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Mitigation and Heterogeneity in Management Practices on New Zealand Dairy Farms

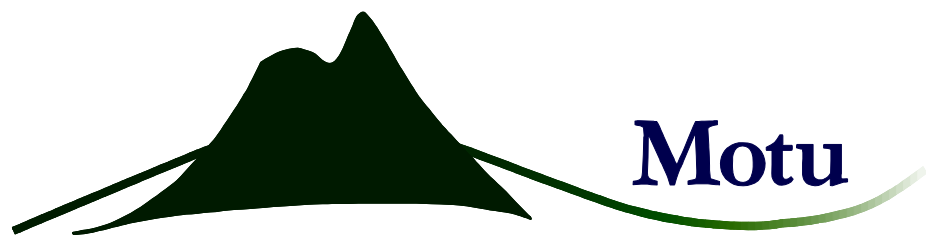
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Public Policy and Economic Research

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Management Practices on
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Simon Anastasiadis and Suzi Kerr

Motu Economic and Public Policy Research

Paper Prepared for NZARES 2012 Conference
August 2012

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Abstract

We consider two approaches to quantify New Zealand farmers' ability to mitigate their farm's environmental impact: The construction of marginal abatement cost curves and improvements in farm management practices.

Marginal abatement cost curves can be constructed by combining information on the effectiveness of mitigation with cost data. However, we find that the available data is not sufficient to support this approach.

We consider improvements in management practices using a distribution of farm production efficiency with regard to nitrogen and greenhouse gas (kg production per unit of emissions). Where differences in production efficiency are due to factors that can be managed by farmers, targeting less efficient farmers to encourage the adoption of management practices similar to those of the more efficient farmers is a potential mitigation strategy.

JEL codes

Q53, Q57

Keywords

Cost curves, greenhouse gas, heterogeneity, leaching, mitigation, nitrogen, production efficiency

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1. Introduction

Pastoral farming contributes significantly to the New Zealand economy but can also result in adverse environmental effects, in particular by emitting nutrients and agricultural greenhouse gases. Nutrients are recognised as contributing to poor water quality in most catchments containing agricultural development (Ministry for the Environment, 2007). Forty-eight percent of New Zealand's greenhouse gas emissions are attributed to agricultural activity (Ministry for the Environment, 2009).

Concerns about the level and intensity of our agricultural emissions can be addressed by mitigation (reducing emissions per unit of product), reductions in the intensity of land use or land use change. In this paper we investigate mitigation two approaches: marginal abatement cost curves and the distribution of farm production efficiency.

Understanding the how much mitigation farms can achieve, and at what cost are critical to informed farmer and policy maker decisions. Policy makers, researchers and farmers are increasingly interested in the effectiveness and cost of mitigation technologies, and farmers' ability to mitigate via changes in their farming system (i.e. stocking rates, fertiliser use, effluent management, imported feed, animal type and ratios, lambing percentages, etc).

Marginal abatement cost curves appear to be the preferred approach of researchers and policy makers. This is the approach taken by the ICF report with regard to agricultural greenhouse gas emissions (Pape et al., 2008). However, we find that the available data is not sufficient to support the construction of abatement cost curves for different types of farms.

We therefore consider the distribution of farm production efficiency as an alternative approach: There is anecdotal evidence of a wide range of production efficiency, with regard to nitrogen (N) leaching and greenhouse gas (GHG) emissions,¹ in existing farming practice (see also work by Ledgard et al. (2011)). Where differences in production efficiency between farms are due to factors that can be managed by farmers, encouraging less efficient farmers to adopt farm management practices similar to those of the more efficient farmers is a potential mitigation strategy (Clark et al., 2011a).

Historically we can observe that farms have become both more productive and more N and GHG efficient since 2001 (de Klein and Monaghan, 2011). Additionally, this production efficiency is positively (or at least not negatively) correlated with higher profitability, i.e. more

¹ i.e. kg milk solids production per kg N leached or per kg CO₂-eq emitted.

profitable farms have lower emissions per unit of production. Assessing the truth of this anecdotal evidence is important for policy development.

The paper is set out as follows: In section 2 we describe our attempt to estimate marginal abatement cost curves from the existing literature. Section 3 provides an overview of the data we use to consider the distribution of N and GHG production efficiency, followed by our choice of models in section 4. Sections 5 and 6 give results with regard to N and GHG production efficiency respectively. Section 7 concludes. Additional tables and figures are found in the appendix.

2. Constructing Marginal Abatement Cost Curves

Two difficulties arise when constructing marginal abatement cost curves. First, the effect of mitigation frequently differs with existing farm management practices and environmental conditions. For example: the effectiveness of nitrogen inhibitors (or DCD) is known to vary with rainfall and temperature (Kelliher et al., 2008) (Menneer et al., 2008). Second, it can be difficult to isolate the effect of a mitigation practice as changes in mitigation practices are frequently accompanied by changes in farm management practices. For example: a farm that puts in a standoff or wintering pad may begin farming more intensively.

In response to this, we would like to construct marginal abatement cost curves for specific geographic regions and farm types. Farms in the same region are expected to have similar environmental conditions such as rainfall and temperature, while farms of the same farm type in the same region are expected to have similar farm management practices, including farming intensity, stock management and existing mitigation practices.

One approach to identifying the potential effects and cost of mitigation is to use simulation models. These models link farm management decisions to profit and environmental outcomes. Existing models include Farmax (Bryant et al., 2010), OVERSEER (AgResearch, 2009), the DairyNZ Whole Farm Model (Beukes et al., 2011), and a non-linear programming model (Doole and Pannell, 2009). Unfortunately these models typically require the user to specify, and assess the feasibility of, every simulation. As we do not have the farming expertise necessary to run informed simulations, we limit ourselves to consider simulation results reported by other researchers.

A survey of the available New Zealand literature in April 2011 revealed a range of papers on nitrogen and greenhouse gas mitigation options and their costs. This included papers that simulate different farming systems: AgriBusiness Group (2009), Anderson and Ridler (2010),

Barton (2005), Beukes et al. (2010), Beukes et al. (2011), Doole and Pannell (2009), Doole (2010), Monaghan et al. (2008), Moyo and Yates (2010), Ridler et al. (2010), Smeaton and Blackman (2007), Smeaton and de Klein (2008) and Anastasiadis et al. (2011); and those that do not: AgFirst (2010), Clark et al. (2011b), Doole et al. (2011), Eckard et al. (2010), Edmeades (2008), Grainger and Beauchemin (2011), Luo et al. (2010), PGgRc (2010), Rae and Strutt (2011) and Robson and Edmeades (2010). Only two papers that considered marginal abatement cost curves were found: Monaghan (2009) and Twaddle (2009).

In May 2011, Motu organised a workshop in Hamilton with the aim of getting a better idea of mitigation opportunities and their costs. We found that there was a significant ongoing focus on the simulation of different farming systems. Following this meeting, Motu compiled a database of farm simulation results. These were drawn from the above papers, with results from research-in-progress generously provided by Barrie Ridler, Graeme Doole and Dan Marsh, and Robyn Dynes and Duncan Smeaton.

The following figures are constructed from our database of farm simulation results. The different coloured markers signify different publications, or different series of results within the same publication. Except as noted below, we have not standardized the simulation results, and hence cannot separate the effect of mitigation from that of different model farms when comparing between studies. Fitted quadratic curves are provided to give a general sense of the data. Marginal abatement cost curves could be estimated as the derivative of these curves.

Figure 1 and Figure 2 give an overview of the relationship between environmental impact and profit for dairy farms in the Waikato region. These are constructed from our database of farm simulation results. Where possible we have standardized the price of milk solids to \$6 per kg. The different coloured markers signify different publications, or different series of simulations within the same publication. Fitted quadratic curves are provided to give a general sense of the data. Marginal abatement cost curves could be estimated as the derivative of these curves.

Figure 1: Nitrogen leaching and profit for Waikato dairy farms

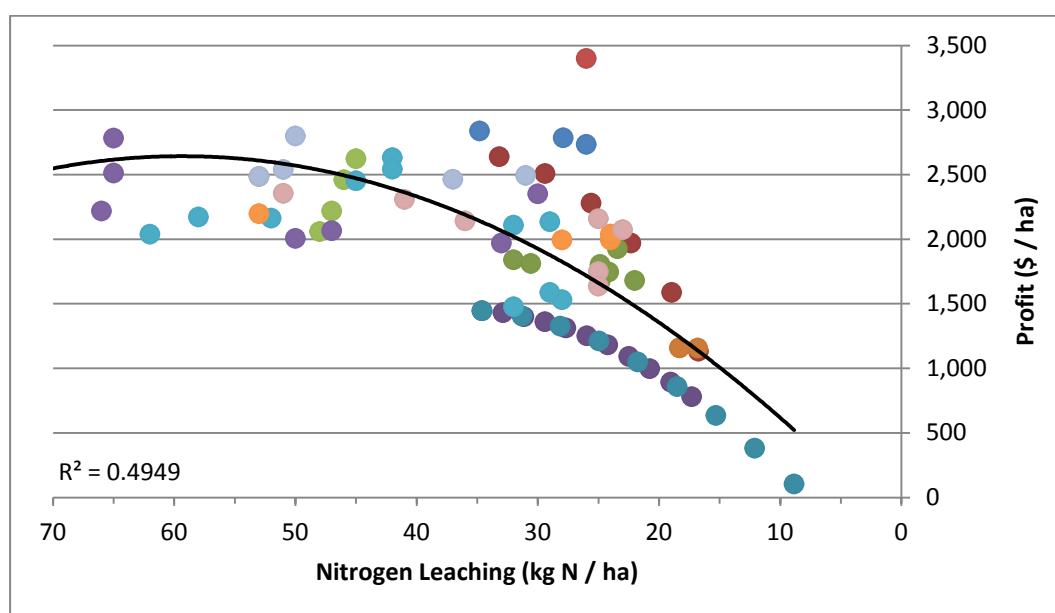


Figure 1 and Figure 2 give an overview of the relationship between environmental impact and profit for dairy farms in the Waikato region. Where possible we have standardized the price of milk solids to \$6 per kg.

For N leaching, the simulation results suggest that farms with high levels of emissions can mitigate with minimal loss of profitability, but that reducing emissions below some point is much more costly. The dark blue and purple points that form a smooth curve are from Doole and Pannell (2009) who optimise farm performance given a specified nitrogen target.

For GHG emissions, the simulation results suggest that any reduction in emissions will have a significant effect on farm profitability. This is unsurprising as there is a strong relationship between milk solid production and GHG emissions, and hence mitigation is likely to result in reduced production.

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

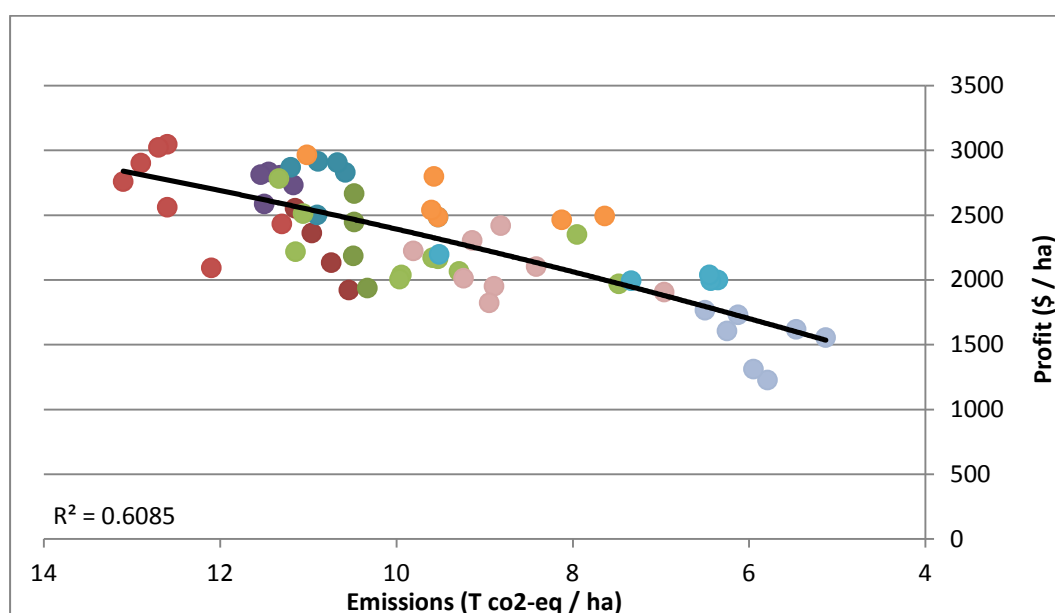
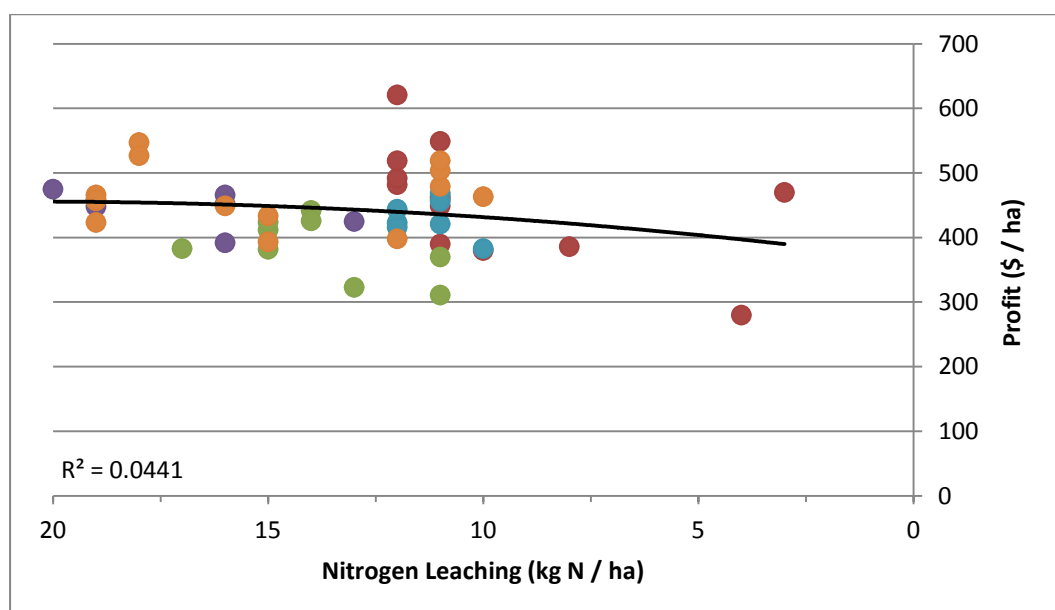


Figure 3 compares N leaching and profit for King Country sheep/beef farms. This suggests that there is a very weak relationship between N leaching and profit for sheep/beef farms.

Figure 3: Nitrogen leaching and profit for King Country sheep/beef farms



While an overview of the simulations contained in the database confirms the general relationship between mitigation and costs², we are not confident using them to construct marginal abatement cost curves. Regardless of the quality of the individual studies that produced

² In general, as mitigation increases the profitability of farms decreases. 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.

these simulation results, they are not suitable to be combined in this way as different authors have made different assumptions about prices and other key inputs, and insufficient information has been provided to standardize the results.

Furthermore, the following limitations with the simulation results would make marginal abatement cost curves constructed from them misleading. While the underlying models have been compared to existing farms, none of the simulation results have 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 of time to learn and implement new systems or technologies were ignored; management costs were not adjusted for, or advisor costs added, in more complex systems; no allowance was made for risk management. Finally, the data is not representative of New Zealand farms as a whole, the simulations focused almost exclusively on Waikato dairy farms or King Country sheep/beef farms.

3. Data

In order to consider the distribution of farm production efficiency, we use unit record 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).³ This data is collected, in a standardized form, from participating farms each year. MAF combines the collected data by region and farm type to construct representative model farms, which are the focus of their monitor farm reports. The monitor farm reports provide a short-term view of the finances and productivity of an average farm across a range of farm types and geographic regions (see (Ministry of Agriculture and Forestry, 2011)). Motu was provided with short term access to a subset of the unit record farm data for the purpose of this analysis.

In order to consider production efficiency, a measure of on-farm production is required. For dairy farms production can be quantified in kg milk solids. For sheep/beef (or deer) farms no explicit production measure was available in the data and constructing such a production measure was beyond our expertise. The following analysis is therefore limited to dairy farms.

3.1. Data description

The farm characteristics included in our analysis are described below. Where relevant we report descriptive statistics of the combined records in Table 2.

³ Motu was also granted access to an AgResearch database where work had been done to standardize farms. We elected not to use this database for this research as it contained predominantly simulated farms and hence would not be representative of the wider population of New Zealand farms.

ID: Unique identifiers were generated by AgFirst for each monitored farm. These enable us to identify data that was collected from the same farm over multiple years.

Region: The geographic region of the farm is given as one of Canterbury (15%), Lower North Island (15%), Northland (12%), Southland (14%), Taranaki (18%) or Waikato (26%).

Rainfall: The mean annual mm of rainfall for the farm was given.

Mean annual temperature: The mean annual temperature for each farm was given. Where these data were missing, the farm was assigned the average temperature for farms in the same region.

Topography: The topography of the farm was classified into one of flat land (74%), rolling land (20%) or easy hill country (6%).

Soil type: The soil type of farms was classified into peat (3%), pumice (5%), recent yellow-grey earth (YGE) (15%), sands (4%), sedimentary (42%) or volcanic soil (30%). For some farms observed in 2008, it was unclear as to which class the recorded soil type should be assigned to. Where these farms were also observed in 2009, we used their recorded soil type in 2009 to classify the farms' soil type in 2008. Observations for which we could not classify the soil type were dropped.

Young stock grazing: The management of young stock and how long they were grazed off the dairy platform was classified into young stock on permanently (25%), young stock off until weaning (52%), young stock off for 9 months (23%) and young stock off permanently (1%). In 2008 only Yes and No responses were recorded; we assume these are respectively equivalent to young stock off until weaning and young stock on permanently.

Irrigated farm: Whether the farm is irrigated was indicated as a binary variable. 17 percent of records were for irrigated farms. As this variable was not observed in 2008, we assume that farms that were irrigated in 2009 were also irrigated in 2008.

Mitigation practices: Binary variables for the following mitigation practices were included: whether animals were grazed off paddocks during winter, whether a feed pad was used, whether a wintering pad was used and whether nitrogen inhibitors (DCDs) were applied. Where there was missing information for any of these variables, we assumed the farm did not use the mitigation practice. 48%, 17%, 7% and 6% of records respectively were for farms that used the mitigation practice.

Farm System: Dairy farm system gives an indication of the intensity of the farming practice. The systems are described by Dairy NZ in Table 1 as follows:

Table 1: Description of farm systems

System 1 (16%) Self contained	No supplement is used. Animals are fed solely from grazing on the effective milking platform.
System 2 (34%) 4-14% of total feed imported	Feed is imported for dry cows, either supplement brought onto the milking platform or by grazing the animals off the milking platform.
System 3 (24%) 10-20% of total feed imported	Feed is imported to extend lactation (typically into autumn) and for dry cows
System 4 (19%) 20-30% of total feed imported	Feed is imported to extend both ends of lactation and for dry cows.
System 5 (7%) >30% of total feed is imported	Feed is imported for use year round.

Nitrogen loss: The number of kg of N lost per hectare per year as determined by the Overseer model is given (kg N/ha/yr).

GHG emissions: The number of tonnes CO₂-equivalent emitted per hectare per year as determined by the Overseer model is given (T CO₂-eq/ha/yr).

Total effective hectare: The number of hectares used for milking and grazing the dairy herd is given (ha).

Stocking rate: The number of animals per hectare is given (animals / ha).

Milk solids: Total milk solid production for the farm is given (kg MS).

Production per animal: Production per cow is given (kg MS / cow).

Production per hectare: Production per hectare is given (kg MS/ha).

Table 2: Mean farm measures by region

	Canterbury	Lower North Island	Northland	Southland	Taranaki	Waikato
Rainfall (mm)	674	1312	1603	981	1560	1304
Temperature (°C)	12.1	13.2	16.0	11.0	13.4	14.0
N leaching (kg N/ha)	33	29	28	20	39	36
GHG emissions (T CO ₂ -eq/ha)	15.6	12.0	9.2	10.6	12.9	12.8
Farm size (ha)	239	148	147	219	90	126
Stocking rate (cows/ha)	3.23	2.77	2.14	2.35	2.92	2.98
Total production (T MS)	297	137	85	190	92	111

Production per animal (MS/cow)	416	344	288	387	344	310
Production per hectare (MS/ha)	1340	942	615	896	1005	929

4. Models

We consider a model where the production efficiency of a farm is a function of five inputs: the land and atmospheric conditions; stock management; the use of specific mitigation technologies; the intensity of the farming operation; and the farmer's skill to combine the other four inputs. We wish to determine how much of the difference in production efficiency between farms is due to differences in inputs that can be managed by the farmer.

Figure 4 and Figure 5 give distributions for farm production 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 long tail of farms which are more efficient.

Figure 4: Distribution of N production efficiency

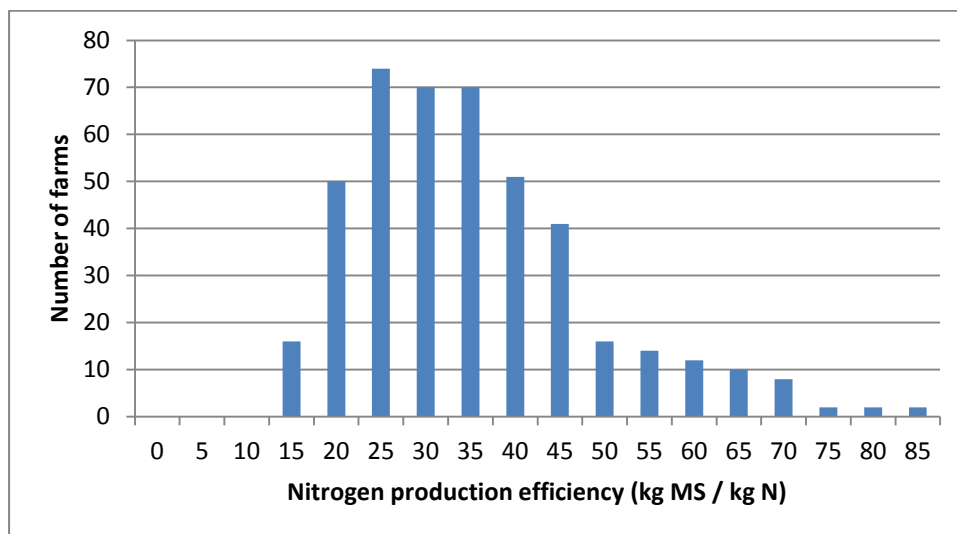
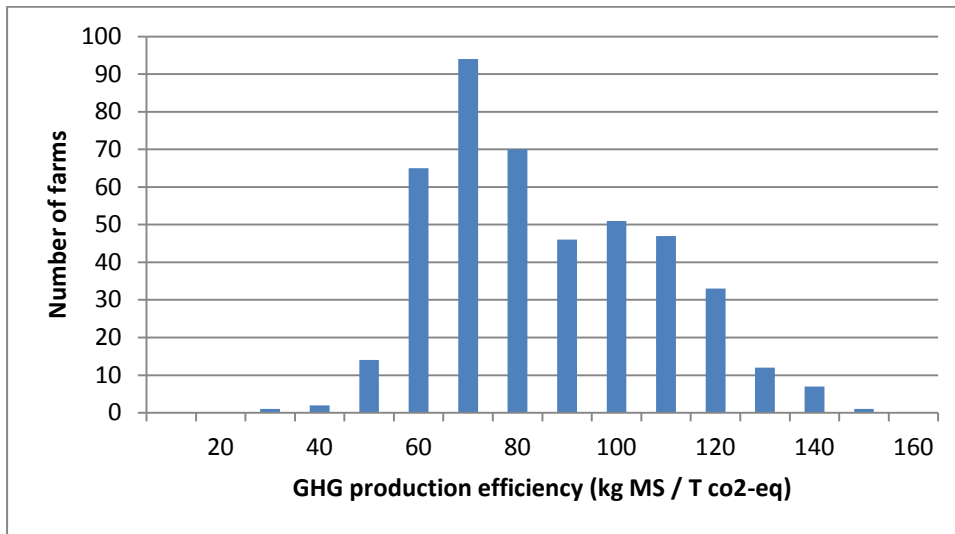


Figure 5: Distribution of GHG production efficiency



The above distributions do not control for factors that cannot be managed by farmers. In order to consider heterogeneity in production efficiency due to farm management practices we control for variation due to factors that cannot be managed by farmers such as differences in land and atmospheric conditions.

Two regression models are considered. For each model we include explanatory variables for the factors that cannot be managed by farmers. Any residual variation between farms is then attributed to factors that can be managed by farmers and therefore are affected by changes in farm management practices.

Model one controls for variation in land and atmospheric conditions. This includes whether a farm is irrigated or not as irrigation is necessary in certain regions in order for dairy farming to be financially viable. We also include the grazing of stock off the farm, as this only moves their emissions elsewhere. The residuals reported from model one will estimate the production efficiency that is due to the use of specific mitigation technologies, the intensity of the farming operations, and farmers' skill.

As farmers may face financial constraints that prevent them from adopting new technologies, model two extends model one to control for the use of specific mitigation technologies. The residuals reported from model two will estimate the production efficiency that is due to the intensity of the farming operation, and farmers' skill.

We fit models one and two using ordinary least squares regression. The effectiveness of this approach depends on how well the residual identifies the production efficiency that is due to factors that can be managed by farmers.

The residual may include factors that cannot be managed by farmers. This occurs where the relationship between efficiency and the explanatory variables is non-linear, or where there are additional factors that cannot be managed by farmers that have not been included as explanatory variables, as these will be reported in the residual.

The residual may not fully include all the factors that can be managed by farmers. This occurs where there is co-linearity between the explanatory variables and the factors that can be managed by farmers (for example, more skilled farmers were more likely to graze stock off-farm) as some of the effect of the farm management practices will be captured by the explanatory variables.

Furthermore, as we are deliberately excluding explanatory variables from the regressions in order to include them in the residual, there will be omitted-variable bias. This is due to co-linearity between included and omitted explanatory variables and means that our coefficient estimates will not be consistent with their true values.

We combine data from all three years to produce an unbalanced panel (not all farms are observed in all years). As we have non-independent observations we should allow for clustering of errors. We have not done so, hence our coefficient estimates in the appendix will be biased. As our intention was to investigate heterogeneity rather than identify statistically significant relationships, we do not consider this to be problematic.

Fixed effects for each year were included in both models to account for annual variation. We also investigated running each of the models separately for each year. The model coefficients estimated for the different years were not significantly different from each other. We therefore report only the results from the model with all three years of data.

N losses and GHG emissions are not measured on farm but are estimated using the Overseer model based on a combination of observed farm characteristics. Hence there is a risk that the results we observe may be due to how N losses and GHG emissions are estimated by Overseer, rather than because of differences between farms and farm management. Also, these distributions are unlikely to be representative of all farmers. There is likely to be sampling bias in the data as inclusion in the monitor farm recording is voluntary.

For completeness and future reference the regression models are also fitted to production per cow, production per hectare, stocking rate, N leaching loss per hectare, and GHG emissions per hectare. Results for these dependent variables can be found in the appendix.

Readers of the appendix may be surprised that so few explanatory variables in our results are statistically significant. The regression results in the appendix show that it is common for

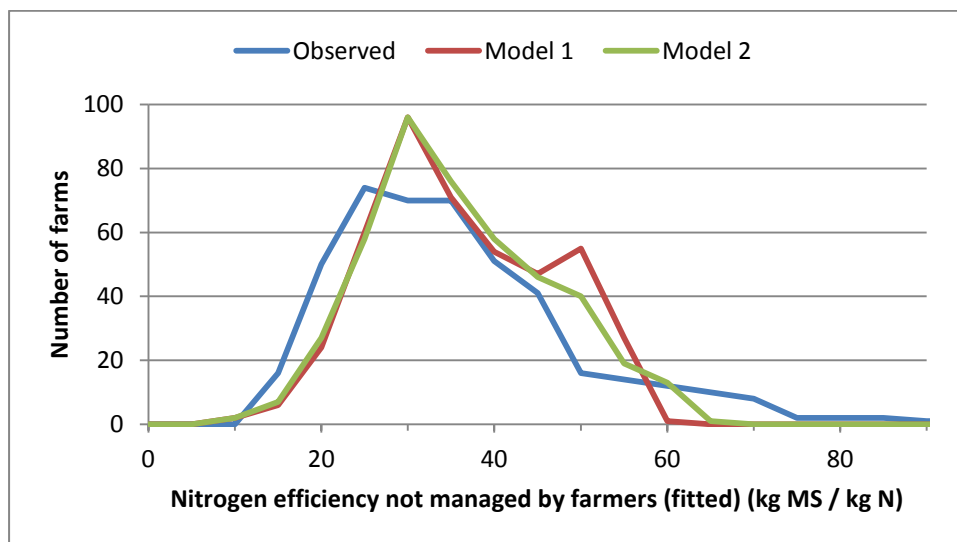
explanatory variables that are associated with higher production per hectare to also be associated with greater N and GHG emissions per hectare. Even though these explanatory variables may have a significant effect on production and emissions separately (for example, the use of a feed pad), they are unlikely to have a significant effect on production efficiency as this is calculated as the ratio of production and emissions.⁴

The opposite effect is also observed: The use of DCDs does not report a statistically significant coefficient on production per hectare or N leaching. However, as the use of DCDs is associated with higher production per hectare and lower N leaching per hectare (even though these associations are not significant), DCDs report a statistically significant affect on N production efficiency.

5. Nitrogen Leaching

We use both models to consider N production efficiency. The regression coefficients are given in the appendix. We calculate and plot the distributions of the estimated production efficiency. Figure 6 compares these distributions against the observed distribution (as given in Figure 4). We construct the following distributions as histograms. For ease of viewing and comparison they are presented as line plots.

Figure 6: Observed and estimated distributions of nitrogen production efficiency

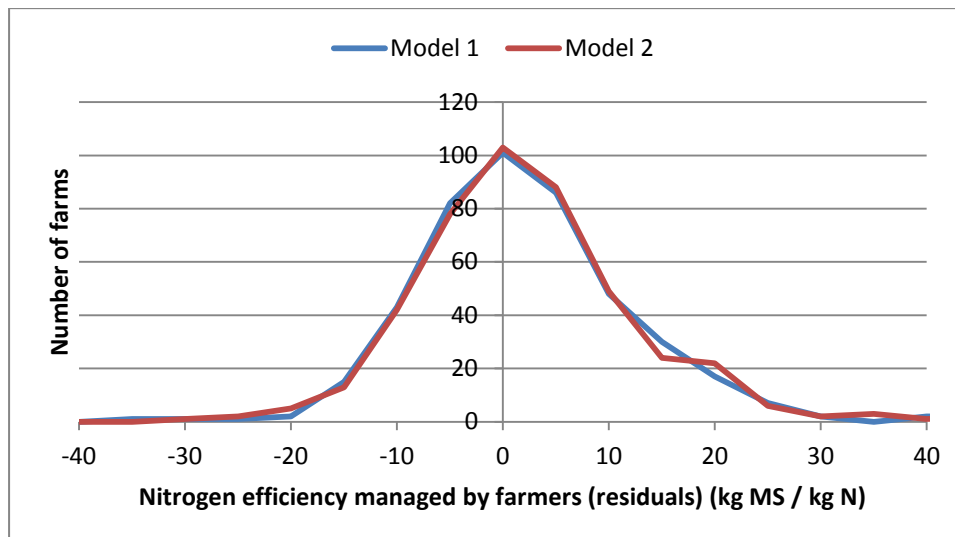


We calculate and plot the frequency of the residuals to give the distribution for N production efficiency due to farm management practices in Figure 7. The most efficient farms

⁴ To demonstrate why this is the case consider a fraction: If we increase the value of both the numerator and the denominator then the change in the value of the fraction is ambiguous; however, if we increase (decrease) the value of the numerator and decrease (increase) the value of the denominator then the value of the fraction must be increasing (decreasing).

are to the right and the least efficient farms are to the left. We observe that the estimated distributions underestimate the proportion of farms with the lowest and with the highest levels of efficiency.

Figure 7: The distribution of N production efficiency due to farm management practices



From these distributions we can consider improvements in N production efficiency from changes in farm management as a mitigation measure. We expect that the farms with the least efficient farm management practices to have the greatest potential gains for improvement in farm management practices. They may be able to identify ways to improve by observing the most efficient farmers.

Figure 8: The effect of gains in farm management practices on N production efficiency

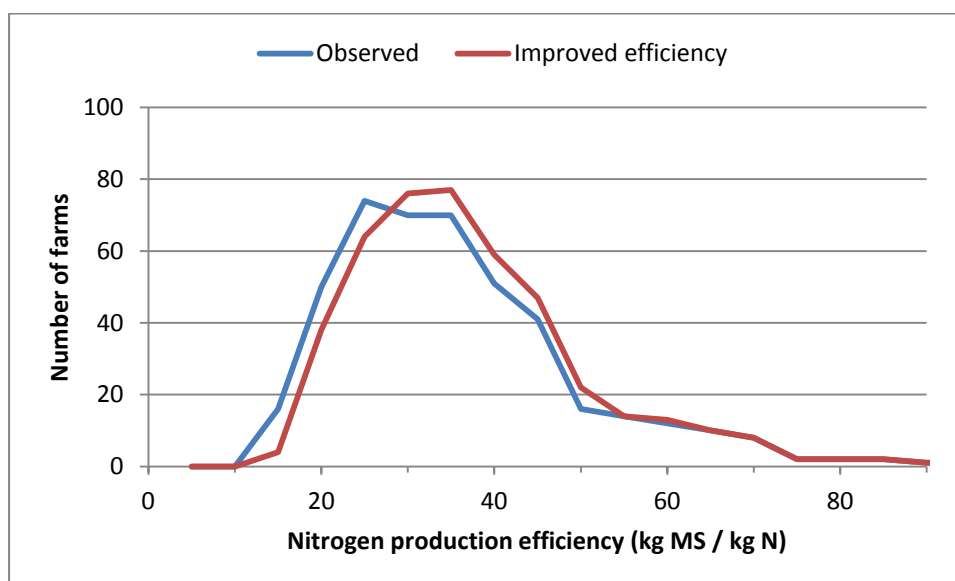


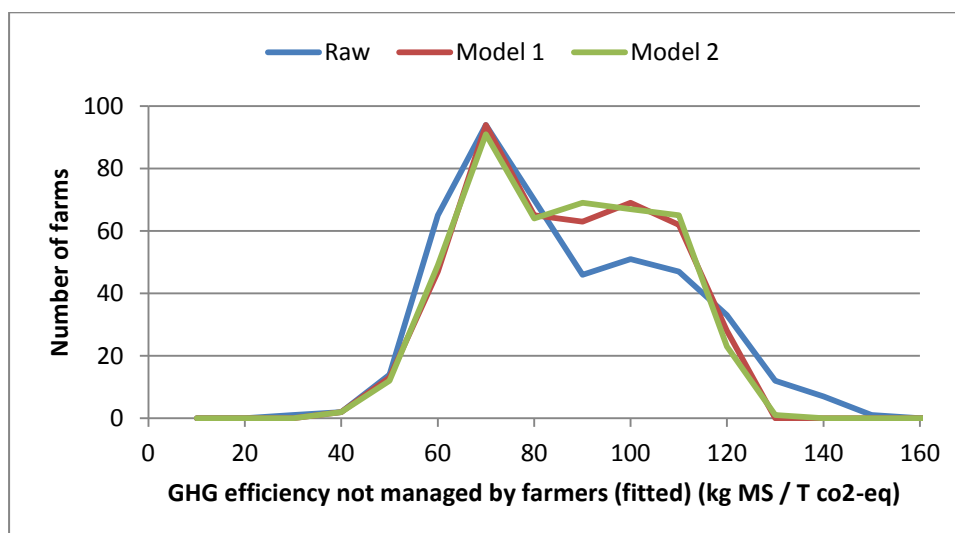
Figure 8 gives an example of implementing mitigation via improvements in farm management efficiency using model two. It shows the change in the distribution of N

production efficiency when all farms with efficiency due to farm management practices below the 50th percentile (the median) improve their efficiency by half the difference between their current efficiency and the 50th percentile via the adoption of new farm management practices. This corresponds to a 5 percent improvement in production efficiency and a 4.8 percent reduction in N leaching, if production levels remain constant.

6. Greenhouse Gases

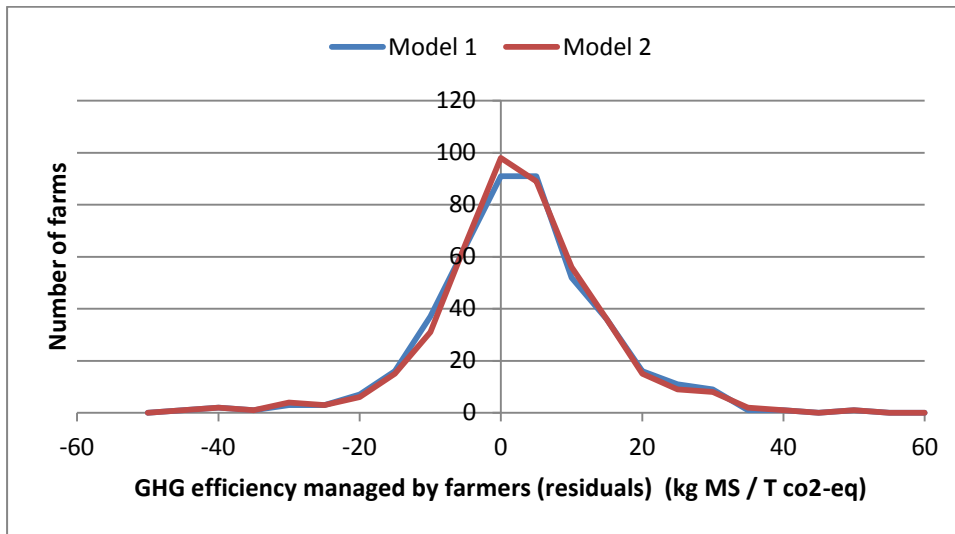
We replicate the above results for GHG emissions. The regression coefficients for both models are given in the appendix. We calculate and plot the distributions of the estimated production efficiency. Figure 9 compares these distributions against the observed distribution (as given in Figure 5).

Figure 9: Observed and estimated distributions of GHG production efficiency



We calculate and plot the frequency of the residuals to give the distribution for GHG production efficiency due to farm management practices in Figure 10. The most efficient farms are to the right and the least efficient farms are to the left. We observe that the estimated distributions underestimate the proportion of farms with the lowest and with the highest levels of efficiency.

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



From these distributions we can consider improvements in GHG production efficiency from changes in farm management as a mitigation measure, in the same way as for N.

Figure 11: The effect of gains in farm management practices on GHG production efficiency

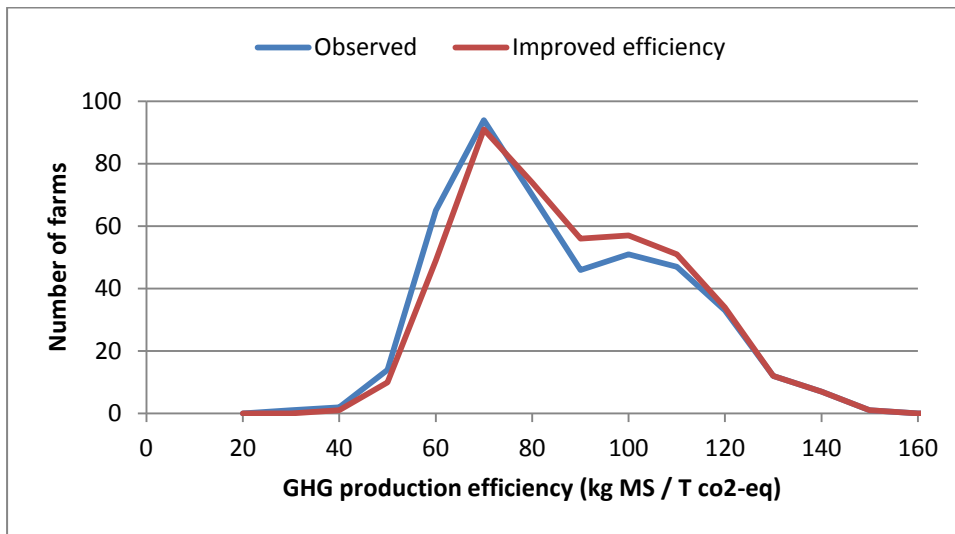


Figure 11 gives an example of implementing mitigation via improvements in farm management efficiency using model two. It shows the change in the distribution of GHG production efficiency when all farms with efficiency due to farm management practices below the 50th percentile (the median) improve their efficiency by half the difference between their current efficiency and the 50th percentile via the adoption of new farm management practices. This corresponds to a 2.5 percent improvement in production efficiency and a 2.4 percent reduction in GHG emissions, if production levels remain constant.

7. Discussions and Conclusions

We have considered two approaches to quantifying farmers' ability to mitigate their farm's environmental impact: The construction of marginal abatement cost curves and improvements in farm management practices.

While marginal abatement cost curves are frequently of interest to researchers and regulators alike, we are not confident that the existing simulation data can be combined to construct robust cost curves.

As users of simulation model results we do not have the expert knowledge possessed by the researchers who run these models. This makes it difficult to assess the credibility of any particular study and limits our ability to make comparisons between studies.

In the absence of marginal abatement cost curves, we instead consider the distribution of production efficiency and the potential for less efficient farmers to mitigate by becoming more like the most efficient farmers. Our results suggest that significant mitigation could be achieved by "bringing up the rear". That is: encouraging less production efficient farmers to adopt management practices similar to those of the more efficient farmers.

It should also be noted that our study cannot be used to access the causal effect of implementing specific farm management practices or mitigation technologies. This is because of selection bias: more intensive farmers will have self selected to implement practices or technologies in order to make their farms more intensive. Hence the distribution of management practices or mitigation technologies across farmers is non-random.

One shortfall of considering the distribution of production efficiency is that it does not capture the costs associated with becoming more N and GHG efficient. We assume that it is desirable, and hence profitable (or at least, no less profitable), for less efficient farmers to adopt similar management practices to more efficient farms. While this is likely to be true, there may be additional barriers to realizing efficiency gains for the less efficient farmers. For example, there may be gains from capital investment that farmers can not realize if they are credit constrained or time required to learn and implement new practices.

We have considered our two approaches to quantifying mitigation separately. Should future research enable the construction of robust marginal cost curves, we anticipate that a more complete picture of mitigation could be constructed by using distributions of current farm performance to scale the cost curves across different farms.

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9. Appendix

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

9.1. Variable distributions and relationships

In addition to the description of the data provided in section 3, we construct distributions for some of the variables in our data. These are raw distributions and do not control for any underlying farm characteristics.

Figure 12: Distribution of N leaching per ha

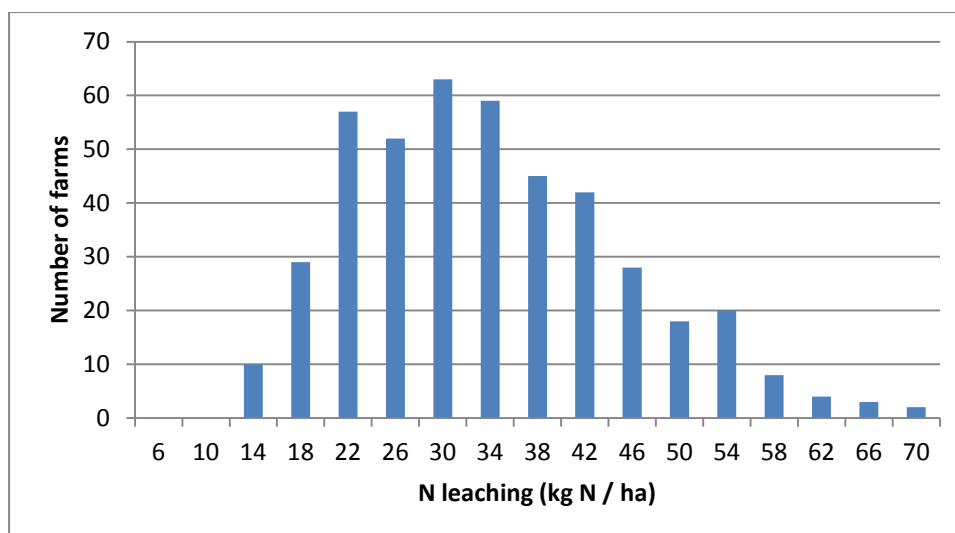


Figure 13: Distribution of GHG emissions per ha

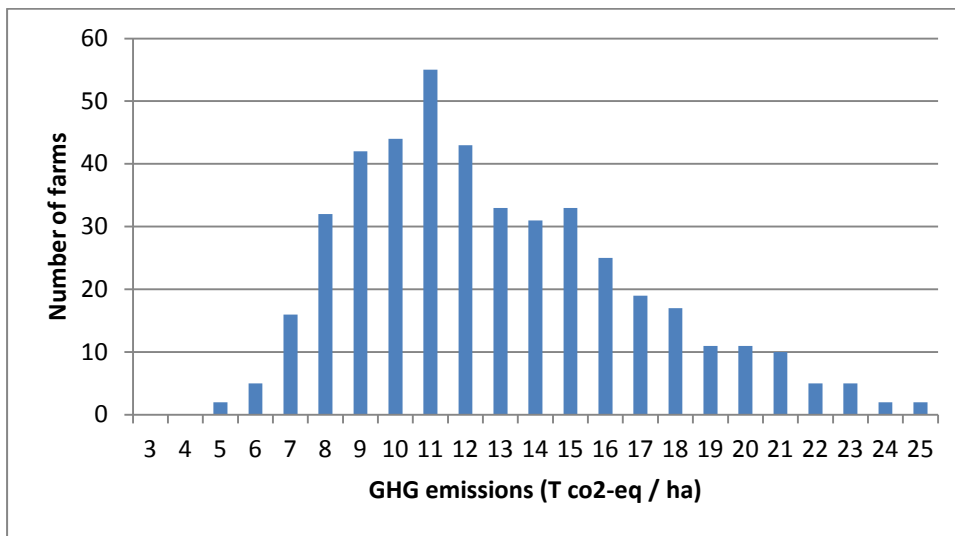


Figure 14: Distribution of Farm size

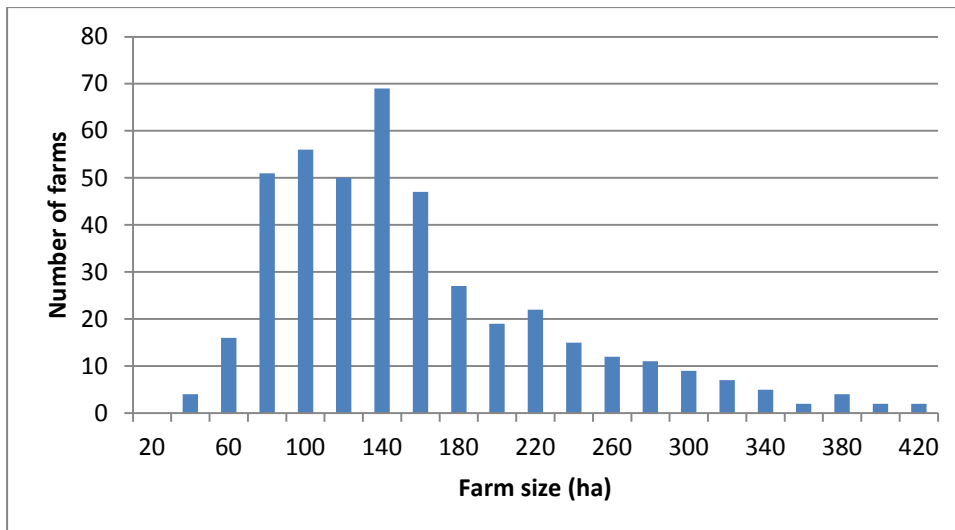


Figure 15: Distribution of stocking rate

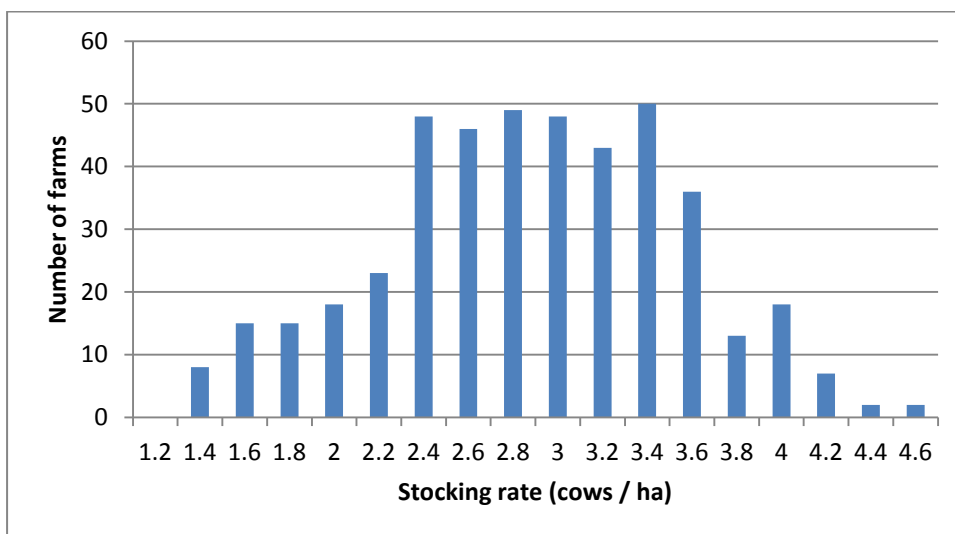


Figure 16: Distribution of production per animal

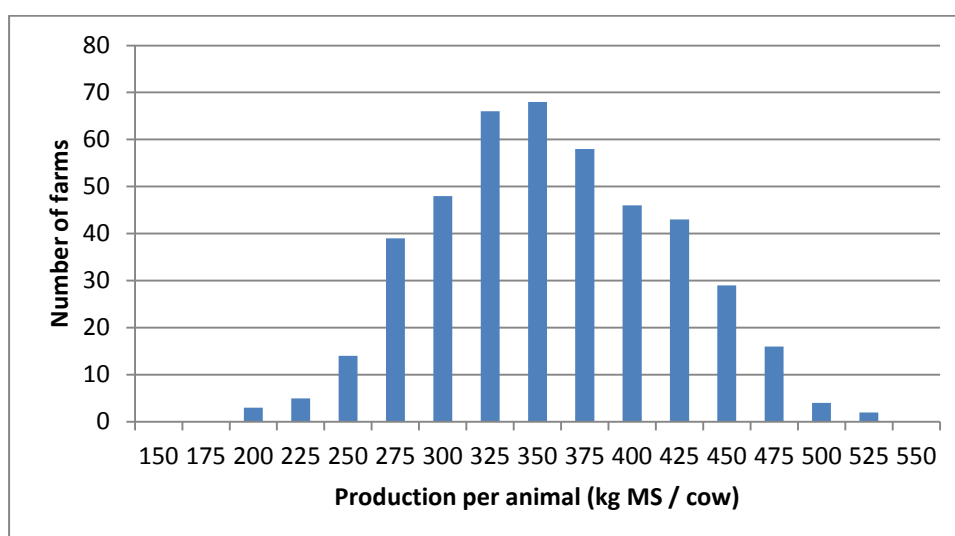
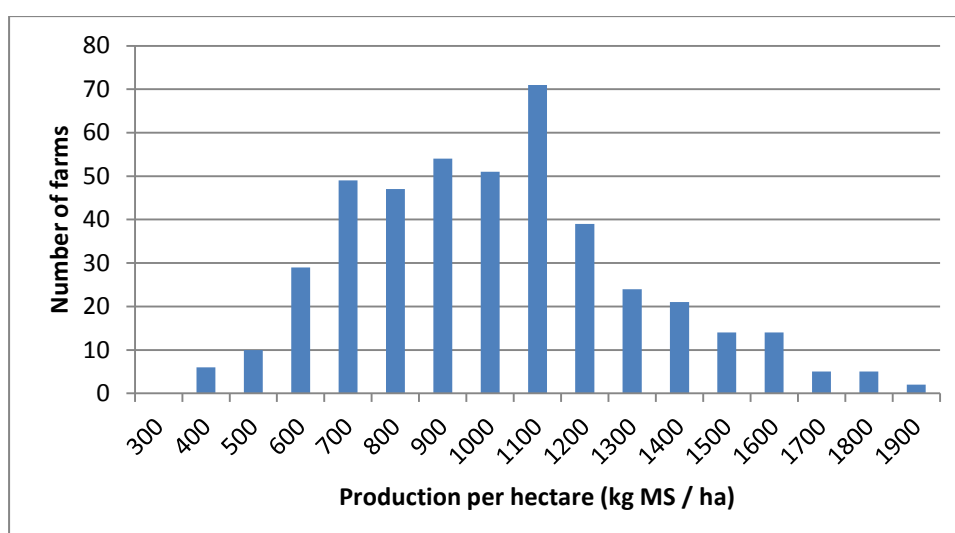


Figure 17: Distribution of production per hectare



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 18 to Figure 20 consider production efficiency while Figure 21 to Figure 23 gives the equivalent results for emissions per hectare. As stocking rates are frequently a significant driver of emissions, these are compared in Figure 24 and Figure 25.

Figure 18: The relationship between N and GHG production efficiency

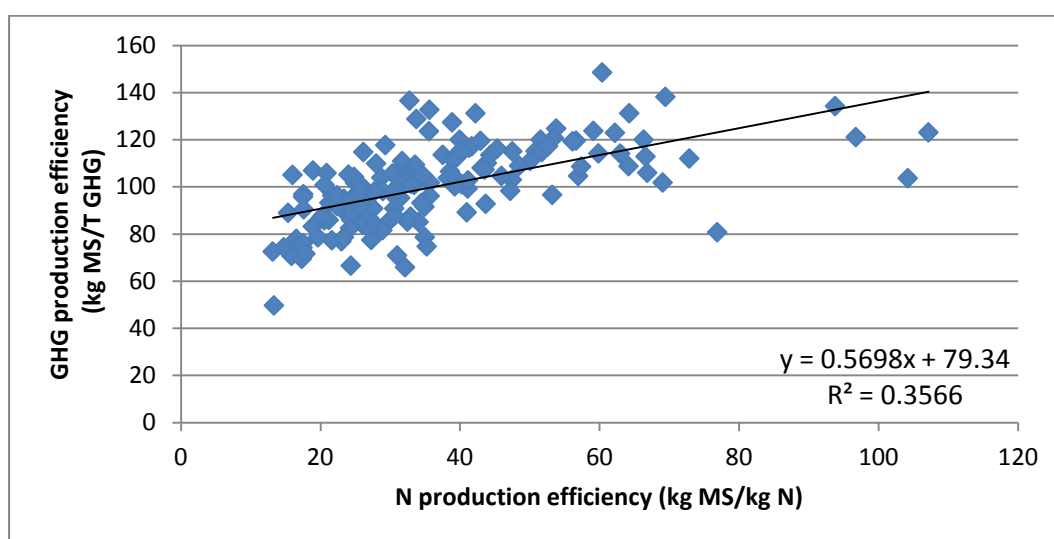


Figure 19: The relationship between production and N production efficiency

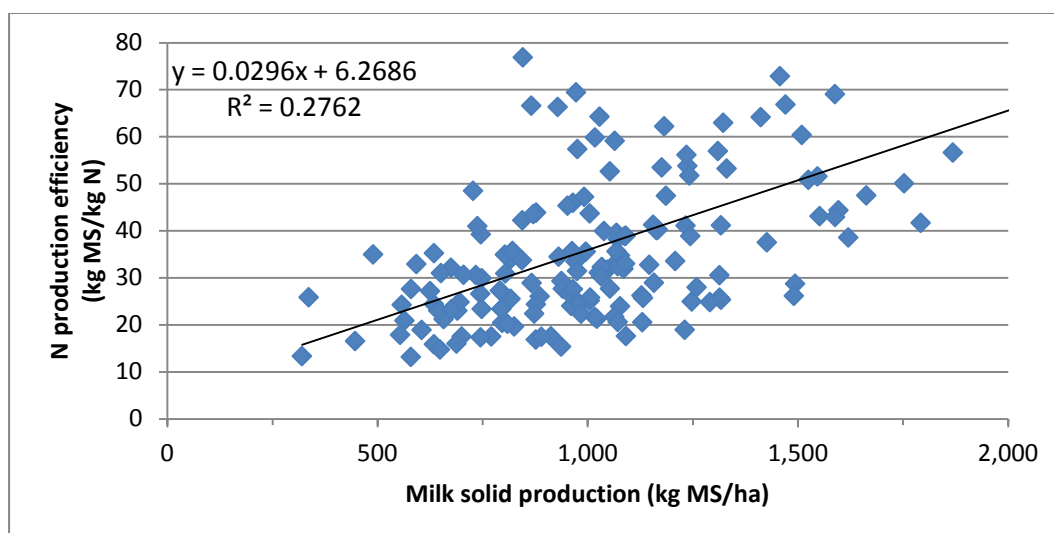


Figure 20: The relationship between production and GHG production efficiency

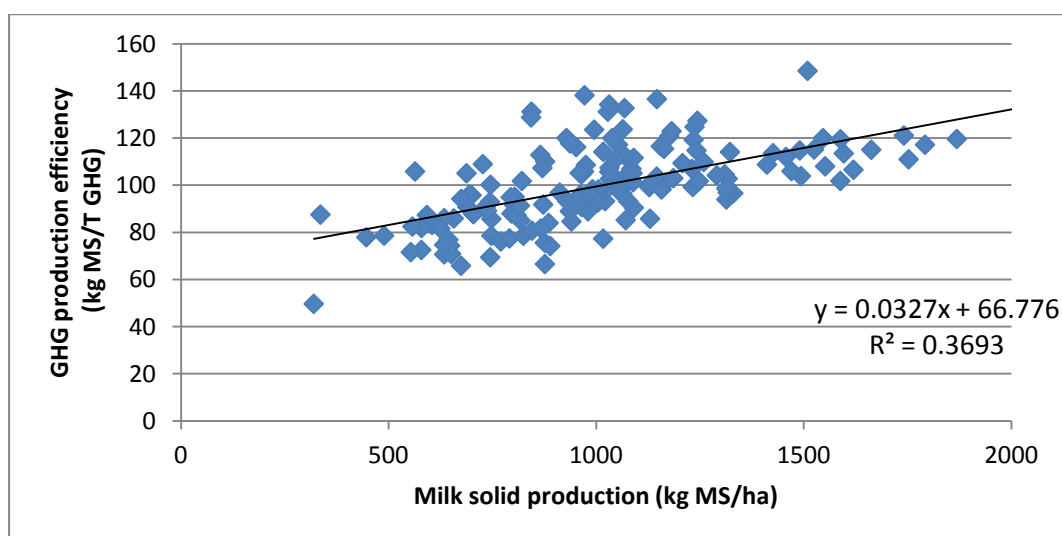


Figure 21: The relationship between N and GHG emissions

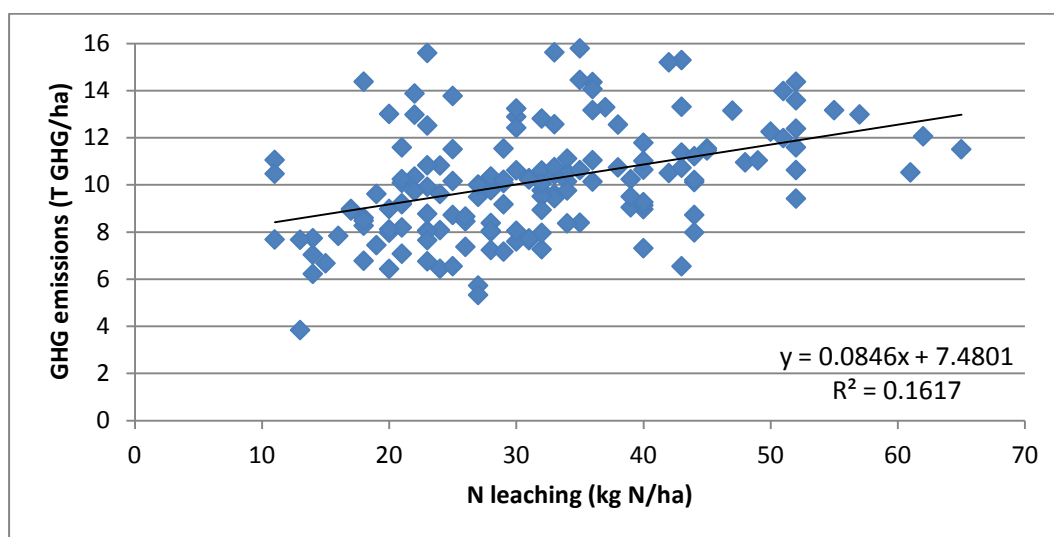


Figure 22: The relationship between production and N leaching

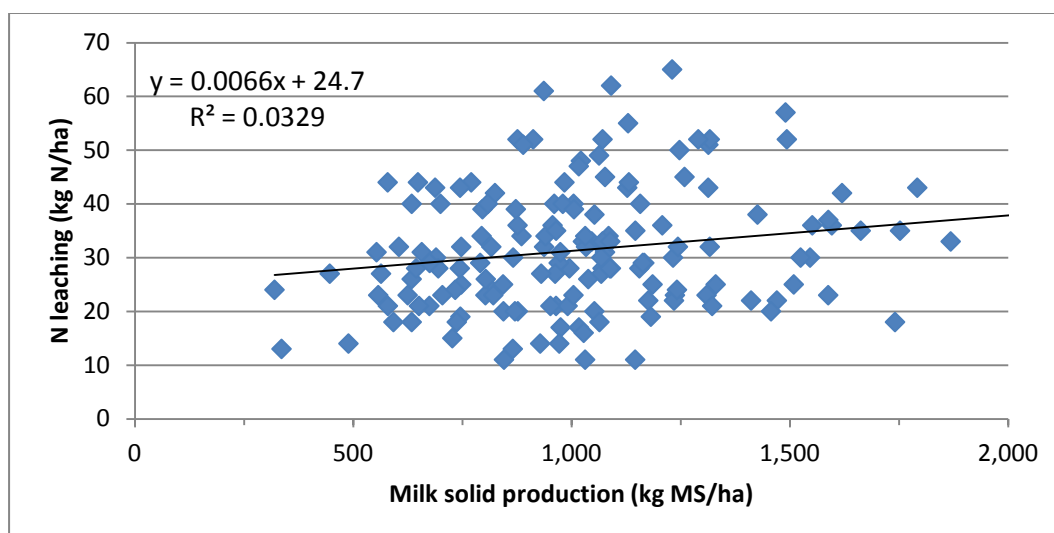


Figure 23: The relationship between production and GHG emissions

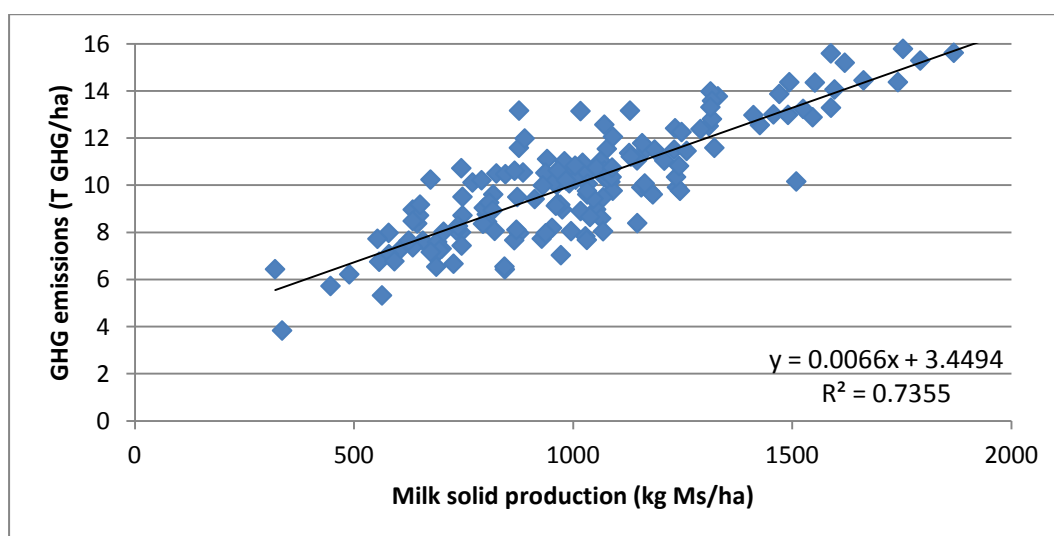


Figure 24: The relationship between stocking rates and N leaching

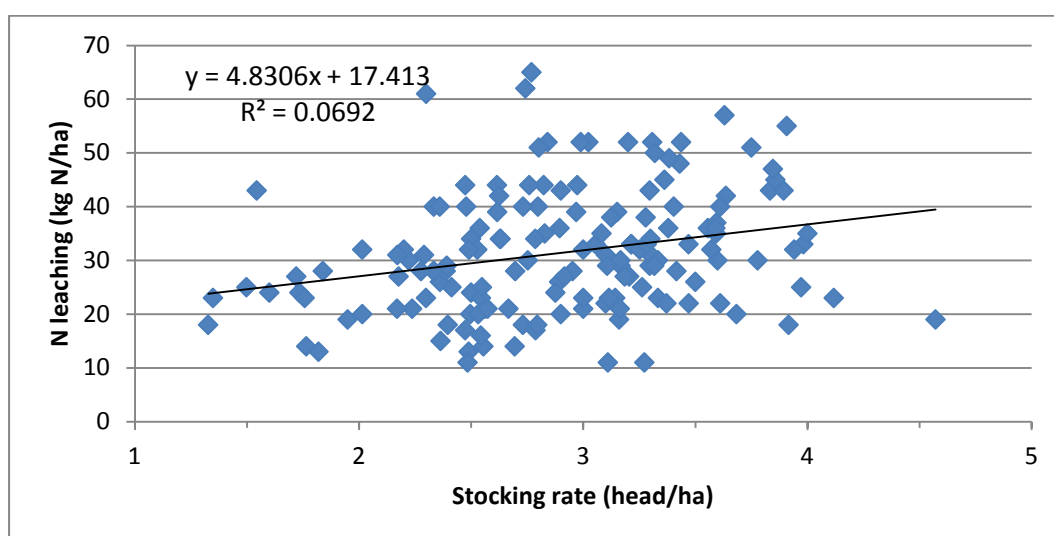
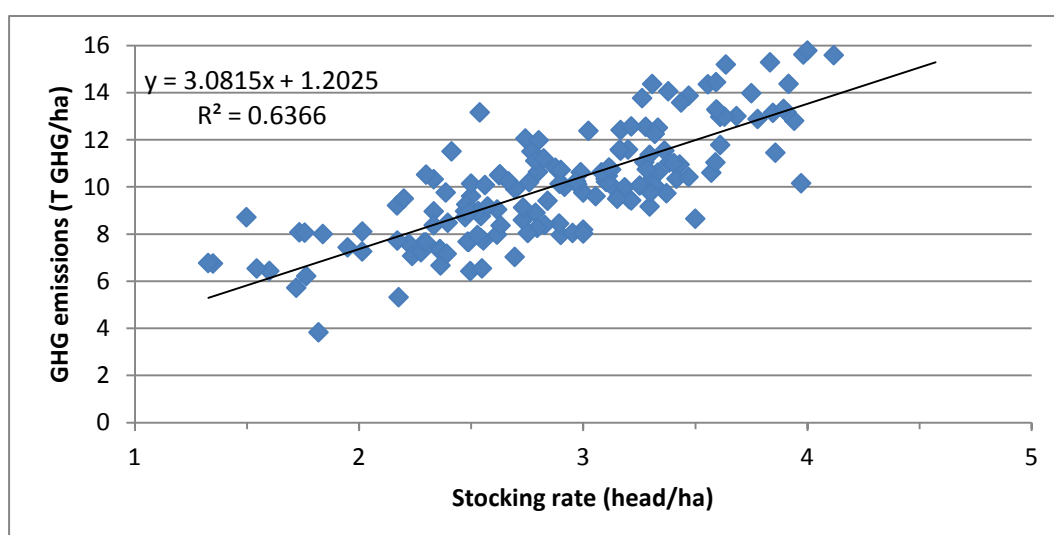


Figure 25: The relationship between stocking rates and GHG emissions



9.2. Regression results

We give here regression results for measures of production efficiency, farm performance and environmental impact, using both models. For these results we have used three years of data (2008 – 2010), allowing for fixed effects by year.

Table 3: Regression results for nitrogen production efficiency

N production efficiency (kg MS / kg N)	Model one			Model two		
	Coef.	Std. Err.	Signif.	Coef.	Std. Err.	Signif.
Rainfall (mm)	-0.0101	0.0020	***	-0.0097	0.0020	***
Mean Annual Temperature (°C)	-3.0362	0.4846	***	-2.8086	0.4976	***
Topography = easy hill	-3.160	2.393		-3.104	2.355	
Topography = flat	(Control)			(Control)		
Topography = rolling hill	-0.028	1.493		0.073	1.483	
Soil = peat	-0.373	3.116		-0.379	3.079	
Soil = pumice	-10.633	2.638	***	-9.870	2.613	***
Soil = recent YGE	-4.205	1.736	**	-4.449	1.753	**
Soil = sands	-3.402	2.994		-3.532	2.971	
Soil = sedimentary	(Control)			(Control)		
Soil = volcanic	-3.669	1.403	***	-3.398	1.389	**
Young stock off for 9 months	-0.609	1.461		-0.764	1.441	
Young stock off permanently	-10.469	6.687		-10.383	6.593	
Young stock on permanently	-5.093	1.725	***	-4.970	1.707	***
Young stock off until weaning	(Control)			(Control)		
Farm is irrigated	0.339	1.813		0.095	1.815	
Winter grazing off	5.385	1.267	***	4.797	1.252	***
Feed pad used				1.791	1.485	
Wintering pad used				0.744	2.083	
DCD used				69.352	37.802	*
DCD used x Temperature				-3.600	2.917	
DCD used x Rainfall				-0.021	0.013	
Fixed effect for 2010	(Control)			(Control)		
Fixed effect for 2009	-2.308	1.229	*	-2.341	1.213	*
Fixed effect for 2008	-2.291	1.892		-2.871	1.871	
Constant	89.600	5.990	***	85.502	6.148	***
Number of observations	443			443		
R-squared	0.4596			0.4845		
Adjusted R-squared	0.4393			0.4588		

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%.

A coefficient of 1 denotes the production of 1 additional kg milk solid per kg N. As the average leaching, on dairy farms, according to our data is 32 kg N per hectare, this would imply the production of an additional 32 kg milk solids per hectare on an average farm.

Table 4: Regression results for greenhouse gas production efficiency

GHG production efficiency (kg MS / T co2-eq)	Model one			Model two		
	Coef.	Std. Err.	Signif.	Coef.	Std. Err.	Signif.
Rainfall (mm)	0.0015	0.0021		0.0015	0.0021	
Mean Annual Temperature (°C)	-3.4292	0.5104	***	-3.0486	0.5299	***
Topography = easy hill	-11.569	2.521	***	-11.540	2.508	***
Topography = flat	(Control)			(Control)		
Topography = rolling hill	-5.340	1.573	***	-5.327	1.579	***
Soil = peat	-1.202	3.282		-1.391	3.279	
Soil = pumice	-4.661	2.779	*	-4.493	2.783	
Soil = recent YGE	-2.105	1.828		-2.081	1.867	
Soil = sands	-0.001	3.154		-0.818	3.163	
Soil = sedimentary	(Control)			(Control)		
Soil = volcanic	3.010	1.478	**	3.199	1.480	**
Young stock off for 9 months	-3.568	1.538	**	-3.756	1.534	**
Young stock off permanently	-18.188	7.043	**	-18.428	7.022	***
Young stock on permanently	-8.229	1.817	***	-8.209	1.818	***
Young stock off until weaning	(Control)			(Control)		
Farm is irrigated	2.664	1.910		2.788	1.933	
Winter grazing off	6.596	1.334	***	6.286	1.333	***
Feed pad used				1.128	1.582	
Wintering pad used				-2.511	2.218	
DCD used				61.884	40.256	
DCD used x Temperature				-4.653	3.107	
DCD used x Rainfall				-0.001	0.014	
Fixed effect for 2010	(Control)			(Control)		
Fixed effect for 2009	-37.109	1.295	***	-37.255	1.292	***
Fixed effect for 2008	-8.613	1.993	***	-8.904	1.992	***
Constant	143.281	6.309	***	138.075	6.547	***
Number of observations	443			443		
R-squared	0.7190			0.7260		
Adjusted R-squared	0.7084			0.7123		

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%.

Positive numbers mean the explanatory variable is associated with higher production for a given amount of GHG emissions (or equivalently lower GHG emissions for a given amount of production).

A coefficient of 12 denotes the production of 1 additional kg milk solid per T CO₂-eq. As the average GHG emissions, on dairy farms, according to our data are 12.4 T CO₂-eq, this would imply the production of an additional 12.4 kg milk solids per hectare on an average farm.

Table 5: Regression results for production per animal

Production per cow (kg MS / cow)	Model one			Model two		
	Coef.	Std. Err.	Signif.	Coef.	Std. Err.	Signif.
Rainfall (mm)	-0.018	0.009	*	-0.015	0.009	*
Mean Annual Temperature (°C)	-15.33	2.23	***	-13.94	2.28	***
Topography = easy hill	-37.47	11.02	***	-37.29	10.81	***
Topography = flat	(Control)			(Control)		
Topography = rolling hill	-26.35	6.88	***	-26.15	6.81	***
Soil = peat	5.54	14.35		6.36	14.14	
Soil = pumice	-15.40	12.15		-12.56	12.00	
Soil = recent YGE	5.35	7.99		4.90	8.05	
Soil = sands	-7.41	13.79		-9.12	13.64	
Soil = sedimentary	(Control)			(Control)		
Soil = volcanic	7.52	6.46		8.74	6.38	
Young stock off for 9 months	0.04	6.73		-1.24	6.62	
Young stock off permanently	-0.49	30.79		-1.89	30.28	
Young stock on permanently	-6.02	7.95		-6.42	7.84	
Young stock off until weaning	(Control)			(Control)		
Farm is irrigated	27.61	8.35	***	25.73	8.34	***
Winter grazing off	16.21	5.83	***	13.51	5.75	**
Feed pad used				4.19	6.82	
Wintering pad used				-1.33	9.56	
DCD used				230.50	173.58	
DCD used x Temperature				-9.97	13.40	
DCD used x Rainfall				-0.08	0.06	
Fixed effect for 2010	(Control)			(Control)		
Fixed effect for 2009	-2.70	5.66		-3.27	5.57	
Fixed effect for 2008	-0.46	8.71		-3.04	8.59	
Constant	567.40	27.58	***	544.45	28.23	***
Number of observations	443			443		
R-squared	0.4116			0.4419		
Adjusted R-squared	0.3895			0.4141		

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%.

Table 6: Regression results for production per hectare

Production per hectare (kg MS / ha)	Model one			Model two		
	Coef.	Std. Err.	Signif.	Coef.	Std. Err.	Signif.
Rainfall (mm)	-0.147	0.038	***	-0.150	0.038	***
Mean Annual Temperature (°C)	-32.93	9.25	***	-34.68	9.50	***
Topography = easy hill	-191.07	45.70	***	-183.80	44.95	***
Topography = flat	(Control)			(Control)		
Topography = rolling hill	-132.76	28.51	***	-117.80	28.31	***
Soil = peat	126.69	59.49	**	108.65	58.77	*
Soil = pumice	53.76	50.37		69.98	49.88	
Soil = recent YGE	48.85	33.14		31.10	33.46	
Soil = sands	-86.17	57.17		-76.57	56.70	
Soil = sedimentary	(Control)			(Control)		
Soil = volcanic	202.27	26.79	***	200.91	26.52	***
Young stock off for 9 months	-63.85	27.89	**	-59.36	27.50	**
Young stock off permanently	-64.26	127.68		-31.61	125.86	
Young stock on permanently	-180.43	32.95	***	-170.52	32.58	***
Young stock off until weaning	(Control)			(Control)		
Farm is irrigated	266.00	34.62	***	271.41	34.65	***
Winter grazing off	63.38	24.18	***	57.26	23.90	**
Feed pad used				114.24	28.35	***
Wintering pad used				-1.64	39.76	
DCD used				240.87	721.58	
DCD used x Temperature				5.12	55.69	
DCD used x Rainfall				-0.25	0.24	
Fixed effect for 2010	(Control)			(Control)		
Fixed effect for 2009	-32.60	23.47		-26.99	23.16	
Fixed effect for 2008	-34.98	36.13		-33.93	35.70	
Constant	1556.16	114.37	***	1554.46	117.36	***
Number of observations	443			443		
R-squared	0.5189			0.5414		
Adjusted R-squared	0.5009			0.5185		

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%.

Table 7: Regression results for stocking rate

Stocking rate	Model one			Model two		
(cows / ha)	Coef.	Std. Err.	Signif.	Coef.	Std. Err.	Signif.
Rainfall (mm)	-0.00031	0.00010	***	-0.00034	0.00010	***
Mean Annual Temperature (°C)	0.01082	0.02402		-0.00306	0.02471	
Topography = easy hill	-0.3176	0.1186	***	-0.2971	0.1170	**
Topography = flat	(Control)			(Control)		
Topography = rolling hill	-0.2461	0.0740	***	-0.2060	0.0737	***
Soil = peat	0.3804	0.1544	**	0.3224	0.1529	**
Soil = pumice	0.3330	0.1308	**	0.3642	0.1298	***
Soil = recent YGE	0.1379	0.0860		0.0974	0.0871	
Soil = sands	-0.2023	0.1484		-0.1629	0.1475	
Soil = sedimentary	(Control)			(Control)		
Soil = volcanic	0.5459	0.0695	***	0.5374	0.0690	***
Young stock off for 9 months	-0.1966	0.0724	***	-0.1731	0.0716	**
Young stock off permanently	-0.1572	0.3314		-0.0467	0.3275	
Young stock on permanently	-0.4165	0.0855	***	-0.3817	0.0848	***
Young stock off until weaning	(Control)			(Control)		
Farm is irrigated	0.4043	0.0899	***	0.4433	0.0902	***
Winter grazing off	0.0507	0.0628		0.0524	0.0622	
Feed pad used				0.3092	0.0738	***
Wintering pad used				0.0335	0.1035	
DCD used				-0.4231	1.8775	
DCD used x Temperature				0.0265	0.1449	
DCD used x Rainfall				0.0000	0.0006	
Fixed effect for 2010	(Control)			(Control)		
Fixed effect for 2009	-0.0579	0.0609		-0.0368	0.0603	
Fixed effect for 2008	-0.1288	0.0938		-0.1082	0.0929	
Constant	2.9927	0.2969	***	3.1316	0.3054	***
Number of observations	443			443		
R-squared	0.3349			0.3630		
Adjusted R-squared	0.3099			0.3312		

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%.

Table 8: Regression results for nitrogen leaching per hectare

N leaching per hectare (kg N / ha)	Model one			Model two		
	Coef.	Std. Err.	Signif.	Coef.	Std. Err.	Signif.
Rainfall (mm)	0.0045	0.0019	**	0.0040	0.0019	**
Mean Annual Temperature (°C)	0.9657	0.4542	**	0.8117	0.4733	*
Topography = easy hill	-4.419	2.243	**	-4.241	2.240	*
Topography = flat	(Control)			(Control)		
Topography = rolling hill	-4.386	1.399	***	-3.964	1.411	***
Soil = peat	2.142	2.920		1.376	2.928	
Soil = pumice	14.788	2.472	***	14.810	2.485	***
Soil = recent YGE	4.909	1.627	***	4.381	1.667	***
Soil = sands	-1.590	2.806		-1.312	2.825	
Soil = sedimentary	(Control)			(Control)		
Soil = volcanic	9.469	1.315	***	9.258	1.322	***
Young stock off for 9 months	-1.147	1.369		-0.869	1.370	
Young stock off permanently	14.976	6.267	**	16.041	6.271	**
Young stock on permanently	-1.905	1.617		-1.539	1.624	
Young stock off until weaning	(Control)			(Control)		
Farm is irrigated	8.003	1.699	***	8.452	1.727	***
Winter grazing off	-2.450	1.187	**	-2.296	1.191	*
Feed pad used				3.050	1.413	**
Wintering pad used				-0.952	1.981	
DCD used				-7.068	35.955	
DCD used x Temperature				0.163	2.775	
DCD used x Rainfall				0.002	0.012	
Fixed effect for 2010	(Control)			(Control)		
Fixed effect for 2009	0.493	1.152		0.696	1.154	
Fixed effect for 2008	2.087	1.773		2.435	1.779	
Constant	10.011	5.614	*	12.101	5.848	**
Number of observations	443			443		
R-squared	0.2912			0.3036		
Adjusted R-squared	0.2646			0.2689		

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%.

Table 9: Regression results for greenhouse gas emissions per hectare

GHG emissions per hectare (T co2-eq / ha)	Model one			Model two		
	Coef.	Std. Err.	Signif.	Coef.	Std. Err.	Signif.
Rainfall (mm)	-0.0021	0.0004	***	-0.0021	0.0004	***
Mean Annual Temperature (°C)	0.0008	0.1055		-0.0751	0.1086	
Topography = easy hill	-1.044	0.521	**	-0.952	0.514	*
Topography = flat	(Control)			(Control)		
Topography = rolling hill	-1.062	0.325	***	-0.880	0.324	***
Soil = peat	2.171	0.678	***	1.979	0.672	***
Soil = pumice	1.647	0.574	***	1.831	0.571	***
Soil = recent YGE	1.086	0.378	***	0.891	0.383	**
Soil = sands	-1.027	0.652		-0.791	0.649	
Soil = sedimentary	(Control)			(Control)		
Soil = volcanic	2.230	0.305	***	2.195	0.303	***
Young stock off for 9 months	-0.399	0.318		-0.313	0.315	
Young stock off permanently	1.422	1.455		1.880	1.440	
Young stock on permanently	-0.864	0.375	**	-0.742	0.373	**
Young stock off until weaning	(Control)			(Control)		
Farm is irrigated	2.515	0.395	***	2.593	0.396	***
Winter grazing off	-0.155	0.276		-0.179	0.273	
Feed pad used				1.265	0.324	***
Wintering pad used				0.398	0.455	
DCD used				-6.858	8.254	
DCD used x Temperature				0.728	0.637	
DCD used x Rainfall				-0.002	0.003	
Fixed effect for 2010	(Control)			(Control)		
Fixed effect for 2009	5.400	0.268	***	5.492	0.265	***
Fixed effect for 2008	0.452	0.412		0.516	0.408	
Constant	11.752	1.303	***	12.454	1.342	***
Number of observations	443			443		
R-squared	0.6514			0.6652		
Adjusted R-squared	0.6383			0.6485		

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%.

9.3. 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 absolute value.

Table 10: 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 production efficiency	1								
GHG production 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	
Mean annual 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
DCD used	0.32	0.15	0.34	0.17	-0.02	-0.16	0.05	-0.25	-0.28
DCD used x Temperature	0.32	0.14	0.33	0.18	-0.01	-0.15	0.06	-0.25	-0.27
DCD used x Rainfall	0.30	0.14	0.31	0.14	-0.04	-0.17	0.03	-0.22	-0.28

Table 11: 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
DCD used	-0.07	0.11	-0.08	-0.05	-0.06	0.08	0.05	0.11	-0.15
DCD used x Temperature	-0.07	0.11	-0.08	-0.05	-0.06	0.08	0.05	0.10	-0.14
DCD used x Rainfall	-0.06	0.10	-0.07	-0.05	-0.06	0.02	0.07	0.13	-0.13

Table 12: Correlation table (3 of 3)

	Young stock				Irrigat-	Winter	Feed	Winter	DCD
	off 9	off	on	off	ion	graze	pad	pad	
	mnths	perm	perm	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	
DCD used	-0.05	-0.02	0.07	-0.02	0.14	0.19	-0.06	-0.07	1
DCD used x Temperature	-0.05	-0.02	0.07	-0.02	0.15	0.18	-0.06	-0.07	1.00
DCD used x Rainfall	-0.03	-0.02	0.07	-0.03	0.09	0.17	-0.05	-0.07	0.98