.0	***	-18	6.0	***	
Young stock on permanently	-8.2	1.8	***	-4.9	1.6	***	
Young stock off until weaning	(Control)						
Farm is irrigated	2.8	1.9		-3.6	1.7	**	**
Winter grazing off	6.3	1.3	***	5.4	1.2	***	
Feed pad used	1.1	1.6		-1.6	1.4		
Wintering pad used	-2.5	2.2		-2.2	1.9		
N inhibitors used	62	40		46	35		
N inhibitors x Temperature	-4.7	3.1		-4.0	2.7		
N inhibitors x Rainfall	-0.0013	0.0135		0.0039	0.0116		
S1: no feed imported	(Control)						
S2: 4-14% of feed imported				-4.0	1.5	***	
S3: 10-20% of feed imported				-4.4	1.7	***	
S4: 20-30% of feed imported				-6.1	1.8	***	
S5: >30% of feed imported				-4.1	2.5		
Milk solids per cow (kg)				0.104	0.010	***	
Stocking rate (cow/ha)				8.9	1.0	***	
Fixed effect for 2010	(Control)						
Fixed effect for 2009	-37	1.3	***	-36	1.1	***	
Fixed effect for 2008	-8.9	2.0	***	-6.7	1.7	***	
Constant	138.1	6.5	***	56.5	8.9	***	***
Number of observations	443			443			

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%. Unclustered standard errors

The final column in each table indicates which parameter estimates are significantly different between the two regressions. We observe that there are no significant changes in the coefficients for N use efficiency. This suggests that omitted variable bias is small with respect to our N results. However, we also observe that there are significant changes in the coefficients for GHG use efficiency, in particular temperature, topography, irrigation, and whether the soil is volcanic or not. This suggests that omitted variable bias may be of concern with respect to our GHG results.

To investigate the implication of our extended regression results, we calculate fitted and residual values for both N and GHG use efficiency using only the explanatory variables that were included in our original regression.

Figure 32: Distributions of N use efficiency for investigating omitted variable bias

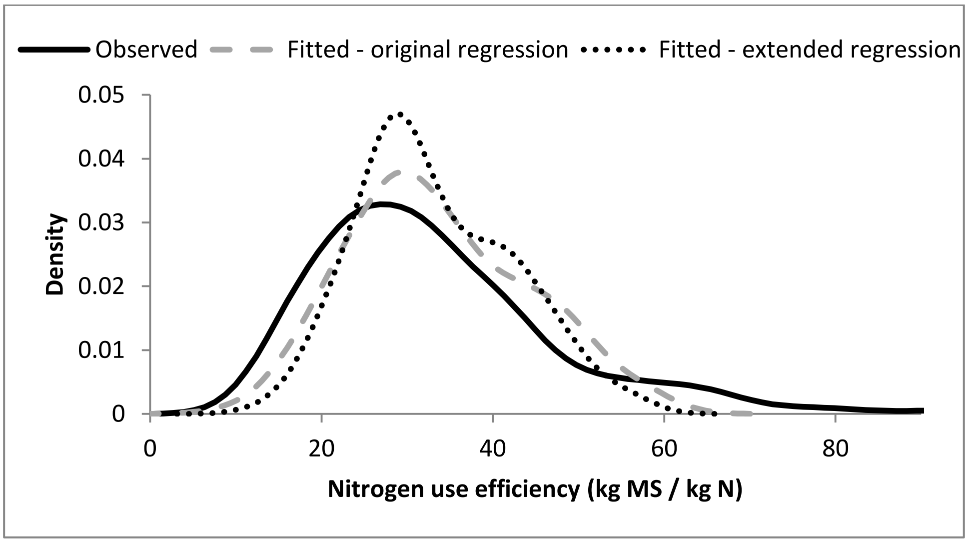


Figure 33: Distributions of N use efficiency residuals for investigating omitted variable bias

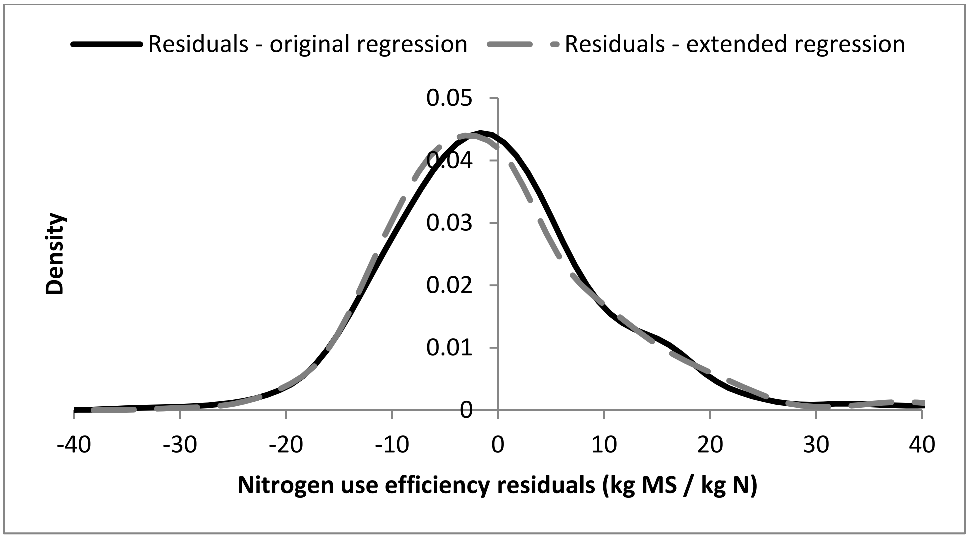


Figure 32 and Figure 33 are equivalent to Figure 5 and Figure 6, but include results from our extended regression. We observe that while the distribution of fitted values is narrower, the distribution of residuals is almost unchanged. Consequently, any omitted variable bias will not have a significant effect on our estimates of the gains from improvements in farm management.

Figure 34: Distributions of GHG use efficiency for investigating omitted variable bias

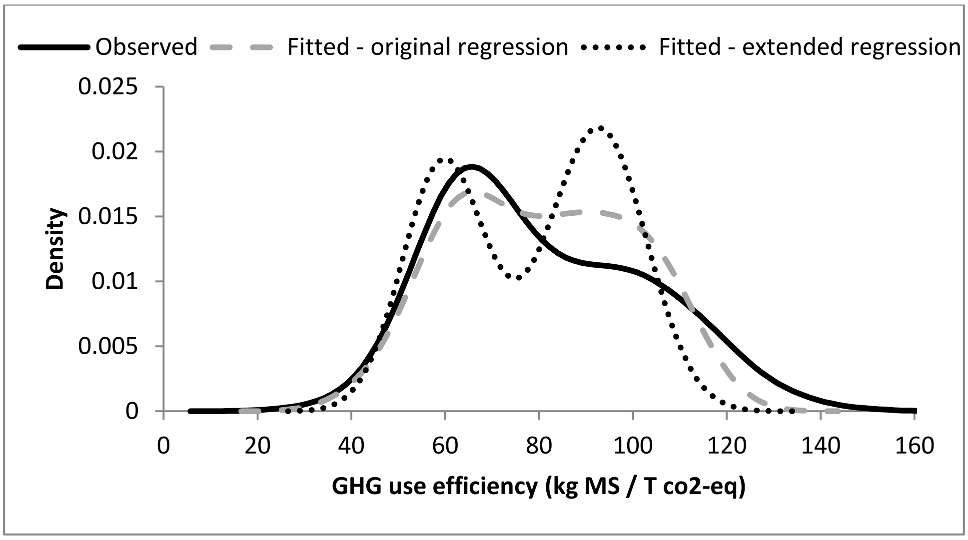


Figure 35: Distributions of GHG use efficiency residuals for investigating omitted variable bias

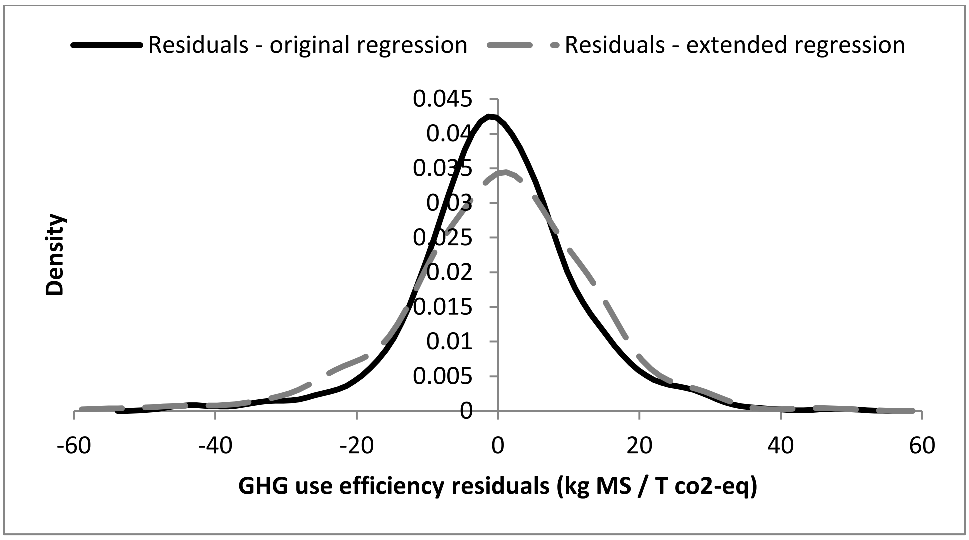


Figure 34 and Figure 35 are equivalent to Figure 9 and Figure 10, but include results from our extended regression. We observe that the distribution of fitted values is narrower with two clear modes. These modes represent clustering of farms observed in the same year. Hence, within years, we observe a narrower distribution of fitted values. This is consistent with our results for N use efficiency. Furthermore, we observe a wider distribution of residual from our extended regression than we observed previously. This suggests that, due to omitted variable bias, the results we present in Section 5 may be underestimates of the potential for mitigation.

Correlation Tables

The following tables give correlations between all the variables considered in this analysis. The table cells have been shaded according to the magnitude of the correlation coefficient, with darker cells corresponding to coefficients or larger absolution value.

Table 8: Correlation table (1 of 3)

	kg MS/ kg N	kg MS/ T GHG	MS/ cow	MS/ha	cows /ha	kg N /ha	T GHG /ha	Rain (mm)	Temp C
N use efficiency	1								
GHG use efficiency	0.44	1							
Production per cow	0.46	0.37	1						
Production per hectare	0.46	0.39	0.60	1					
Stocking rate	0.24	0.23	0.05	0.81	1				
N leaching	-0.59	-0.11	0.01	0.32	0.40	1			
GHG emissions	0.09	-0.41	0.28	0.65	0.62	0.41	1		
Rainfall	-0.51	-0.18	-0.45	-0.44	-0.24	0.18	-0.28	1	
Temperature	-0.52	-0.30	-0.54	-0.38	-0.12	0.19	-0.16	0.54	1
Topography = easy hill	-0.17	-0.13	-0.22	-0.20	-0.10	0.01	-0.10	0.10	0.14
Topography = flat	0.22	0.20	0.39	0.37	0.22	0.08	0.22	-0.22	-0.36
Topography = rolling hill	-0.14	-0.14	-0.30	-0.29	-0.18	-0.10	-0.18	0.18	0.31
Soil = peat	0.00	-0.02	-0.01	0.04	0.07	0.00	0.07	0.02	0.11
Soil = pumice	-0.20	-0.11	-0.13	-0.09	-0.01	0.21	0.01	0.11	0.09
Soil = recent YGE	0.12	0.01	0.22	0.21	0.11	0.04	0.19	-0.36	-0.18
Soil = sands	0.01	0.01	-0.04	-0.12	-0.12	-0.13	-0.12	-0.07	0.03
Soil = sedimentary	0.25	0.07	0.05	-0.12	-0.22	-0.35	-0.19	-0.10	-0.12
Soil = volcanic	-0.27	-0.03	-0.14	0.04	0.17	0.30	0.07	0.35	0.17
Young stock off for 9 months	-0.09	-0.14	-0.09	-0.09	-0.05	0.02	0.03	0.22	0.12
Young stock off permanently	-0.09	0.00	-0.02	-0.01	0.01	0.13	-0.02	0.07	0.04
Young stock on permanently	-0.14	0.00	0.00	-0.24	-0.27	-0.02	-0.23	-0.02	-0.13
Young stock off until weaning	0.21	0.12	0.08	0.28	0.28	-0.02	0.17	-0.18	0.00
Farm is irrigated	0.27	0.12	0.36	0.50	0.32	0.11	0.36	-0.52	-0.24
Winter grazing off	0.40	0.23	0.32	0.25	0.09	-0.20	0.07	-0.29	-0.34
Feed pad used	-0.01	0.05	-0.03	0.12	0.19	0.11	0.08	0.12	0.12
Wintering pad used	-0.03	-0.02	-0.10	-0.08	-0.03	-0.05	-0.07	0.05	0.16
N inhibitors used	0.32	0.15	0.34	0.17	-0.02	-0.16	0.05	-0.25	-0.28
N inhibitors x Temperature	0.32	0.14	0.33	0.18	-0.01	-0.15	0.06	-0.25	-0.27
N inhibitors x Rainfall	0.30	0.14	0.31	0.14	-0.04	-0.17	0.03	-0.22	-0.28

Table 9: Correlation table (2 of 3)

	Topography			Soil					
	Easy	Flat	Rolling	peat	pumice	YGE	sands	sedim	volcanic
Topography = easy hill	1								
Topography = flat	-0.44	1							
Topography = rolling hill	-0.13	-0.83	1						
Soil = peat	-0.05	0.11	-0.09	1					
Soil = pumice	0.27	-0.14	-0.01	-0.04	1				
Soil = recent YGE	-0.11	0.14	-0.08	-0.08	-0.10	1			
Soil = sands	0.00	-0.05	0.06	-0.04	-0.05	-0.08	1		
Soil = sedimentary	-0.07	0.00	0.05	-0.16	-0.20	-0.36	-0.17	1	
Soil = volcanic	0.05	-0.06	0.03	-0.12	-0.15	-0.28	-0.13	-0.57	1
Young stock off for 9 months	-0.03	0.04	-0.02	0.08	0.00	-0.18	-0.02	-0.02	0.14
Young stock off permanently	-0.02	0.05	-0.04	-0.02	-0.02	-0.03	-0.02	-0.02	0.07
Young stock on permanently	0.00	0.07	-0.07	-0.08	0.03	0.14	-0.03	-0.04	-0.04
Young stock off until weaning	0.03	-0.10	0.09	0.01	-0.02	0.04	0.04	0.05	-0.09
Farm is irrigated	-0.12	0.21	-0.16	-0.02	0.03	0.37	-0.09	0.03	-0.29
Winter grazing off	-0.07	0.13	-0.10	-0.03	0.02	0.20	0.06	0.18	-0.36
Feed pad used	-0.02	0.07	-0.07	0.12	-0.08	0.03	-0.05	-0.07	0.06
Wintering pad used	0.00	-0.09	0.10	-0.01	-0.07	-0.07	-0.05	0.12	-0.02
N inhibitors used	-0.07	0.11	-0.08	-0.05	-0.06	0.08	0.05	0.11	-0.15
N inhibitors x Temperature	-0.07	0.11	-0.08	-0.05	-0.06	0.08	0.05	0.10	-0.14
N inhibitors x Rainfall	-0.06	0.10	-0.07	-0.05	-0.06	0.02	0.07	0.13	-0.13

Table 10: Correlation table (3 of 3)

	Young stock				Irrigat-ion	Winter graze	Feed pad	Winter pad	N Inhibit
	off 9 mnths	off perm	on perm	off wean					
Young stock off for 9 months	1								
Young stock off permanently	-0.04	1							
Young stock on permanently	-0.31	-0.05	1						
Young stock off until weaning	-0.56	-0.09	-0.60	1					
Farm is irrigated	-0.17	-0.04	-0.05	0.19	1				
Winter grazing off	-0.21	-0.08	-0.10	0.27	0.22	1			
Feed pad used	0.02	-0.04	-0.10	0.08	-0.10	-0.02	1		
Wintering pad used	-0.03	-0.02	-0.02	0.05	-0.06	-0.02	-0.01	1	
N inhibitors used	-0.05	-0.02	0.07	-0.02	0.14	0.19	-0.06	-0.07	1
N inhibitors x Temperature	-0.05	-0.02	0.07	-0.02	0.15	0.18	-0.06	-0.07	1.00
N inhibitors x Rainfall	-0.03	-0.02	0.07	-0.03	0.09	0.17	-0.05	-0.07	0.98

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