The Impact of Nitrogen Management Strategies within Grass Based Dairy Systems

Teagasc

AGRICULTURE AND FOOD DEVELOPMENT AUTHORITY

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Glossary of Terms

C	Carbon
CH_4	Methane
CO_2	Carbon Dioxide
CSO	Central Statistical Office
DM	Dry Matter
EPA	Environmental Protection Agency (Ireland)
€riN[1]	Model simulating (N) flows on an Irish grass-based dairy farm
FPCM	Fat and protein corrected milk yield
GHG	Greenhouse Gas
LU	Livestock Unit
MACC	Marginal Abatement Cost Curve
MAC	Maximum **a**dmissible concentration
MoSt[2]	Moorepark St Gilles Grass Growth Model
MDSM[3]	Moorepark Dairy System Model
N	Nitrogen
NH_3	Ammonia
N_2O	Nitrous Oxide
NO_3^-	Nitrate
NO_2^-	Nitrite
NFS	National Farm Survey
NLF	Nitrogen Loss Fractions
NUE	Nitrogen Use Efficiency
NFS	National Farm Survey
P	Phosphorus
PBHDM[4]	Pasture Based Herd Dynamic Milk Model
WFD	Water Framework Directive
NLF	Nitrogen Loss Fractions

[1]€riN: excel model simulating N flow on an Irish base farms, developed in Teagasc Johnstown. The model linked with the MDSM[3] for the financial part. Calculations are based on a monthly time-step and outputs are presented on a yearly basis.
[2]MoSt: the Moorepark St Gilles grass growth model is a model developed in C++ in Teagasc Moorepark in conjunction with INRAE St Gilles. The model works on a daily time step and predicts mainly; grass growth, grass N content and N leaching depending on; weather condition, grass management and N application.
[3]MDSM: The Moorepark dairy system model is an excel model developed in Teagasc Moorepark. It is a budgetary simulation model of a dairy farm, integrating animal inventory and valuation, milk supply, feed requirement, land and labour utilisation and economic analysis.
[4]PBHDM: The pasture-based herd dynamic milk model is a dynamic, stochastic agent–based model developed in C++ in Teagasc Moorepark in conjunction with INRAE St Gilles. The model works on a daily time step, comprises of a herd dynamic milk model, and integrates it with a grazing management and a paddock sub-model.

Executive Summary

1. The Department of Agricultural, Food and Marine requested Teagasc to model the impact (environmental and economic) of a number of farm nitrogen mitigation measures in order to inform policy of the best current and potential actions to deliver the catchment based nitrate load reduction estimated by the EPA.
2. In a review of the literature a significant linear relationship was found between N surplus per hectare and N leaching to groundwater on free draining soils, therefore suggesting that reducing surplus N is an effective method on reducing N leaching. The relationship between N surplus and N leaching was not as apparent in moderate and heavy soil types.
3. There was strong agreement between the MoSt/PBHDM and the €riN/MDSM models on the influence of chemical N application rates and stocking rate on N leached to 1 m depth. The concordance between the two models provides confidence that the findings are robust. Both models have different approaches and offer different advantages and disadvantages. The MoSt/PBHDM could model the influence of timing of slurry and chemical N fertilizer on potential losses to the environment as well as the impact of variability between years. The €rin/MDSM model could estimate the influence of chemical N and stocking rate on N gaseous emissions.
4. There is evidence that observance of the closed period is effective in minimising N losses to the environment. Spreading cattle slurry during the closed period will result in an increase in N leaching (+3.2 kg N/ha based on spreading 28,000 l/ha) for lands receiving slurry during the closed period.
5. N application in excess of 250 kg of chemical N/ha across a grassland farm will result in an increase in N leaching to the environment (+2.9 and +6.1 kg N/ha for 300 and 350 kg N/ha application respectively when compared to 250 kg N/ha).
6. The modelling showed large year-to-year variation in N use efficiency (22.0-32.5%), N surplus (187-332 kg N/ha) and N leached (38.6-88.4 kg N/ha). The year to year variation consistently surpassed any management intervention within this modelling framework. Findings from the Agricultural Catchment Programme also show significant year to year variations.
7. The use of precision N application strategies, taking cognisance of meteorological conditions would improve N use efficiency and reduce losses to the environment. For example, in 2018, the appropriate amount of N to be applied was modelled as 171 kg N/ha, which would have reduced N surplus by 82 kg N/ha and N loss by 12 kg N/ha, with little or no impact on grass growth. Precision management advice has been issued weekly by Teagasc since 2020, based on modelled grass growth and leaching risk, which will be further refined over the coming years. Precision application strategies will also be important in the timing of the first chemical N application in spring.
8. Reduction of chemical nitrogen from 250 kg N/ha (while applying best farm practices) to 225 or 200 kg N/ha resulted in N loss reduction of 1.4 and 2.7 kg N/ha respectively. Starting N application later in spring (1st of February) and finishing earlier in autumn (1st of September) while applying 250 kg N/ha with an organic N stocking rate of 250 kg N/ha reduced N losses by 0.5 kg N/ha. Reducing overall stocking rate from 250 kg organic N/ha to 230 reduced N loss by 1.7 kg N/ha at a chemical N fertiliser level of 250 kg N/ha.

9. Stocking rate grazing intensity above 250 kg organic N/ha per year have the potential to lead to increased N losses. Stocking rates of 340 kg and 430 kg of organic N/ha were predicted to increase N loss by 5.7 and 11.8 kg N/ha respectively. If stocking rate of 340 and 430 kg of organic N/ha had support blocks for silage production creating an overall farm stocking of 250 kg organic N/ha and assuming even application of slurry across the whole farm, the predicted increase in N losses was reduced to 0.8 and 1.6 kg N/ha respectively due to the lower N leaching from non-grazed area i.e. silage ground..
10. Scenarios to reduce nitrate leaching also reduced ammonia and nitrous oxide emissions. Reducing chemical N fertiliser from 250 to 200 kg N/ha reduced nitrous oxide emissions by up to 14% but had little effect on ammonia. Reducing stocking rate from 250 to 230 kg N/ha reduced ammonia emissions by up to 10% but had little effect on nitrous oxide. Where part of a farm was stocked at 340 kg N/ha, ammonia and nitrous oxide emissions increased by 35 and 14%, respectively on that part of the farm but this will be offset by emissions reductions on the non-grazed area of the farm.
11. Banding dairy cow organic N excretion rates linked to milk yield/cow creates a more equitable basis of implementing nitrate regulations. This is similar to the way that N excretion rates are implemented in other countries.
12. The economic impact at farm level of reduced chemical N and stocking rate or banding can be significant. Therefore, careful consideration should be taken in implementing any further restrictions on farms that comply with best practice concerning current Nitrate Regulations (S.I. No. 605 of 2017, as amended in 2018 and 2020).

Background

The Department of Agricultural, Food and Marine requested Teagasc to model the impact (environmental and economic) of a number of farm nitrogen mitigation measures in order to inform policy of the best current and potential actions to deliver the catchment based nitrate load reduction estimated by the EPA. The assessment was confined to nitrate losses from freely draining soils where farming intensity is greater than 130 kg N/ha/year. The following scenarios were requested to be investigated:

1. Chemical N reduction of approximately 10% and 20% i.e. chemical N application rates of 250, 225 and 200 kg/ha.
2. Delaying the first chemical N application in spring from 15 January.
3. Finish final chemical N application in autumn earlier than 15 September.
4. Uneven distribution of chemical N fertilizer across the farm i.e. applying 300 and 350 kg N/ha on the grazing platform.
5. Stocking rate reduction- 250 kg N/ha (2.74 cows/ha) versus 230 kg N/ha (2.52 cows/ha).
6. High platform stocking rates- 340 kg N/ha (3.73 cows/ha) and 430 kg N/ha (4.72 cows/ha).
7. Spreading slurry during the closed period- 12% and 25% of slurry spread during the month of December.
8. Implementations of using precision farming to increase N use efficiency.
9. Options for banding organic N excretion rates for dairy cows.

1. Meta-analysis and description of the modeling approaches

1.1. Meta-analysis of nitrate leaching studies and overview models to simulate N loss from Irish dairy systems

1.1.1. Meta-analysis of nitrate leaching studies

A review of research studies was carried out on a range of soil types using a variety of nitrate measurement systems. Data published within these studies were used to form a dataset to perform a meta-analysis of nitrate leaching on Irish dairy farms. For the purpose of this review, Irish soil types were divided into three groups; heavy, moderately drained and well drained. The methods used to measure nitrate leaching in the reviewed research included ceramic cups, lysimeters, hydrologically isolated drainage plots and groundwater boreholes. The primary aim of this review and analysis was to develop prediction equations on the dominant factors that affect groundwater leaching on Irish dairy farms in particular within highly intensive farms located on well-drained soils. A summary of the meta-analysis dataset is outlined in Table 1.1. The criteria for creating the meta-analysis dataset was based upon collecting available data for independent variables that were potentially highly correlated with dependent variables for nitrate leaching loss (kg NO_3-N ha^{-1}) and nitrate leaching concentration (mg L^{-1} NO_3-N). Independent variables included; farm stocking rate (LU ha^{-1}), chemical N fertilisation rate (kg N ha^{-1}), soil type, rainfall (mm), drainage (mm), surplus N (kg N ha^{-1}) and N leaching fraction (NLF = NO3-N loss/ surplus N). Annual soil water drainage was calculated by subtracting the effects of evapotranspiration and soil moisture deficit from precipitation (McCarthy et al., 2015). Not all studies included data for annual farm gate surplus N (Treacy et al., 2008) and where relevant, some surplus N had to be estimated on the basis of reported figures for stocking rate and N fertilisation using simulation outputs from the previous report on the interaction between fertiliser application, stocking rate and agroclimatic location (Dillon et al., 2020). To evaluate the combined effects of farm management and climate on nitrate leaching for a well-drained soil, Nitrogen Leaching Fractions (NLF = NO3-N loss/ surplus N) as outlined by Fraters et al. (2015) was used. The NLF was used to quantify the volume of surplus N that leached from the root zone (≥ 1m) to groundwater. Simple linear regression and analysis of variance (ANOVA) were used to assess the potential factors that affected leaching, using R (R Core Team, 2018).

Table 1.1. Summary of studies included in meta-analysis dataset

Paper/ dataset	Year	Measure	Depth	Location	Avg SR (LU ha^{1})	Avg N Fert (kg ha^{1})	Surplus N (kg ha^{1})	Avg NO_3-N Loss (kg N ha^{1})	Avg NO_3-N conc. (mg L^{1})
Well drained soil									
Fenton *et al.*, 2017	2009 - 2010	Borehole	Groundwater	Kilworth	3.00	299	263	83	16.50
McAleer *et al.*, 2017	2013 - 2015	Borehole	Groundwater	Timoleague	1.90	298	200*	56	4.75
Dupas *et al.*, 2017	2010 - 2015	Borehole	Groundwater	Timoleague	1.90	310	208*	37	8.50
Huebsch *et al.*, 2014	2002 - 2011	Borehole	Groundwater	Curtins	2.68	278	224	56	11.91
Mellander *et al.*, 2014	2010 - 2010	Borehole	Groundwater	Timoleague	1.80	225	145*	40	7.96
O' Connor *et al.*, 2015	2010 - 2010	Lysimeter	1 m	Moorepark	-	0	-	51	14.46
Selbie *et al.*, 2014	2009 - 2010	Lysimeter	1 m	Moorepark	-	48	-	100	22.92
Dennis *et al.*, 2012	2007 - 2007	Lysimeter	1 m	Clonakilty	-	173	-	65	8.52
Stark *et al.*, 2007	2005 - 2005	Lysimeter	1 m	Clonakilty	-	291	-	4	0.57
Creighton *et al.*, 2016	2008 - 2009	Cups	1m	Moorepark	3.10	260	247*	58	12.20
McCarthy *et al.*, 2015	2011 - 2013	Cups	1m	Curtins	2.90	209	127	108	23.96
Ryan *et al.*, 2006	2001 - 2006	Cups	1m	Curtins	2.38	285	220*	37	8.32
Dairygold 2010 *(Unpublished)*	2007 - 2010	Cups	1m	Kilworth	2.12	220	154*	119	27.27
Moorepark2016	2013 - 2016	Cups	1m	Moorepark	2.74	250	219*	219	50.12
Ryan *et al.*, 2011	-	Modelled	1 m	Curtins	2.52	275	234	35	8.09
Prado *et al.*, 2006	-	Modelled	1 m	sandy loam	2.05	196	141*	104	13.04
Moderate drained soils									
Watson et al., 2000-2007	1989 - 1997	Drainage	1 m	Hillsborough	4.00	110	284	38	8.80
Scholefield et al., 1993	1983 - 1989	Drainage	1 m	UK	4.50	326	-	78	12.32
Richards et al., 2015	2002 - 2005	Cups	1 m	Grange	2.66	176	202	15	6.03
Hoekstra et al., 2020	-	Modelled	1 m	Moderate drained soil	2.21	205	200	7	-
Heavy soils									
Valbuena et al., 2019	2014	Borehole	Groundwater	Solohead	2.35	0	-	2	0.96
Burchill et al., 2016	2001 - 2012	Borehole	Groundwater	Solohead	2.30	110	166	3	-
Jahangir et al., 2012	2009 - 2010	Borehole	Groundwater	Solohead	-	213	137	5	0.77
Necpalova et al., 2012	2008 - 2009	Borehole	Groundwater	Solohead	1.75	33	-	3	0.37
Humpreys et al., 2008	2001 - 2002	Borehole	Groundwater	Solohead	2.21	284	186	7	1.79
Calgnan et al., 2018	2015 - 2016	Drainage	Groundwater	Heavy soils farm	2.47	307	252	2	0.24

'-' = denotes where data was not published/not applicable as part of study, * = denotes where surplus N was predicted using the MoSt model

1.1.2. Results

No significant relationship was found between chemical N fertilisation rate, stocking rate or surplus N and leaching for any of the ceramic cup studies on well-drained soils ($P > 0.05$). The majority of experimental treatments investigated and reviewed for lysimeter studies, combined the effects of both N fertilisation studies on well-drained soils, and urine deposition at < 1m^2 scale. The direct effect of chemical fertiliser N on leaching for lysimeter studies was investigated by plotting chemical fertiliser only treatments against leaching loss. No significant relationship was found ($P > 0.05$). A positive linear relationship ($R^2 = 0.72$, $P < 0.05$) was found between total N (urine N + inorganic fertiliser N) and NO_3-N loss as seen in Figure 1.1 (a). This relationship was extrapolated to predict NO_3-N loss at field scale (1 ha) using the calibration outlined by Di and Cameron (2000) and Selbie (2014) as seen in Figure 1.2 (b). This calibration assumed an annual urine patch deposition coverage of 23% of pasture area. Reported lysimeter NO_3-N losses appear high at sub-meter scale, however, when extrapolated to field scale all losses were < 60 kg NO_3-N/ha.

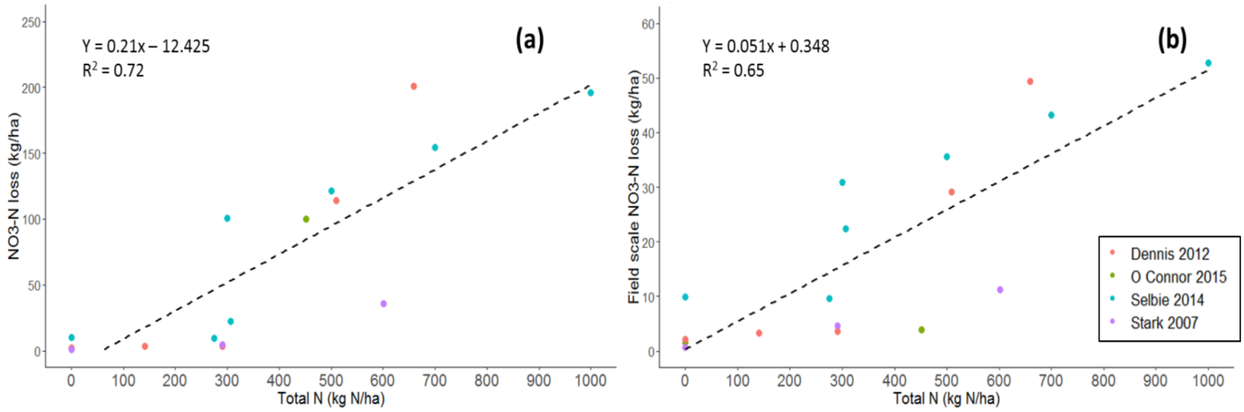

Figure 1.1. Relationship between total Nitrogen application (chemical fertiliser N + urine N) and (a) lysimeter nitrate loss; (b) estimated field scale nitrate loss

No studies were found in the literature that used drainage plots to measure leaching on well-drained soils. No significant relationship was found between fertiliser application rate, stocking rate and NO_3-N loss at groundwater level ($P > 0.05$) for the reviewed borehole studies. There was a significant relationship between surplus N and groundwater NO_3-N loss ($R^2 = 0.49$, $P = 0.003$) for the borehole studies, as seen in Figure 1.2 . Reported groundwater mean NO_3-N loss was 56 kg/ha on well-drained soils and ranged between 27 – 83 kg/ha. The studied farms were stocked between 1.8 – 3.0 LU/ha and applied 225 – 331 kg/ha of chemical N fertiliser. The reported groundwater mean NO_3-N concentration was 10.77 mg/l, which was just below the maximum admissible concentration (MAC) limit of 11.3 mg/l, and reported concentration ranged between 3.32 – 16.5 mg/l.

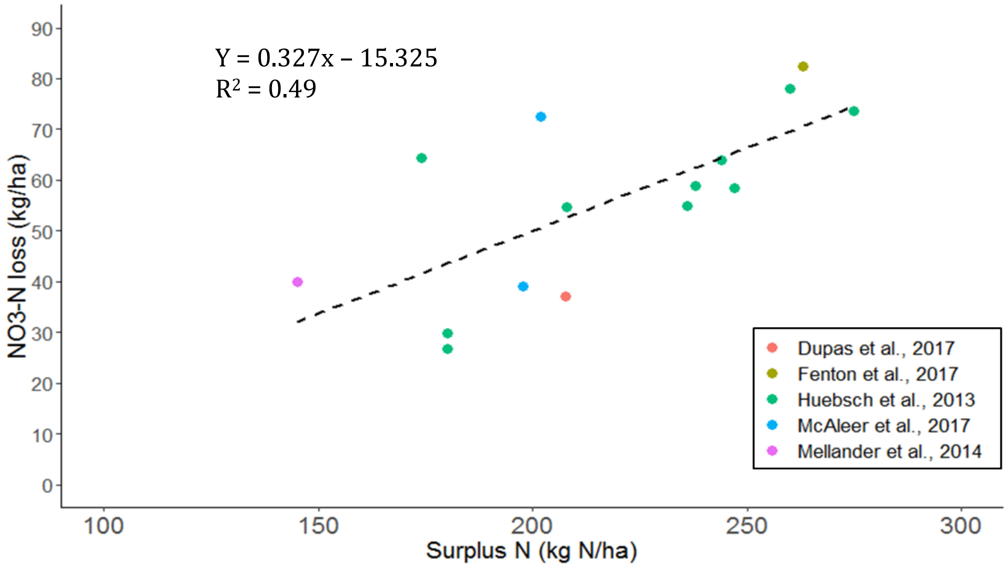

Figure 1.2. Relationship between surplus N and groundwater NO3-N loss from the reviewed literature on well-drained soils

For comparative purposes, the relationship in Figure 1.2 was compared to similar relationships that were found for groundwater data from the reviewed studies on moderate and heavy drained soils (Figure 1.3). The soil types in Teagasc's Heavy Soils Programme outlined by Clagnan et al., (2018) were considered heavier than the soil at the Solohead research farm. Subsequently, the leaching data for heavy soils were separated into two groups with individual relationships developed for surplus N for each group. Figure 1.3 illustrates that the increase in NO_3-N loss for every additional kg of farm surplus N was much higher on well-drained soils.

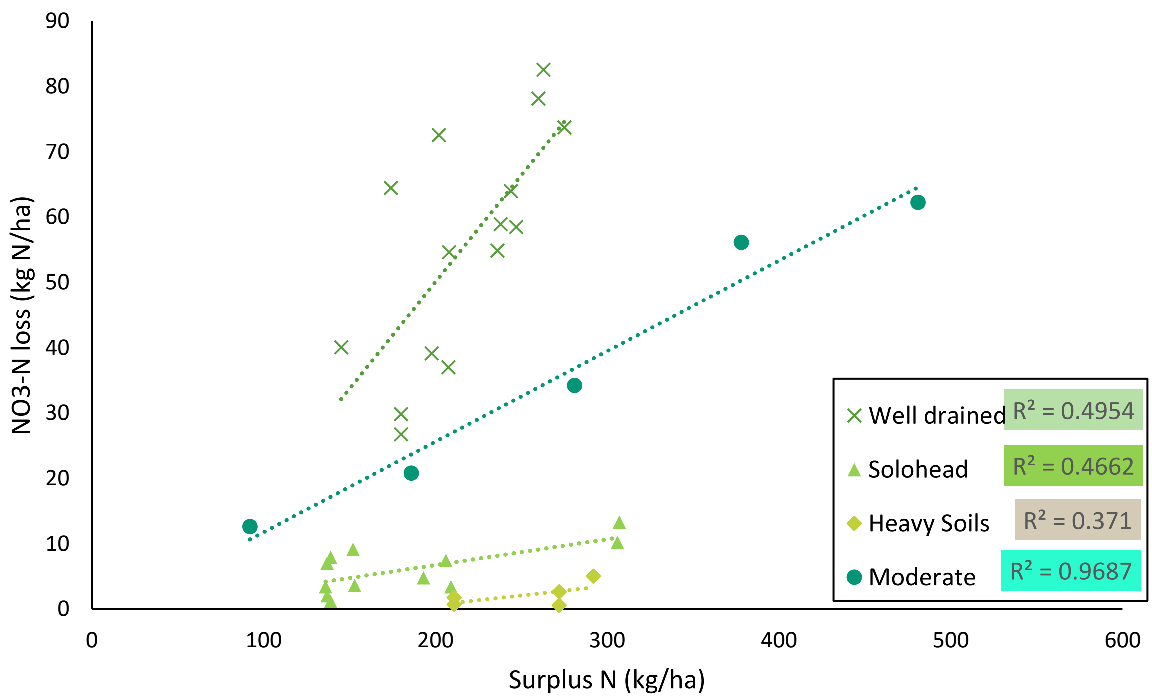

Figure 1.3. Relationships between surplus N and groundwater NO3-N loss from reviewed studies on the range of different soil types used for pasture-based farming in Ireland

The NLF values outlined in Figure 1.4 represent the volume of surplus N that is leached to groundwater (NLF = NO3-N loss/ surplus N). There was a significant positive relationship between NLF and drainage (R^2 = 0.29, P = 0.037). This relationship indicates that the proportion of N surplus leached to groundwater increases with groundwater drainage. However, as groundwater drainage increases the concentration of N in ground water decreases through dilution.

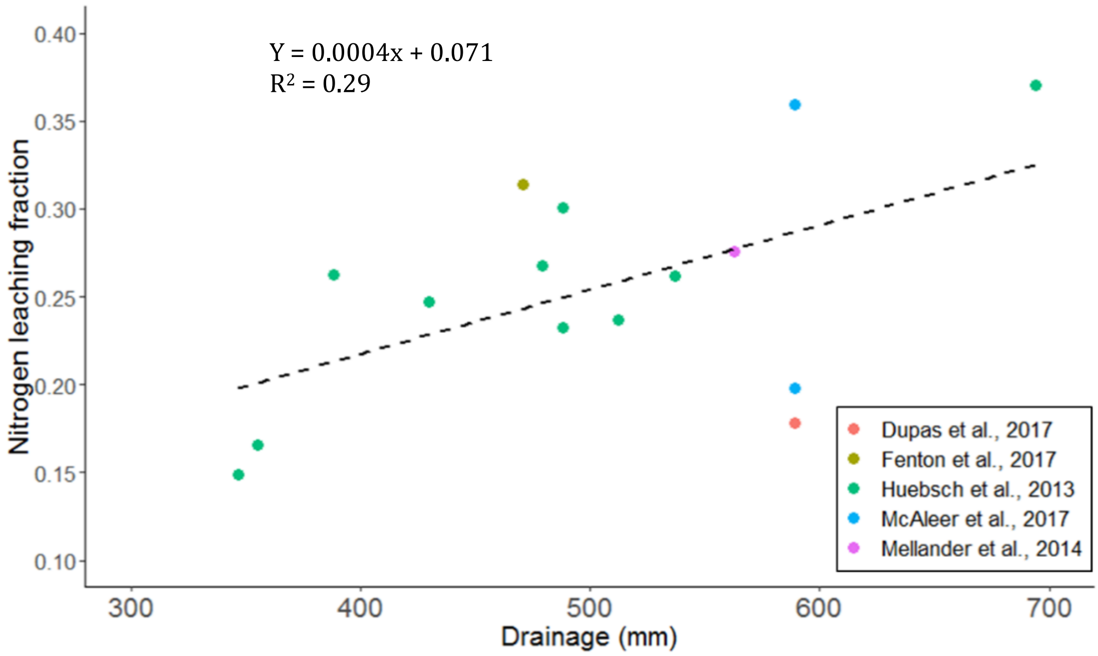

Figure 1.4. Relationship between N leaching fraction (NO3-N loss/ surplus N) and drainage from reviewed data on well-drained soils

1.1.3. Summary

With regard to the cup studies, no relationship was found between surplus N and leaching. This was likely to be a result of the well-noted high spatial variability in reported NO_3-N losses from ceramic cup studies (Lord and Shepherd, 1993; Watson et al., 2000). Lysimeter data for total N (fertiliser + urine) (Figure 1.1) was highly correlated with leaching, this suggests that there is a combined effect of N fertilisation and stocking rate on leaching. However, even at high point loads of total N (1000 kg) field scale leaching loss did not surpass 60 kg/ha at ≤ 1m below ground level. Large discrepancies between reported leaching values in the root zone (≤ 1m) and at groundwater level have been extensively reported in the literature (Huebsch et al., 2013; McCarthy et al., 2015; Ryan et al., 2006). This may be linked to the occurrence of denitrification below the root zone and consequently measurement data from groundwater borehole studies offer the best indication of actual nitrate leaching to water surfaces from farms (Dupas et al., 2017). A significant linear relationship was found in this review between surplus N and leaching to groundwater, which is in agreement with Fraters et al., (2015), Ryan et al., (2011) and Scholefield et al., (1991). The findings of this review suggest that reducing surplus N on well-drained soil is an effective method of reducing leaching. Figure 1.3 outlines that the relationships between surplus N and leaching are not as apparent for moderate and heavy soils and highlights the increased risk of leaching on well-drained soils. This is as a result of the higher denitrification and N attenuation characteristics of heavier soils (Burchill et al., 2016; Jahangir et al., 2012). The effect that climate has on leaching is highlighted in Figure 1.4, which shows that the risk of surplus N leaching is increased as drainage through the soil to groundwater rises. Therefore, in a wetter than average year with low soil moisture deficit and evapotranspiration, more surplus N is leached to groundwater, but the volumes have a counteracting effect on nitrate concentration. This is in agreement with high seasonal and annual fluctuations in leaching reported in the literature (Huebsch et al., 2013; Mellander et al., 2014). High levels of annual drainage can also increase leaching up to a peak, beyond which additional precipitation will dilute any mineral N in the soil (Huebsch et al., 2014; Scholefield et al., 1993).

1.2. Models to simulate N loss from Irish dairy systems

Two modelling approaches are available to model scenarios to limit N losses from Irish dairy systems. The first approach uses Moorepark St Gilles Grass Growth model (MoSt model) (Ruelle *et al.,* 2018) in combination with Pasture Based Herd Dynamic Milk Model (PBHDM model) (Ruelle *et al.,* 2015). The second uses the €riN (Hoekstra et al. 2020) which is a Microsoft excel-based model simulating N flows on Irish grass-based dairy systems.

1.2.1. MoSt-PBHDM models

MoSt is a dynamic model developed in C++ describing the grass growth and the nitrogen and water fluxes of a paddock. The model is run with a daily time step simulating soil N mineralisation, immobilisation and water balance, grass growth, N uptake, N leaching and grass N content. The model is driven by a daily potential growth depending on the solar radiation and the total green biomass. To calculate the actual daily growth, this potential growth is then multiplied by parameters depending on environmental conditions (temperature, water in the soil and radiation) and a parameter depending on the availability of the mineral N in the soil compared to the N demand associated with the potential grass growth. Leaching in the model occurs when the amount of water in the soil is over the water holding capacity, which will depend on the soil type. The model only predicts total N leaching at 1m.

PBHDM comprises of the herd dynamic milk model and integrates it with a grazing management and a paddock sub-model. Animal intake at grazing is dependent not only on the animal characteristics but also on grass availability and quality. It also depends on the interactions between the animal and the grass during the defoliation process. Management of grass on farm can be regulated through different rules during the grazing season including the decision to cut some paddocks in the case of a grass surplus and to allocate supplementation in the case of a grass deficit.

1.2.2. €riN model

€riN is a mathematical model for modelling N cycling in a grass-based dairy farm. This semi-mechanistic model works in conjunction with a bio-economic model of milk production, the Moorepark Dairy System model (MDSM). Both €riN and the MDSM run in Microsoft Excel and operate on a monthly basis. The former simulates N inputs, N outputs in agricultural products and N losses i.e. nitrate, ammonia, nitrous oxide and dinitrogen. Research studies by Hoekstra et al. (2020) and Shalloo et al. (2004) provide a comprehensive account of the modules in €riN and the MDSM; Hoekstra et al. (2020) also described the connections between these models. Briefly, the main input variables required to parameterize €riN are location, grassland area, soil type and fertility, synthetic fertiliser levels, manure application, reseeding rates and grazing and silage dates. Spatial and temporal input parameters split the dairy farm into three areas 1) grazing only 2) grazing and one-cut of silage 3) grazing and two-cuts of silage. €riN computes grass supply according to the seasonal pattern of growth and uses fertiliser, manure and reseeding rates to modify the potential level of grass production (17.5 t DM/ha; O'Donovan et al. 2011). Separate calculations simulate the amount of grass produced in the grazing and silage areas of the farm.

1.2.3. Scenarios investigated

Both modelling approaches used a sandy loam (6% OM, 60% sand and 15% of clay soil to a depth of 100 cm). This sandy loam soil type (Teagasc Moorepark type soil) is representative of between 4 – 10% of the soils most at risk to N leaching in the country (McCarthy et al., 2015). The MoSt-PPHDM approach was used to simulate the influence of chemical N fertilizer, stocking rate, seasonal N application strategy, timing of slurry application and precision farming on N leached to 1 m and N use efficiency. The €riN model was used to simulate the influence of chemical N application rate and stocking rate on N leached to 1 m and N gaseous emissions. Having two different modelling approaches investing the impact of similar scenarios provided greater confidence around the modelling outcomes.

2. MoSt –PBHDM modelling approach

2.1. Methodology

Table 2.1 shows the chemical N application strategy use in the various scenarios simulated. The MoSt model used weather data recorded in the Met Eireann weather station located at Moorepark (52°09'52.3"N 8°15'36.6"W) over an 18 year period (2003-2020). Each of the simulations was completed on a daily time step for those 18 years consecutively meaning that weather or management happening in one year could have consequences (for example N still available for leaching) in the subsequent year.

The PBHDM model simulated good practices in terms of grassland, dairy cow nutrition and slurry management. Concentrate was fed at 3.5 kg DM per cow per day for the first 40 days of lactation and 2 kg DM per cow per day afterward irrespective of the amount of grass on the farm. Indoors lactating cows were fed grass silage ad libitum (quality 1.1 FV, 0.78 UFL, 75 PDI), while dry cows were allocated 80% of ad libitum intake of a lactating cow to meet energy requirements for maintenance, pregnancy and body condition score change (circa 10 kg silage DM per cow per day). During the grazing season cows were housed when the soil saturation level was over 90%. Grazing management was dictated by both pre- and post-grazing height, while farm grass cover was evaluated daily and was compared with herd requirement. In a situation where farm grass cover was greater than target, surplus paddocks were removed as silage. In a situation where grass supply was not adequate, areas closed for silage were brought back into grazing. In a grass deficit situation, extra concentrate was fed up to 4 kg DM per day per cow (on top of the base concentrate); if grass supply was still in deficit, grass silage was fed up to a maximal rate of 6 kg DM/cow. In the simulations, priority was given to grazing over silage conservation; if silage produced on the farm was in deficit, it was purchased.

The PBHDM simulated the number of days at grazing, the number of days at grazing without supplementation, grass intake (kg/cow and kg/ha), silage intake (while cows are grazing, while lactating cows are indoors due to soil saturation and while cows are dry and indoors; kg DM/cow and kg DM/ha), milk, protein and fat produced (kg/cow and per ha), the amount of silage produced (kg/ha) and yearly surplus or deficit of silage (kg/ha). All outputs were simulated per day and were then summarised by week, season, year or over the full period.

2.2. Scenarios

2.2.1. Influence of year on grass growth, feed budget and N flows

Table 2.2 shows the influence of year on grass growth; feed budget and nitrogen flows from pasture grazed by dairy cows stocked at 2.75 cows per hectare using 250 kg of chemical N on a free draining soil. It can be observed that there is significant year-to-year variability in all of the factors modelled with no change in management. This is because of weather variability from year to year and highlights the requirement of dynamic management at farm level to minimise loss in those periods. Years 2006 and 2018 had the greatest N surplus/ha and the lowest NUE; while years 2007 and 2017 had the lowest N surplus/ha and the highest NUE. In 2006 and 2018 grass growth rates were lowest, requiring higher concentrate supplementation/cow as well as a requirement to import a large proportion of the grass silage required per cow. In contrast grass growth was high in 2007 and 2017, requiring lower levels of concentrate feeding and there was a surplus of silage produced.

2.2.2. *Chemical N application*

Different chemical N application strategies were simulated. The base scenario was based on a chemical N application rate of 250 kg/ha being applied from 12th of January to the 15th of September. The timings of the chemical N applications are shown on Table 2.2.

Table 2.3 shows the influence of chemical N application rates of 250, 225 and 200 kg/ha on grass growth, the feed budget and nitrogen flows to 1 meter depth, at a stocking rate of 250 and 230 kg of organic nitrogen per hectare as well as the same fertiliser and organic N strategies where fertiliser was spread between February1st and September 1st.

Table 2.4 shows the influence of timing of first N application date on grass growth, feed budget and N flows to 1 meter depth, at a stocking rate of 2.75 cows per hectare. This was simulated by either applying the first chemical N application (29 kg N/ha) for every paddock of the farm (blanket spreading) on either the 12th, 19th, 26th of January or 2nd February (obviously this is not recommended practice). Normal chemical N pattern was then applied from early March onwards for the remainder of the year.

Table 2.5 shows the influence of chemical N application rates greater than specified in SI 605 of 2017 on the grazing platform on grass growth, feed budget and N flows to 1 meter depth, at a stocking rate of 2.75 cows per hectare. This may result in lower levels of chemical N fertilizer on other parts of the farm.

Table 2.1. Chemical N application strategy use in the various scenarios simulated on dairy farm												
Year	**Fertiliser level variation**					**Autumn timing variation (last application 30 August)**			**Smart 2018 simulation**	**Closed period for chemical N 1st February-1st September**		
Total N applied	**350**	**300**	**250**	**225**	**200**	**250**	**225**	**200**	**171**	**250**	**225**	**200**
January	22	19	**16**	14	13	16	16	16	11	0	0	0
February	18	16	**13**	12	10	13	13	13	12	29	26	23
March	60	52	**43**	39	34	43	43	43	25	43	39	34
April	57	49	**41**	37	33	41	41	41	41	41	37	33
May	55	47	**39**	35	31	39	39	39	39	39	35	31
June	49	42	**35**	32	28	40	35	24	35	35	32	28
July	31	26	**22**	20	18	28	19	14	8	22	20	18
August	34	29	**24**	22	19	30	19	9	0	41	37	33
September	24	20	**17**	15	14	0	0	0	0	0	0	0

Table 2.2. Influence of year on grass growth; feed budget and N flows simulated from pasture grazed by dairy cows stocked at 2.75 cows per hectare using 250 kg of chemical N on a free draining soil										
Year	Grass growth (kg D,M/ha)	Grass intake (kg DM/cow)	Silage intake (kg DM/cow)	Concentrate (kg DM/cow)	N leaching (1m) (kg/ha)	MS (kg/cow)	Silage balance (kg DM/ha)	N surplus (kg/ha)	NUE (%)	Rainfall (mm/year)
2003	14,729	3,158	1,081	867	46.9	412	1,195	199	30.6	882
2004	14,351	3,490	940	791	66.7	429	331	209	30.3	1,032
2005	13,792	3,388	976	908	60.6	436	49	222	29.3	1,028
2006	9,718	2,508	1,645	1,333	60.5	444	-2,927	315	22.9	1,094
2007	15,016	3,468	935	813	44.8	429	862	199	31.3	918
2008	13,596	3,304	1,062	903	74.5	433	-183	227	28.7	1,052
2009	14,518	3,446	961	845	88.4	435	459	209	30.6	1,293
2010	14,086	3,273	1,089	955	38.6	438	216	221	29.5	869
2011	14,611	3,404	969	915	39.9	435	436	214	30.0	856
2012	13,547	3,430	969	828	77.4	430	-128	221	29.2	1,097
2013	11,809	2,922	1,369	1,110	49.8	438	-1,518	270	25.5	946
2014	14,922	3,365	1,037	899	76.5	438	678	207	30.8	1,239
2015	14,647	3,383	993	915	73.9	438	555	211	30.4	1,209
2016	13,614	3,310	1,094	923	49.1	441	-278	229	28.9	979
2017	15,049	3,537	896	751	62.1	426	843	196	31.6	1,015
2018	**9,253**	**2,291**	**1,842**	**1,382**	76.2	**443**	**-3,515**	**332**	**22.0**	**1,078**
2019	**15,390**	**3,461**	**944**	**767**	67.4	**425**	**1,288**	**187**	**32.5**	**1,082**
2020	14,885	3,451	972	882	60.9	441	530	209	30.8	1,100
Max	15,390	3,537	1,842	1,382	88.4	444	1,288	332	32.5	1,293
Min	9,253	2,291	896	751	38.6	412	-3515	187	22.0	856
Avg	13,752	3,255	1,099	932	61.9	434	-61	227	29.2	1,043

Table 2.3.	Influence of chemical N application rate on grass growth, feed budget and nitrogen flows to 1 meter depth from pasture grazed by dairy cows, at a stocking rate of 250 and 230 organic N per hectare on a free draining soil (40 ha)										
Nitrogen (kg/ha)	**Organic N (kg/ha)**	**No. cows**	**Grass growth (kg DM/ha)**	**Grass intake (kg DM/cow)**	**Silage intake (kg DM/ha)**	**Con. intake (kg DM/ha)**	**N leaching (1m) (kg /ha)**	**Milk solids (kg MS/cow)**	**Silage Balance (kg DM/ha)**	**Nitrogen surplus (kg N/ha)**	**NUE (%)**
250	250	110	13,752	3,255	1,099	932	61.9	434	-61	227	28.8
225	250	110	13,390	3,237	1,113	934	60.5	433	-303	207	30.7
200	250	110	13,014	3,211	1,129	957	59.2	435	-556	189	32.7
250	230	101	13,622	3,328	1,055	883	60.2	433	685	210	28.4
225	230	101	13,261	3,283	1,084	909	58.8	433	448	191	30.2
200	230	101	12,874	3,267	1,095	909	57.4	432	187	172	32.5
Closed period: 1st September to 1st of February											
250	250	110	13,765	3,249	1,099	941	61.4	434	-46	227	28.8
225	250	110	13,402	3,233	1,113	945	60.0	433	-281	207	30.7
200	250	110	13,032	3,195	1,140	960	58.7	434	-538	189	32.7
250	230	101	13,635	3,303	1,064	903	59.6	433	713	210	28.3
225	230	101	13,278	3,288	1,078	915	58.3	434	467	191	30.3
200	230	101	12,898	3,270	1,093	934	57.0	435	202	173	32.6

Table 2.4.	Influence of timing of first N application date on grass growth, feed budget and nitrogen flows to 1 meter depth from a paddock receiving 29kg N/Ha from pasture grazed by dairy cows, at a stocking rate of 2.75 cows per hectare on a free draining soil								
1st Nitrogen application	Grass Growth (kg DM/ha)	Grass Intake (kg DM/cow)	Silage Intake spring (kg DM/cow)	Concentrate (kg DM/cow)	Silage Intake (kg DM/ha)	N leaching (1m) (kg /ha)	Milk Solids (kg MS/cow)	Nitrogen surplus (kg N/ha)	NUE (%)
12-Jan	13,828	3,250	145	816	1,067	61.9	415	209	29.2
19-Jan	13,849	3,258	140	812	1,061	61.1	415	208	29.2
26-Jan	13,848	3,263	137	811	1,060	60.8	415	208	29.3
02-Feb	13,868	3,232	157	821	1,083	60.2	415	209	29.2

Table 2.5.	Influence of chemical N application rates greater than specified in SI 605 of 2017 on the grazing platform on grass growth, feed budget and N flows to 1 meter depth from pasture grazed by dairy cows, at a stocking rate of 2.75 cows per hectare on a free draining soil							
Nitrogen (kg/ha)	Grass Growth (kg DM/ha)	Grass Intake (kg DM/cow)	Silage Intake (kg DM/cow)	Concentrate Intake (kg DM/cow)	N leaching (1m) (kg /ha)	Milk Solids (kg MS/cow)	N surplus (Kg N/ha)	NUE (%)
250	13,752	3,255	1,099	932	61.9	434	227	28.8
300	14,436	3,296	1,068	898	64.8	432	264	25.7
350	15,075	3,306	1,071	888	68.0	432	305	23.6

2.2.3. Slurry application during the closed period

Of the slurry available, a third was applied In January/February, a third in March and a last third in April in all simulations. The only exceptions were for the simulations where 12% or 25% of the slurry was applied on the 15th of December, (closed period which is prohibited by SI 605 of 2017) subsequent application was reduced accordingly (Table 2.6).

2.2.4. Stocking rate simulations

In all the simulations carried out the farm area was 40 hectares. Three different stocking rates were simulated- 2.94 cows/ha corresponding to 268 organic N/ha (corresponding to the highest allowed SR when the organic N/cow was based on 85 kg recalculated based on an organic N of 91 N/cow); 2.75 cows/ha corresponding to 250 organic N/ha and 2.53 cows/ha corresponding to 230 organic N/ha (Table 2.7).

Also simulated was a platform stocking rate of 3.7 cows/ha (340 kg of organic N/ha) and 4.6 cows/ha (430 kg of organic N/ha), while overall farm stocking rate remained at 2.75 cows/ha. It was assumed that the platform was used for grazing and the land that was not accessible to grazing was used for silage production. In those platform simulations it was assumed that the slurry was spread uniformly on the grazing platform and the silage ground, and that both the grazing platform and the silage ground were receiving 250 kg of chemical N/ha. It was assumed that the silage ground was cut three times with a total chemical N application of 250 kg/ha/year (Table 2.8).

Table 2.6. Influence of applying 12% or 25% of slurry (by volume) in mid-December (prohibited by SI 605 of 2017) on grass growth, feed budget and N flows to 1 meter depth from pasture grazed by dairy cows, at a stocking rate of 2.75 cows per hectare on a free draining soil

Nitrogen (kg/ha)	Slurry Spreading During Closed Period (%)	Grass Growth (kg DM/ha)	N leaching (1m) (kg /ha) Total farm	N leaching (1m) (kg /ha) Proportion of farm where slurry was applied
250	0	13,752	61.9	61.9
250	12	13,729	62.3	65.1
250	24	13,709	62.9	65.4

Table 2.7. Influence of organic N rate (268, 250 & 230 N/ha) on grass growth, feed budget and N flows to 1 meter depth from pasture grazed by dairy cows, on a free draining soil using 250 kg/ha of chemical N (40 ha)

Organic N (kg/ha)	No. cows	Grass Growth (kg DM/ha)	Grass Intake (kg DM/cow)	Silage Intake (kg DM/cow)	Concentrate Intake (kg DM/cow)	N leaching (1m) (kg /ha)	Milk Solids (kg MS/cow)	Nitrogen surplus (kg N/ha)	NUE (%)
268	118	13,842	3,205	1,122	944	63.2	433	238	29.2
250	110	13,752	3,255	1,099	932	61.9	434	227	28.8
230	101	13,622	3,328	1,056	883	60.2	433	210	28.4

Table 2.8. Influence of socking rate on the grazing platform (250, 340 & 430 kg organic N/ha) on grass growth, feed budget and N flows to 1 meter depth from pasture grazed by dairy cows, on a free draining soil using 250 kg/ha of chemical N

Organic N (kg/ha)	No. cows	Farm Size (ha)	Grass Growth (kg DM/ha)	Grass Intake (kg DM/ha)	Silage Intake (kg DM/cow)	Concentrate Intake (kg DM/cow)	N leaching (1m) (kg /ha)	Milk Solids (kg MS/cow)	Nitrogen surplus (kg N/ha)	NUE (%)
250	110	40	13,752	3,255	1,099	932	61.9	434	227	28.8
340	110	30	14,095	3,005	1,283	1,073	67.6	439	293	29.6
430	110	24	14,426	2,774	1,450	1,200	73.7	441	366	29.8
Whole Farm										
340	110	40	13,653	3,005	1,283	1,073	62.7	439	242	27.7
430	110	40	13,587	2,774	1,450	1,200	63.5	441	255	26.8

2.2.5. ***Precision chemical N application***

Both Table 2.9 and Table 2.10 highlight the potential of precision N application in increasing nitrogen use efficiency (NUE). Table 2.9 shows the nitrate leaching losses for each of the 18 years using the four first N application dates. Table 2.10 shows the advantage of using precision chemical N application strategy in 2018, based on extreme meteorological conditions. For the 2018 analysis, the base chemical N application strategy used was the same as that used for the previous years, with a targeted application strategy using precision fertiliser timing developed to deal with 2018 weather based on the following:

- If the predicted grass growth in spring for the week ahead was lower than 10 kg of DM/ha; fertiliser N application for the week ahead was delayed.
- Similarly, if the forecasted rainfall in the 3 days following the planned date of application was high, the application was delayed,
- 24 kg of N in March was not applied due to the very low soil temperatures/snow (Beast from the East); no growth for almost 3 weeks,
- During the main grass-growing season, as soon as the predicted grass growth for the week ahead went below 25 kg of DM/day no more N fertiliser was applied until grass growth rates recovered above this level.

This resulted in a total chemical N application of 171 kg of N/ha for 2018 (a reduction of 79 kg of N/ha); the timing and outputs from the simulation are presented in Table 2.2. In 2018, reducing chemical N application from 250 kg/ha to 171 kg/ha (79 kg/ha reduction) only reduced grass production per hectare by 259 kg of DM.

Table 2.9. Influence of timing of first chemical N application date in 2003 to 2020 on N leaching to 1 meter depth from a paddock receiving 29kg N/Ha from pasture grazed by dairy cows, at a stocking rate of 2.75 cows per hectare on a free draining soil

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Control (no N)	52.2	60.3	64.9	44.4	38.6	80.0	88.3	30.6	38.1	89.1	34.0	61.5	64.7	30.9	53.1	44.2	56.0	52.1	54.6
12-Jan	57.3	66.7	70.1	48.4	44.7	86.2	97.2	38.3	43.5	93.1	41.3	72.8	70.7	39.4	60.2	51.9	61.5	59.5	61.3
19-Jan	57.5	66.3	69.1	47.1	44.9	85.4	96.0	35.2	42.2	93.2	41.3	72.8	69.3	39.8	60.5	50.3	62.2	58.2	60.6
26-Jan	56.8	66.1	67.4	46.8	44.7	84.3	94.3	34.0	42.1	93.6	40.1	73.5	68.9	39.5	61.3	49.9	62.6	58.5	60.2
02-Feb	56.8	65.7	67.4	46.8	45.3	84.2	91.3	33.8	42.1	92.7	38.5	72.8	68.5	38.8	60.4	49.2	61.8	58.8	59.7
Mean	57.1	66.2	68.5	47.3	44.9	85.0	94.7	35.3	42.5	93.2	40.3	73.0	69.4	39.4	60.6	50.3	62.0	58.8	60.5
Max	57.5	66.7	70.1	48.4	45.3	86.2	97.2	38.3	43.5	93.6	41.3	73.5	70.7	39.8	61.3	51.9	62.6	59.5	61.3
Min	56.8	65.7	67.4	46.8	44.7	84.2	91.3	33.8	42.1	92.7	38.5	72.8	68.5	38.8	60.2	49.2	61.5	58.2	59.7
Diff	0.5	1.0	2.7	1.6	-0.6	2.0	5.9	4.5	1.4	0.4	2.8	0.0	2.2	0.6	-0.2	2.7	-0.3	0.7	1.6

Table 2.10. Influence of applying precision chemical N application strategy based on metrological condition on grass growth, feed budget and N flows to 1 meter depth from pasture grazed by dairy cows, at a stocking rate of 2.75 cows per hectare on a free draining soil (40 ha)

Year	Nitrogen (kg/ha)	Grass growth (kg DM/ha)	Grass intake (kg DM/cow)	Silage intake (kg DM/ha)	Con. intake (kg DM/ha)	Net mineralisation (kg/ha)	N leaching (1m) (kg /ha)	Milk solids (kg MS/cow)	Silage Balance (kg DM/ha)	Nitrogen surplus (kg N/ha)	NUE (%)
Avg.	250	13,752	3,255	1,099	932	82	62	434	-61	227	28.8
2018	250	8,987	2,352	1,680	1.215	-12	77	414	-2,639	306	22.4
2018	171	8,728	2,483	1,569	1,154	23	65	412	-2,672	224	25.8

2.2.6. Financial implications

Table 2.11 shows the impact of reduced chemical N where cow numbers were fixed and where feed was purchased onto the farm to fill the feed deficit due to the reduced grass growth. Spend on purchased feed on the farm increased by €4,239 and €8,322 for reductions in chemical N fertiliser of 25 and 50 kg/ha, respectively. In this scenario, reducing chemical N fertiliser reduces grass growth thereby creating a situation where a relatively cheap feed (grazed grass) is being replaced with a much more expensive feed (grass silage and concentrates). Table 2.12 shows the effect of platform organic N/ha on farm profitability. The influence of different organic N/ha levels were modelled which included 250 (2.75 cows/ha) to 230 kg (2.53 cows/ha) on the profitability of a 40ha dairy farm. Additionally, the impact of platform organic N of 340 kg/ha (3.74 cows/ha) and 430 kg/ha (4.73 cows/ha) on farm profitability was investigated.

No effect or cost was included for reducing stocking rate from a current level and the implications for fixed/sunk costs which would be significant on these farms.

Table 2.11. Influence of chemical N application rate on the financial performance on a 40 ha dairy farm based on holding cow numbers constant

		250	225	200
Physical	Cows	110	110	110
	Milk produced (kg)	601,520	601,520	601,520
	Stocking rate (cows/ha)	2.63	2.63	2.63
	MS sales (kg)	50,010	50,010	50,010
Receipts	Milk receipts	213,267	213,267	213,267
	Livestock receipts	23,746	23,746	23,746
	Total Receipts	**237,013**	**237,013**	**237,013**
Variable costs	Purchased feed	13,251	17,490	21,573
	Fertiliser	14,400	13,615	12,843
	Replacement costs	20,973	20,973	20,973
	Veterinary and AI	11,465	11,465	11,465
	Silage	5,409	5,859	5,951
Fixed costs	Labour	24,617	25,341	26,065
	Depreciation	14,752	14,752	14,752
	Interest	8,029	8,029	8,029
	Electricity	3,230	3,230	3,230
	Insurance	9,040	9,040	9,040
	Total Costs	**143,989**	**148,617**	**152,943**
Net profit	Per farm	93,071	88,449	84,120

Table 2.12. Influence of platform stocking rate (kg organic N/ha) on the financial performance on a 40 ha dairy farm							
				Cows fixed		Cows reducing	
Organic N		**250**	**230**	**340**	**430**	**250**	**250**
Physical	Milk Platform (ha)	40	40	29.5	23.3	29.5	23.3
	Cows	110	101	110	110	81	64
	Milk produced (kg)	611,820	559,742	619,300	623,700	450,522	355,620
	Stocking rate (cows/ha)	2.75	2.53	3.73	4.73	2.75	2.75
	MS sales (kg)	46,416	42,461	46,995	47,336	34,179	26,979
Receipts	Milk receipts	199,907	182,877	202,401	203,869	147,204	116,196
	Livestock receipts	32,270	29,629	32,270	32,270	23,762	18,757
	Total Receipts	**232,176**	**212,506**	**234,671**	**236,139**	**170,966**	**134,952**
Variable costs	Imported Silage costs	0	-2,447	11,094	18,324	0	0
	Fertiliser	12,958	13,055	10,057	8,220	9,542	7,532
	Replacement costs	28,645	26,302	28,645	28,645	21,093	16,650
	Veterinary and AI	11,477	10,544	11,477	11,477	8,471	6,703
	Contractor	10,145	10,522	6,6061	6,632	7,456	6,202
	Labour	28,236	25,926	31,558	34,880	20,792	16,412
	Depreciation	14,754	13,669	15,629	16,499	11,268	9,217
	Interest	7,409	6,802	8,125	8,841	5,455	4,306
	Electricity	3,163	2,955	3,193	3,210	2,519	2,140
	Insurance	8,895	8,167	8,895	8,895	6,550	5,170
	Total Costs	**164,537**	**150,840**	**179,137**	**195,842**	**117,363**	**89,593**
Net profit (incl) labour	Per farm	67,985	61,960	55,886	40,596	53,836	45,525
	Per hectare farmed	1,700	-	1,397	1,015	1,828	1,958
Net profit (excl) labour	Per farm	96,211	-	87,443	75,475	74,628	61,937
	Per hectare farmed	2,406	-	2,965	3,245	2,834	2,664

2.3. Key results of the modelling scenarios

2.3.1. Influence of year on N leaching, N surplus and NUE simulated

Table 2.1 shows the grass growth, feed budgets and N flows for each of the 18 years simulated. Over the 18-year period, the quantity of N leached that was simulated varied from 38.6 kg N/ha to 88.4 kg N/ha, with an average of 61.9kg/ha. Nitrogen surplus ranged from 187 to 332 kg/ha with an average of 227 kg/ha; while NUE ranged from 22.0% to 32.5% with an average 29.2% over the 18-years.

2.3.2. Chemical nitrogen application

Reducing chemical N application rates from 250 to 225 kg/ha and from 250 to 200 kg/ha, reduced modelled N leaching to 1 m depth by 2.3% and 4.4% respectively; N surplus was reduced by 9% and 16.7% respectively and NUE increased by 1.9% and 3.9% respectively (Table 2.3). Overall farm profitability was reduced by €4,622 and €8,951 at chemical N rates of 225 and 200 kg/ha, respectively. Net profit per hectare was reduced by €116/ha and €224/ha, respectively. Reducing the open period for chemical N to between the 1st of February and 1st of September reduced N leached to 1 m by less than <1% and had no impact on N surplus per hectare or NUE.

Applying chemical N rates of 50 and 100 kg/ha in excess of that specified in the Nitrate Directive (S.I. 605 of 2017) resulted in increase of 4.7% and 9.9% in N leached per hectare respectively. Additionally, it increased N surplus per hectare by 16.3% and 34% respectively, and reduced NUE by 3.1% and 5.2% respectively (Table 2.5).

2.3.3. Stocking rate scenarios simulations

Reducing organic N/ha from 268 kg (2.94 cows/ha) (previous stocking rate when organic N per cow was assumed to be 85 kg) to 250 kg (2.75 cows/ha) reduced N leached, N surplus and increased NUE by 2.1%, 4.8% and 0.4% respectively. Reducing organic N/ha from 250 kg (2.75 cows/ha) to 230 kg (2.53 cows/ha) reduced N leached, N surplus and increased NUE by 2.7%, 7.5% and 0.4% respectively (Table 2.7). Farm profitability at an organic N level of 250 kg (2.75 cows/ha) and 230 kg (2.53 cows/ha) on a 40 hectare farm were €67,985 and €61,960 respectively (Table 2.11). The impact for a farmer that is currently stocked at 250 kg/ha, having to reduce to 230 was not simulated; in this situation it is anticipated that the reduction in profitability would be greater given that the fixed costs are already in place.

Increasing platform stocking rate to 3.7 cows/ha (340 kg of organic N/ha) and 4.6 cows/ha (430 kg of organic N/ha), increased N leaching by 9.2% and 19% respectively; increased N surplus by 29% and 61% respectively and increased NUE by 0.8% and 1% respectively (Table 2.8). However, when the whole farm was considered (assuming the grazing platform and silage ground are in the same water catchment), increasing stocking rate to 3.7 cows/ha (340 kg of organic nitrogen/ha) and 4.6 cows/ha (430 kg of organic nitrogen/ha) over the total farm, increased N leaching by 1.3% and 2.6% respectively; increased N surplus by 6.6% and 12.3% respectively and reduced NUE by 1.1% and 2% respectively.

Farms that operate at a higher milking platform stocking rate due to land fragmentation are at a financial disadvantage. In the analysis completed, when the milking platform reduced, so did the profitability. At a milk platform size of 29.5 hectares and 23.3 hectares and where cow numbers were held constant (110) profitability reduced by €12,099 and €27,389 respectively when compared to a situation where the milking platform was 40 Ha. If the farmer operated a system where cow numbers were less when the milking platform was smaller (i.e. 29.5 hectares and 23.3 hectares) in order to maintain the stocking rate on the platform at 2.75 cows/Ha, then the profitability would reduce by €14,148 and €22,460 relative to a 40 hectare platform operated at 2.75 cows/Ha. Reducing stocking rate (not simulated) would increase the difference in profitability shown here substantially due to sunk costs that would not reduce with reduced stocking rate.

*2.3.4. **Slurry application during the closed period***

Applying 12% or 25% of the slurry in mid-December increased N leaching by less than 1% and 1.6% respectively when looking at the whole farm; however when looking only at the paddock receiving slurry 5 and 10.4 ha respectively, the N leaching for those paddocks increased by 5.2% and 5.6% respectively.

*2.3.5. **Precision N chemical application***

On average over the 18 years, if 29 kg of N per hectare was applied on the 12th of January application date as compared to the 2nd of February there was 1.6 kg higher N leached per hectare. However, in three of these years the losses were greater for the 2nd of February application compared to the 12th of January, while in other years the quantity leached with the early January application was greater than that with the 2nd of February application. These differences were associated with large differences in meteorological conditions; 2009 January total rainfall was 213 mm with a mean monthly temperature of 4.6 °C, compared to 2007 January total rainfall was 77 mm and a mean monthly temperature of 7 °C.

The summer of 2018 was one of the warmest and driest summers on record for Ireland; consequently, grass growth was significantly reduced (33%; 9,253 vs an average of 13,752 kg DM/ha). Table 2.10 shows that reducing chemical N in line with reduced grass growth in 2018 reduced N leached per hectare by 12 kg; (77 vs 65 kg N/ha), reduced N surplus by 27% (306 vs 224 kg/ha) and increased NUE by 3.4% (22.4% vs 25.8%).

3. €riN modelling approach

3.1. Methodology

3.1.1. Model description

Demand for grazed grass and grass silage largely determines the proportion of grass utilised in the models. €riN assigns monthly utilisation rates to grazed grass and applies a fixed proportion (e.g., 75%) to grass silage. The MDSM quantifies grass demand based on the herd's dietary requirements and the nutritional value of forages and supplements. The nutritional module of this model requires data on milk yields, animal body weights, pregnancy rates, calving pattern, replacement rates, housing periods and supplementary feeding levels. O'Mara's (1996) net energy (NE) system computes the herd's energy demand in lactation feed units (UFL) and provides NE values for feeds in UFL. The NE system takes the NE supplied by concentrate supplements from the animals' NE demand to calculate the NE provided by forage. The model estimates NE from grazed grass by relating the length of grazing season to NE supplied by forage, and uses the housing period to compute NE from grass silage. Additional computations convert NE required from forages to DM. Aggregating the DM required from forage and concentrate feed estimates the total DM demand, which the MDSM multiplies by the N content of the diet to calculate an animal's intake of N. Nitrogen outputs are calculated from milk and cattle sales and the N content of these products.

The €riN model uses N intakes and N outputs from the MDSM to estimate N excretion and related N losses. €riN quantifies N excretion in sheds and paddocks based on the length of the housing and grazing periods. The model accounts for N excreted on passageways and on collecting yards i.e. soiled water, and partitions N excretion between dung and urine based on the work of Kebreab et al. (2001). €riN calculates ammonia, nitrate and nitrous oxides losses from urine, dung, slurry, soiled water and fertiliser N by multiplying the N load with emission factors from empirical Irish research. Nitrate emission factors vary by soil drainage class and by season for nutrient applications in the form of urine and dirty water. Ammonia emission factors for urine, dung and slurry are sensitive to timing and storage facilities, and nitrous oxide loss factors depend on soil type. The model uses a dinitrogen to nitrous oxide loss ratio to estimate dinitrogen losses. Excess or surplus N not vulnerable to leaching, volatilization or denitrification returns to the soil N pool. €riN uses a mass flow approach to calculate the soil N balance, and computes a farm's N surplus as the difference between N imports and N exports.

3.1.2. Dairy farm characteristics

The baseline dairy farm covered 40 hectares and carried 110 livestock units. Stocking rate averaged 2.75 livestock units/hectare (ha). The farm was in permanent pasture and the average age of the sward was 5 years. Well-drained soils were the predominant drainage class on the farm. Soils were weakly acidic i.e. pH 6.3, and in the recommended index for P and K, index three. The farm spread 15 kg of P, 37 kg of K, 150 kg of lime and 250 kg of fertiliser N/ha per year. On average, a hectare of grassland produced 13.7 tonnes of dry matter (DM)/year. The herd utilized 85% of the grass grown and received concentrate feed at an average rate of 2.55 kg/cow per day (i.e. 932 kg/cow per year). Pasture accounted for 62% of the dairy herd's annual feed budget. Grass silage represented about a fifth of the feed budget and less than 1% of silage was imported. Holstein Friesian was the main breed of cow in the herd. The average herd live weight was 550 kilogrammes and yielded 5,607 kilogrammes of milk/annum. Milk fat content averaged 42.5 g/kg and protein content averaged 35.4 g/kg. Dairy cows usually lived for six or seven years and on average had four lactations.

Twenty-four-month-old heifers replaced dairy cows. Contractors reared replacement heifers' off-farm. Male calves and surplus female dairy calves spent 3-4 weeks on the holding prior to sale. Cows gave birth in a block throughout spring. Half of the herd calved between the 20th of January and 15th of February. The calving season finished at the end of March. Once ground conditions were suitable for grazing, milking cows went to pasture. The herd returned to the cubicle sheds at the end of the growing season in the final weeks of November. Concrete tanks stored 439 m^3 of manure (dung and urine) excreted by animals during the housing period. A separate tank gathered soiled water from the collecting yard of the milking parlour. Vacuum tankers and umbilical equipment applied 90% of the slurry onto grassland in spring and applied the balance in summer following a harvest of silage. Splash plate fitted tankers spread slurry at a rate of 2,500-3,000 gallons/acre. The same machinery land spread soiled water. Current water regulations permit spreading of soiled water throughout the year, but prohibit application of slurry during the closed spreading period.

3.2. Scenario analysis

€riN ran five different stocking rate N scenarios; at each stocking three different chemical N application, rates were evaluated. Scenario 1 (Table 3.1) represents present regulations permitting a maximum average stocking rate of 250 kg organic N/ha using an annual N excretion rate of 91 kg N/cow (2,75 cows/ha). Scenario 2 shows the impact of a reduction of 20 kg organic N/ha (2.53 cows/ha). Scenario 3 represent previous regulations using an annual N exertion rate of 85 kg N/cow (2.95 cows/ha) with the average cow producing 91 kg organic N. Scenario 4 and 5 investigate the influence of platform stocking rates of 340 kg N/ha (3.74 cows/ha) and 430 kg N/ha (4.73 cows/ha), respectively. All scenarios were evaluated using 250, 225 and 200 kg of chemical fertilizer/ha, using a 40 ha farm. The same cow genotype were used in all five stocking scenarios and 100% of the slurry excreted was recycled.

3.3. Results

3.3.1. Feed and milk production

In Scenario 1 reducing chemical fertilizer by 10% (225 kg N/ha) and 20% (200 kg N/ha) reduced grass production by 0.5 and 0.8 tonnes of DM production, respectively; this corresponded to a requirement to import 158 and 267 kg of silage DM/cow. Reducing organic N per hectare by 20 kg (230 kg organic N/ha) reduced milk production from the farm by 9% and resulted in a surplus of silage by 370, 241 and 113 kg DM/cow for chemical N application rates of 250, 225 and 200 kg/ha, respectively. The opposite occurred when stocking intensity increased to 268 kg of organic N/ha (2.94 cows/ha); 22%, 31% and 41% of the silage requirement is imported at chemical N application rates of 250, 225 and 200 kg/ha, respectively. At the very high platform stocking rates, milk production per hectare increased by 34% and 70% above the baseline scenario at a stocking rate of 340 and 430 kg organic N/ha, respectively. However, approximately 80% and 100% of the silage requirement at stocking rate of 340 and 430 kg organic N/ha were imported, respectively.

3.3.2. Nitrogen balances

The baseline dairy farm had an annual import of 334 kg N/ha, export of 99 kg N/ha in the form of milk and cattle sales and had an N surplus of 235 kg N/ha (Table 3.2). Milk deliveries and cattle sales accounted for 88% and 11% of the N exported, respectively. Approximately 75% and 23% of N entered the baseline farm as fertiliser N and concentrate N, respectively; the remainder entered as silage and cattle purchases. Lowering fertiliser N application from 250 to 225 kg N/ha increased the purchases of silage and concentrate by 9 kg N/ha and had no effect on cattle purchases or N exports. These changes decreased annual N imports by 16 kg N/ha and resulted in a similar reduction in N balance/ha. Reducing chemical fertiliser N by 20% (200 kg N/ha) reduced N balance to 200 kg N/ha and increased farm N efficiency from 30% to 33%. Purchases of feed increased by 15 kg N/ha in this scenario to make up the feed deficit.

Lowering the stocking rate on the base farm to 230 kg organic N/ha (Scenario 2) reduced N imports by 12 kg/ha, increased exports by 11 kg/ha (sold silage) resulting in a reduction of 23 kg/ha in N surplus. In this scenario reducing chemical N application helped to balance feed supply on farm and further reduce N balance/ha.

Increasing organic stocking rate to 268 kg/ha (Scenario 3) increased N imports by 22 kg/ha, increased N exports by 7 kg/ha and increased N surplus by 15 kg N/ha above the baseline scenario. Increasing platform stocking rates to 340 and 430 kg of organic N/ha (Scenario 4 and 5), increased N surplus by 81 and 157 kg N/ha, respectively. These increases in N surpluses were associated with large increases in both concentrate and silage imports.

Table 3.1. Description of agricultural inputs and outputs for spring-calving grass-based dairy farms on 40 hectares of well-drained soil										
Scenario	**Stocking rate (kg organic N/ha)**	**Fertilizer N (kg N/ha)**	**Dairy Cows (Average/yr)**	**0-1 year olds (Average/yr)**	**Grass Yield (t DM/ha)**	**Concentrate feed (kg DM/cow)**	**Grass silage demand (kg DM/cow)**	**Silage imports (kg DM/cow)**	**Milk solids (kg /cow)**	**Milk yield (t/ha)**
Scenario 1: Influence of chemical N application rate on farm feed budget at a stocking rate of 250 kg organic N per hectare										
Baseline	250	250	107	9	13.7	932	1098	8	435	15.1
S1	250	225	107	9	13.2	932	1098	166	435	15.1
S1	250	200	107	9	12.9	932	1098	275	435	15.1
Scenario 2: Influence of chemical N application rate on farm feed budget at a stocking rate of 230 kg organic N per hectare										
S2	230	250	98	8	13.7	880	1055	-370	434	13.7
S2	230	225	98	8	13.2	910	1085	-241	434	13.7
S2	230	200	98	8	12.9	910	1093	-113	433	13.7
Scenario 3: Influence of chemical N application rate on farm feed budget at a stocking rate of 268 kg organic N per hectare										
S3	268	250	115	9	13.8	944	1121	252	433	16.1
S3	268	225	115	9	13.4	966	1152	352	434	16.1
S3	268	200	115	9	12.9	993	1191	483	436	16.1
Scenario 4: Influence of chemical N application rate on farm feed budget at a stocking rate of 340 kg organic N per hectare										
S4	340	250	143	12	14.1	1068	1283	948	439	20.3
S4	340	225	143	12	13.6	1084	1299	1048	439	20.3
S4	340	200	143	12	13.2	1114	1356	1141	441	20.3
Scenario 5: Influence of chemical N application rate on farm feed budget at a stocking rate of 430 kg organic N per hectare										
S5	430	250	179	15	14.3	1183	1435	1421	444	25.6
S5	430	225	179	15	13.9	1207	1483	1485	444	25.6
S5	430	200	179	15	13.5	1216	1567	1568	444	25.6

Table 3.2. Annual nitrogen imports, exports and balances (kg N/ha) for spring-calving grass-based dairy farms varying in stocking rate and applying different levels of fertiliser nitrogen to a well-drained soil. A dairy farm's annual N imports consists of fertiliser N, concentrate feed, silage purchases and cattle purchases. Milk, cattle and silage sales make up a farm's annual N exports										
Scenario	**Stocking rate**	**Fertilizer N**	**Concentrate feed**	**Silage purchases**	**Cattle purchases**	**N imports**	**Milk sales**	**Cattle sales**	**N exports**	**N surplus**
Scenario 1: Influence of chemical N application rate on annual N balance at a stocking rate of 250 kg organic N per hectare										
Baseline	250	250	76	1	7	334	88	11	99	235
S1	250	225	76	10	7	318	88	11	99	219
S1	250	200	76	16	7	299	88	11	99	200
Scenario 2: Influence of chemical N application rate on annual N balance at a stocking rate of 230 kg organic N per hectare										
S2	230	250	65	0	6	322	80	10	110	212
S2	230	225	68	0	6	299	80	10	103	196
S2	230	200	68	0	6	274	80	10	96	178
Scenario 3: Influence of chemical N application rate on annual N balance at a stocking rate of 268 kg organic N per hectare										
S3	268	250	83	16	7	356	93	12	106	250
S3	268	225	84	22	7	339	94	12	106	233
S3	268	200	87	30	7	324	94	12	106	218
Scenario 4: Influence of chemical N application rate on annual N balance at a stocking rate of 340 kg organic N per hectare										
S4	340	250	116	73	9	449	118	15	133	316
S4	340	225	118	81	9	433	118	15	133	300
S4	340	200	121	88	9	419	119	15	134	285
Scenario 5: Influence of chemical N application rate on annual N balance at a stocking rate of 430 kg organic N per hectare										
S	430	250	161	137	12	560	149	19	168	392
S5	430	225	164	141	12	541	149	19	168	373
S5c	430	200	166	143	12	520	149	19	168	352

3.3.3. Nitrate leaching

Approximately 20% of surplus N (48 kg N/ha/year) in the baseline farm (Scenario 1) was leached in the form of nitrate (Table 3.3). Approximately, 30 kg of this N loss originated from urine deposited in paddocks, 14 kg came from the application of fertiliser N and 4 kg came from slurry, atmospheric deposition and soiled water (Figure 3.1). The €riN model calculated a nitrate loss rate of approximately 28% for urine N and used a 5.6% loss rate for fertiliser N. The model predicted that spreading 10% less chemical fertiliser N, in the baseline farm, mitigated the risk of nitrate loss by 3%, while reducing chemical N by 20% reduced potential nitrate loss by 7% (Table 3.4). Increasing stocking rate from 250 kg (Scenario 1) to 268 kg (Scenario 3) organic N/ha increased the risk of nitrate loss by 7%. Further intensification of the baseline farm to 340 kg organic N/ha increased potential nitrate loss by 26%; increasing to 430 kg organic N/ha increased predicted nitrate loss by 52%. At stocking rates above 250 kg organic N/ha, lowering fertilizer N by 25 kg/ha (10%) decreased the risk of nitrate leaching by 1-2 kg N/ha (Table 3.5). Reducing chemical fertilizer N by 50 kg/ha (20%) in these scenarios reduced predicted nitrate loss by 3-4 kg N/ha. Reducing stocking rate from 250 to 230 kg organic N/ha decreased this potential emission by 3-4%.

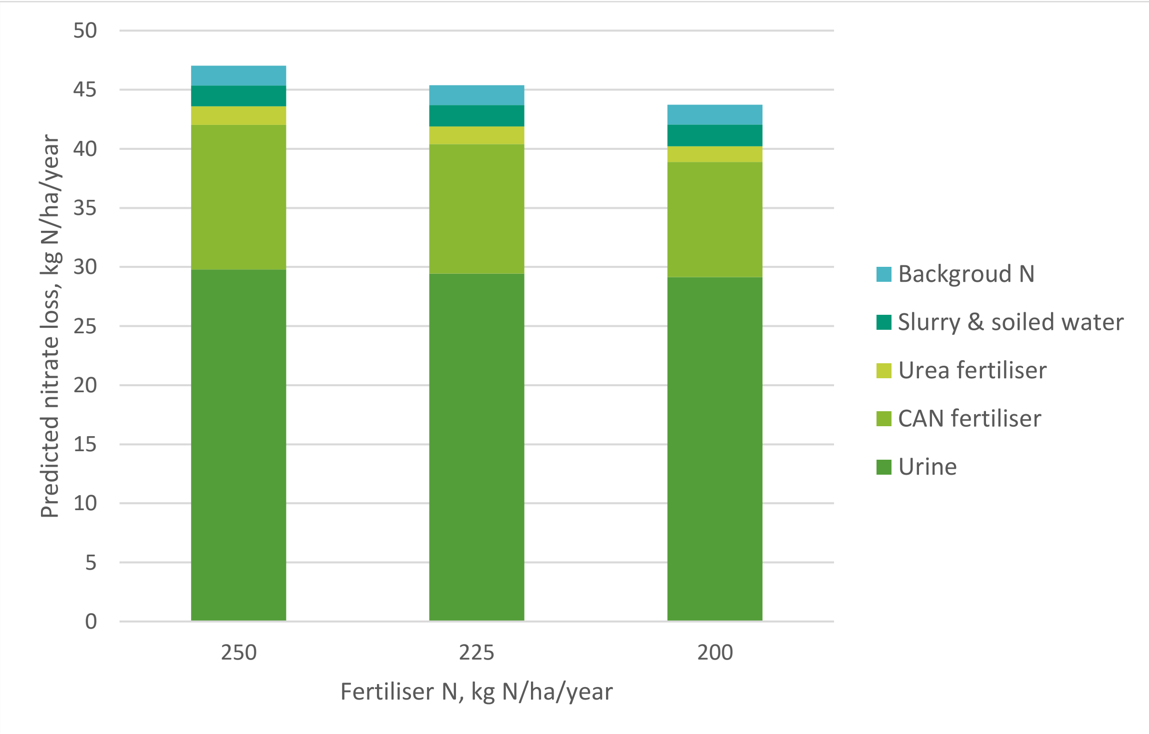

Figure 3.1. The impact of fertiliser N on predicted nitrate losses from a well-drained spring-calving grass-based dairy farm operated at a stocking rate of 250 kg organic N/ha.

Table 3.3. Impact of chemical N fertiliser level on the organic N inputs and nitrate losses of spring-calving grass-based dairy farms stocked at 250 kg organic N/ha on a well-drained soil (kg N/ha per year)					
Fertilizer N	**Urine N**	**Dung N**	**Slurry N**	**Soiled water N**	**Nitrate leaching to 1 metre**
350	109	90	54	17	54
250	106	89	60	17	48
225	105	89	62	17	46
200	104	89	63	17	44

Table 3.4. Impact of stocking rate on the organic N inputs and the potential nitrate losses of well-drained spring-calving grass-based dairy farms spreading 250 kg fertiliser N/ha (kg N/ha per year)					
Stocking rate	**Urine N**	**Dung N**	**Slurry N**	**Soiled water N**	**Nitrate leaching to 1 metre**
230	100	82	51	15	45
250	106	89	60	17	48
268	113	95	68	18	51
340	149	120	86	23	60
430	197	153	100	30	72

Table 3.5. Potential influence of stocking rate and fertiliser nitrogen on the nitrogen losses of spring-calving dairy farms on a well-drained soil in kg N/ha per year							
Scenario	**Stocking rate**	**Fertilizer N**	**N loss to 1 metre**	**Ammonia Emission**	**Dinitrogen**	**Nitrous oxide**	**N losses**
Scenario 1: Influence chemical N fertilisation on N use efficiency at a stocking rate of 250 kg N/ha							
Baseline	250	250	48	75	49	7	179
S1	250	225	46	75	48	7	176
S1	250	200	44	74	47	6	171
Scenario 2: Influence chemical N fertilisation on N use efficiency at a stocking rate of 230 kg N/ha							
S2	230	250	45	68	46	7	166
S2	230	225	44	68	45	6	163
S2	230	200	42	67	44	6	159
Scenario 3: Influence chemical N fertilisation on N use efficiency at a stocking rate of 268 kg N/ha							
S3	268	250	51	81	50	7	189
S3	268	225	49	80	49	7	185
S3	268	200	47	80	48	6	181
Scenario 4: Influence chemical N fertilisation on N use efficiency at a stocking rate of 340 kg N/ha							
S4	340	250	60	101	65	8	234
S4	340	225	58	101	64	7	230
S4	340	200	57	100	64	7	228
Scenario 1 Influence chemical N fertilisation on N use efficiency at a stocking rate of 430 kg N/ha							
S5a	430	250	72	123	81	9	285
S5b	430	225	71	122	81	8	282
S5c	430	200	69	122	81	8	280

3.3.4. Gaseous N emissions

The majority (73-75%) of predicted N losses from dairy farms (Table 3.5) occurred as gases. Ammonia constituted the bulk of predicted gaseous N emissions (58-59%), followed by dinitrogen (36-38%) and nitrous oxide (4-5%). Regardless of stocking rate or fertiliser N level, most of the potential ammonia losses came from slurry spreading (26-28%), and manure excreted onto shed floors, yards, fields and passageways (58-62%). Urine deposited on pasture explained the majority of dinitrogen emissions (79-86%) in all scenarios and contributed to nitrous oxide losses (23-28%). The rest of this gas originated from atmospheric N deposition (28-38%), fertiliser N (23-29%) and slurry N (12-16%).

Within stocking rate, dropping fertiliser N from 250 to 225 kg N/ha lowered predicted gaseous N emissions by 0.5-1% (1-1.4 kg N/ha) and reducing chemical fertiliser N to 200 kg N/ha decreased gaseous losses by 2-2.5%. These management changes reduced nitrous oxide by 2-6% (0.2-0.4 kg N/ha), and had a similar effect on ammonia and dinitrogen losses, mitigating both by about 0.6-1.2 kg N/ha. Increasing stocking rate caused an increase in predicted gaseous N losses analogous to surplus N. For example, ammonia, dinitrogen losses and surplus N increased by 33-35% going from a stocking rate of 250 to 340 kg organic N/ha. The influence of reducing chemical fertiliser N on potential gaseous N emissions tended to decline on a relative and absolute basis as stocking rate increased. Increasing the milking platform stocking rate assumed that all the manure generated was applied on the platform did not take account of the emissions associated with the silage production areas outside of the platform. This has artificially increased the ammonia emissions on a per hectare basis compared to a whole farm emission.

4. Organic N excretion rates for dairy cows

4.1. Background

The organic nitrogen (N) excretion rate of 85 kg per cow has been in place for a period of time. There have been significant increases in dairy cow productivity from both milk volume yield and milk solids concentrations perspectives over this period. As yield increases, it would be expected that the organic N excretion rates per cow would also increase. Across Europe over the years different countries have updated their dairy cow organic N excretion rates. As part of a response to a request from the Department of Agriculture, Food and the Marine the organic N excretion per cow was updated and discussed in this document. Secondly, in response from an additional request from the Department of Agriculture, Food and the Marine, a banding system of N excretion per cow was investigated based on milk yield per cow.

4.2. Methodology

The organic N excretion per cow for the average dairy cow in Ireland was calculated over the period 2012 to 2019. The methodology to update the organic N excretion per cow encompasses a number of areas described below.

4.2.1. ***Intake***

The feed budget (grass, grass silage and concentrate) was determined by meeting the net energy requirement, for milk production and body weight change (Jarrige, 1989). Energy requirement is calculated for each cow based on milk yields and cow live weight. Cows were assumed to be on average 550 kg live-weight, which are typical in Irish pasture based systems (Archibald et al., 2012). Activity adjustments are included based on animals grazing with *20% of maintenance and when animals are housed the corresponding maintenance figure is *10% (Jarrige, 1989). Concentrate feeding levels were included based on data from the Teagasc National Farm Survey. The energy supplied from concentrate is deducted from the total energy requirement with the remaining energy supplied in the form of grazed grass and grass silage with the proportion of each calculated based on grazing season length.

4.2.2. **Assumptions**

Milk yield

Milk yield was calculated based on Central Statistics Office (CSO) total domestic milk deliveries divided by the average of June and December; cow numbers originating from the CSO. Both the milk deliveries as well as the June and December cow numbers were collected from the CSO over the period 2010 and 2019. Over the period 2010 to 2019, milk production per cow increased from 4,980 litres to 5,452 litres, fat content from 3.85% to 4.17%, protein content from 3.37% to 3.54% and milk solids per cow from 370 kg to 432 kg (Table 4.1).

Table 4.1. Trends in milk delivery, dairy cow numbers and milk production plus composition per cow										
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Milk Deliveries (L *mill)	5,173	5,377	5,233	5,423	5,649	6,395	6,651	7,271	7,576	7,990
June Cow numbers	1,007	1,036	1,060	1,083	1,128	1,240	1,295	1,343	1,481	1,505
December Cow Numbers	1,071	1,117	1,141	1,163	1,226	1,296	1,398	1,433	1,369	1,426
Milk Yield (L/cow)	4,980	4,996	4,754	4,829	4,799	5,044	4,939	5,238	5,316	5,452
Fat %	3.85	3.89	3.94	3.94	3.98	4.03	4.10	4.09	4.14	4.17
Protein %	3.37	3.37	3.36	3.39	3.43	3.50	3.45	3.48	3.48	3.54

Source: CSO

Concentrate crude protein concentration

A survey of the feed compounders was completed by DAFM in 2015 to 2019 in order to ascertain the crude protein concentrations of dairy compound feed. Results are shown in Table 4.2. The analysis shows that the average compound feed CP concentration has reduced over the past number of years from 16.6% in 2015 to 16.3% in 2019 on a fresh weight basis. The vast majority of the reduction has taken place during the grazing season. In order to convert to dry matter it was assumed that the concentrate would have a dry matter concentration of 90%. This result in the CP of the concentrate offered to dairy cows to be between 18.1% and 18.4% on a dry matter basis.

Table 4.2 Crude protein concentration of dairy cow concentrate feeds in fresh weight basis.				
Category (Time of year)	**2015**	**2017**	**2019**	**Trend 2015-2019 (% change)**
Jan – March	17.6	17.6	17.4	**-1.1**
April - June	16.1	15.7	15.7	**-2.5**
July - September	15.9	15.6	15.5	**-2.5**
Oct – Dec	17.3	17.2	17.1	**-1.2**
Overall	**16.6**	**16.5**	**16.3**	**-1.8**

Source: DAFM

Grazed Grass Crude Protein

In general there has been little grass CP analysis undertaken on commercial grassland farms; much of reported grass CP values reported are from Teagasc research farms. Creighton (2008) established the level of CP on commercial farms. In three separate studies the average CP measured was 18.2% (s.d. 1.67), 16.9% (s.d. 1.32), 17.6% (s.d. 1.5). In 2019, a new farm system research study was established in Clonakilty Agricultural College farm comparing a chemical N input per hectare of 250 kg versus 150 kg/ha. The mean CP concentration across the year for these swards at 250 kg N/ha input was 18.6 % CP and for 150 kg N/ha input was 18.0 % CP, respectively (Figure 4.1). There was a large seasonal influence on grass CP content; being highest in both early spring (23.5%) and autumn (18.5%) and lowest during the main grazing season (17.0%). Although grass CP concentrations were elevated during the spring and autumn, these periods coincide with a time when the lactating dairy cow's diet comprises of a large proportion of grass-silage, which is inherently low in CP concentration (~ 13 % CP, discussed further below) plus concentrate feeds. For example, a typical early lactation dairy cow diet comprises of 10 kg DM grass, 3 kg DM grass-silage and 3 kg DM concentrate supplement. Likewise, a typical late lactation dairy cow diet comprises of 10 kg DM grass, 4 kg DM grass-silage and 2 kg DM concentrate supplement. Based on the data from the above sources the CP content for grazed grass nationally was assumed to be 18 %.

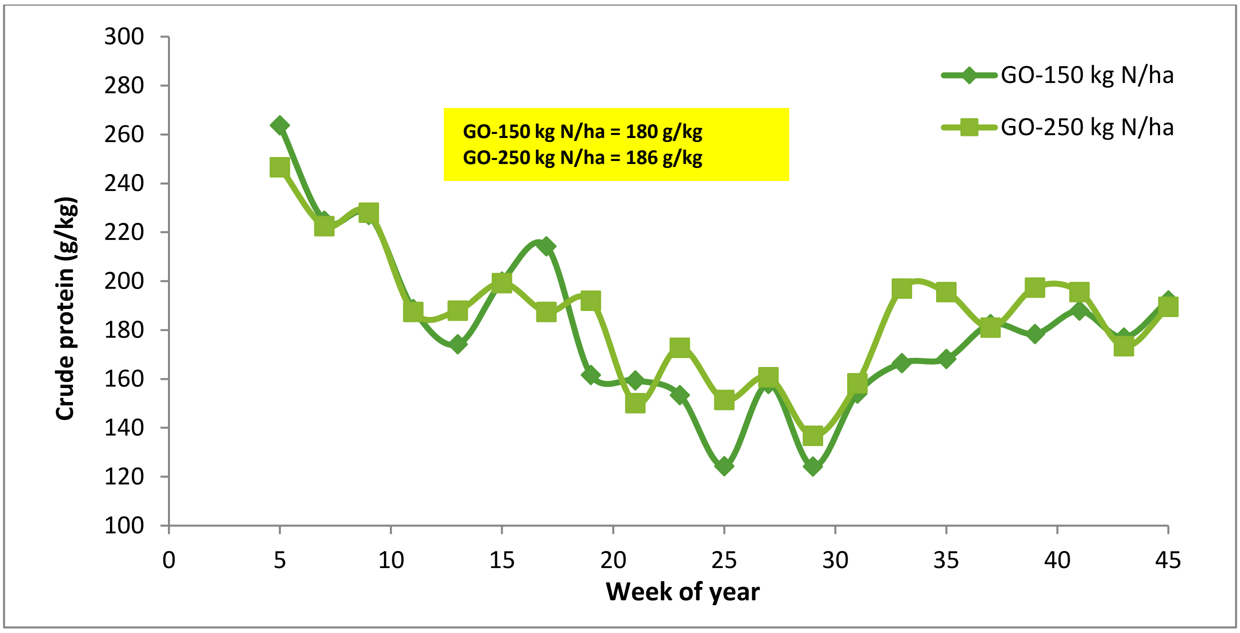

Figure 4.1. Concentration of crude protein in swards receiving 150 and 250kg N/ha

Grass silage crude protein

Grass silage crude protein data from FBA laboratory (Cappoquin, Co Waterford) was used to generate an assumption around crude protein concentrations of grass silage. FBA labs analyse the CP content of 5,000 samples of grass silage per year for farmers and is the largest database in the Republic of Ireland with all major Co–ops supplying samples to the laboratory. The average CP concentration of the grass silage samples over the period 2016 to 2019 was 12.7%.

*4.2.3. **Organic N excretion calculations***

The organic N excretion per cow were calculated based on nitrogen intake by the animal in the form of grazed grass, grass silage and concentrate. Nitrogen in the form of milk produced, calves produced and live-weight gain were assumed to be the outputs. Both calf and live-weight gain were included as outputs within the analysis with the nitrogen content included at 0.029 and 0.024 kg of N per kg of live weight (ARC 1994). Surplus nitrogen was calculated based on inputs minus outputs. In order to calculate the organic N, gaseous losses were deducted based on 10% of the surplus nitrogen (recommended by the EU for Nitrates Derogation applications). Finally, the organic N excretion figure was calculated based on deducting the gaseous losses from the surplus nitrogen.

4.3. Results

Table 4.3 show that the organic N excretion rate per cow has increased over the period 2012 to 2019 from 88 kg to 94 kg per cow. On average over the five year period between 2015 and

2019 the average organic N excretion per cow was 91 kg. Figure 4.2 shows the increases in organic N excretion rate per cow over the period 2010 to 2019.

On average the organic N excretion rate increased by 0.6 kg per cow per year over the period. Nitrogen output per cow increased from 28 to 33 kg per cow over this period, while nitrogen intake at the cow level increased from 126 kg to 138 kg per year. Gaseous losses were assumed to increase across the time period.

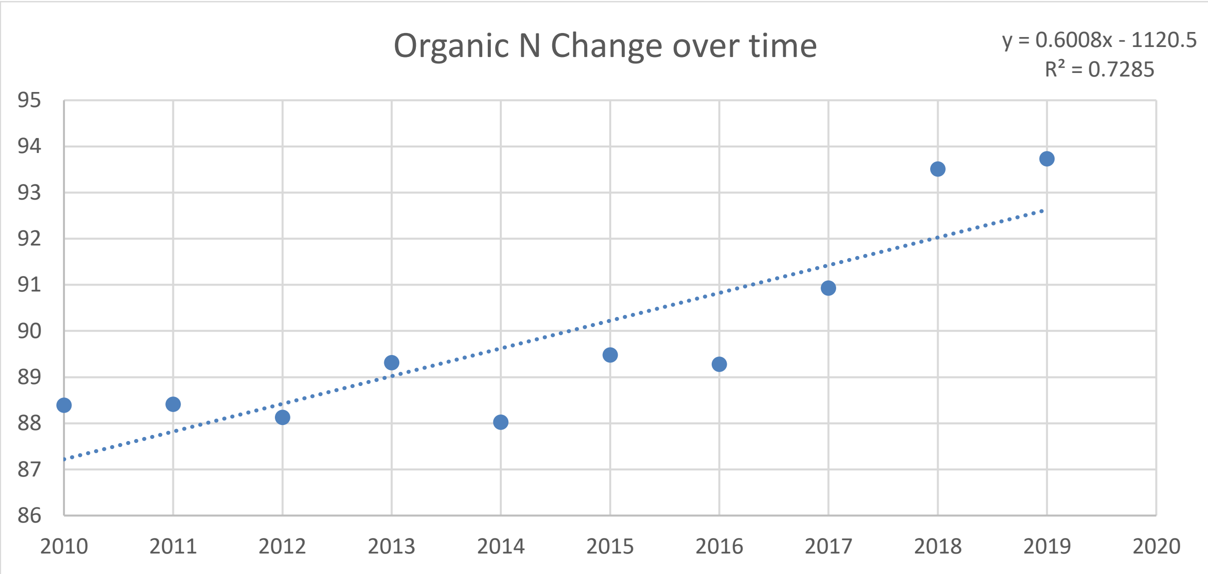

Figure 4.2. Annual increase in organic N excretion rate per cow over the period 2010 to 2019.

Table 4.3. Annual organic N balance and excretion rate per cow (kg N/cow) over the period 2012 to 2019									
		2019	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**
Grazed Grass									
	DM Intake	2,860	2,688	2,795	2,775	2,826	2,682	2,574	2,621
	CP%	18	18	18	18	18	18	18	18
	Nitrogen kg	82	77	80	80	81	77	74	75
Grass Silage									
	DM Intake	1,265	1,179	1,258	1,233	1,248	1,211	1,166	1,192
	CP%	13	13	13	13	13	13	13	13
	Nitrogen kg	26	24	26	25	25	25	24	24
Concentrate									
	DM Intake	1,018	1,196	908	821	794	840	1020	890
	CP%	18.1	18.1	18.1	18.1	18.3	18.3	18.4	18.4
	Nitrogen kg	30	35	27	24	23	25	30	26
Weight gain	Liveweight	40	40	40	40	40	40	40	40
	Nitrogen kg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Calves	Liveweight	45	45	45	45	45	45	45	45
	Nitrogen kg	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Milk									
	Yield Kg	5,615	5,474	5,388	5,088	5,194	4,942	4,973	4,896
	Protein %	3.54	3.48	3.48	3.46	3.50	3.43	3.39	3.36
	Protein kg	199	191	188	176	182	170	169	165
	Nitrogen kg	31	30	29	28	28	27	26	26
Nitrogen	Intake kg	138	136	133	129	130	127	128	126
	Output kg	33	32	32	30	31	29	29	28
	Excretion kg	104	104	101	99	99	98	99	98
	Gaseous kg	10	10	10	10	10	10	10	10
	Organic N kg	94	94	91	89	89	88	89	88

4.4. Organic N banding

Many countries in the EU have a banding system where the annual milk yield per cow in the herd determines the N excretion band for that farm. While countries operate different cut-offs, they generally have a similar approach, where the average milk yield per cow in the herd goes up so does the organic N excretion per cow. For example in the Netherlands, the annual organic N excretion per cow ranges from 99 kg for an average milk yield per cow of 5,500 kg to 131 kg for a cow with a milk yield of 9,500 kg. In Sweden a milk yield of 8,000 kg/cow in a liquid slurry system has an excretion rate of 117 kg of N/cow while the same cow in a solid manure system has an excretion rate of 71 kg N/cow. The French on the other hand have gone for an even more complicated system where both milk yield per cow and the length of the grazing season are included in the calculations. The French system currently has twelve categories that are constantly evolving with organic N excretion ranging from 75 to 126 kg per cow per year. In Ireland up until now, there was just one figure of 85 kg of organic N per cow per year. Therefore, herds that are high yielding and herds that are low yielding are allocated the same organic N excretion rate even though they are excreting substantially different amounts of nitrogen. This creates the potential for increased nitrogen losses in certain circumstances while complying with policy while at the same time restricting cohorts in relation to stocking rate that have much lower nitrogen excretion rates. It could be argued that this policy unfairly restricts herds that milk cows once a day or herds that are more focused on extensive/organic type systems. A system that creates bands and allows farmers to sit in the different bands could be viewed as more equitable. In these situations, farmers would move between the bands as their herd milk yields change. While more complicated to operate the advent of integrated data systems makes it possible to manage a band system.

A banding system was developed based on a tiered system being introduced for Ireland similar to other countries across the EU. The system introduced in this paper has three categories;

Band 1 <4,500 kg
Band 2 4,501 and 6,500 kg,
Band 3 >6,500 kg

The Teagasc National Farm Survey and IBCF databases were used to generate the milk production and milk solids concentrations, number of herds, and the concentrate feed levels in each bands. Average milk yields, milk fat and protein concentrations and concentrate feeding levels were generated for each band from the database. Table 4.4 shows the base assumptions dependent on the band included in the model for each year from 2015 to 2019. Over the 5-years the average milk yield per cow, fat %, protein % and concentrate fed per were:

- 3,714 kg/cow, 4.04% fat, 3.45% protein and 770 kg of concentrate DM fed per cow for Band1;
- 5,428 kg/cow, 4.09% fat, 3.49% protein, 945 kg of concentrate DM fed per cow for Band 2;
- 7,155 kg/cow, 4.01% fat, 3.44% protein and 1,432 kg of concentrate DM fed per cow for Band 3.

Band 1 represents 12.6% and 24% of the milk produced and suppliers on average over the 5 year period, Band 2 represents 70% of the milk produced and 65% of the suppliers and Band 3 represents 17.4% of the milk produced and 11% of the milk and suppliers, respectively.

Table 4.4. Base assumptions included in the development of organic N excretion bands based on an average of 2015 to 2019							
		Representation					
Milk Yield bands		Supplier %	Milk %	Milk Yield kg	Milk Fat %	Milk Protein %	Concentrate Kg DM
<4,500	2015	25	15	3,797	4.0	3.47	711
	2016	30	17	3,717	4.04	3.42	703
	2017	23	12	3,697	4.02	3.44	751
	2018	24	12	3,671	4.05	3.44	948
	2019	18	8	3,687	4.11	3.50	739
4,501-6,500	2015	66	72	5,379	4.02	3.50	807
	2016	63	71	5,336	4.10	3.46	820
	2017	66	71	5,431	4.08	3.48	905
	2018	63	67	5,469	4.12	3.47	1,215
	2019	67	68	5,523	4.15	3.53	980
<6,501	2015	9	13	7,144	3.93	3.43	1,285
	2016	7	12	7,127	4.01	3.41	1,324
	2017	11	17	7,155	3.99	3.44	1,381
	2018	13	22	7,186	4.06	3.44	1,724
	2019	15	24	7,162	4.08	3.49	1,445

Source: ICBF and NFS

Table 4.5 shows the organic N excretion rates for the three bands included in this analysis. As the milk yields increase so, too do the intakes of grass and silage as well as concentrate, and the N excretion rate. As milk yields increase so too does the organic N coming from the animal. The range in this analysis goes from 80 kg of organic N excretion rate for the lowest category to 106 kg for the highest milk yield category with 92 kg of organic N excretion rate being the intermediate category. This analysis suggests that there are approximately 15% of dairy farmers, which have an organic N excretion/cow above the average, and approximately 18% of dairy farmers below the national average N excretion rate of 92 kg/cow. The banding of N excretion rates will not impact the majority of suppliers (~67%), however it will have a significant impact on suppliers with milk production per cow greater than 6,500 kg as they will be required to maintain stocking rates of less than 2.36 cows/ha (N excretion rate of 106 kg/cow). These farmers would require a significant lead in time to allow either increase land area, reduce milk yield per cow or reduce cow numbers.

Table 4.5. Feed budgets, N balances and N excretion rates per cow (kg of N / cow) across three bands based on milk yields of <4,500kg, 4,501kg-6,500 and >6,500kg				
		<4,500kg	4,501-6,500kg	>6,501 kg
Grazed Grass				
	DM Intake	2,292	2,846	3,176
	CP%	18	18	18
	Nitrogen kg	66	82	91
Grass Silage				
	DM Intake	1,147	1,239	1,246
	CP%	12.7	12.7	12.7
	Nitrogen kg	23	25	25
Concentrate				
	DM Intake	770	945	1432
	CP%	18.2	18.2	18.2
	Nitrogen kg	22	28	42
Weight gain	Live-weight	40	40	40
	Nitrogen kg	0.96	0.96	0.96
Calves	Live-weight	45	45	45
	Nitrogen kg	1.31	1.31	1.31
Milk				
	Yield Kg	3,714	5,428	7,155
	Protein %	3.45	3.49	3.44
	Protein kg	128	189	246
	Nitrogen kg	20	30	39
Nitrogen	Intake kg	112	135	158
	Output kg	22	32	41
	Excretion kg	89	103	117
	Gaseous kg	9	10	12
	Organic N kg	80	92	106

There are also GHG emissions implications associated with the different systems and milk yields. In order to get a more comprehensive picture of the associated implications from a GHG emissions perspective an analysis was completed using the Teagasc GHG emissions model (O'Brien et al., 2014) to ascertain the impact of analysis completed for organic N on GHG emissions intensity. This analysis was completed using data from ICBF and the NFS similar to what was used to calculate the organic N excretion rates across milk yield categories. The stocking rates were 2.05 LU/ha, 2.08 LU/ha and 2.12 LU/ha for the <4,500kg. 4501-6,500 kg and >6500 kg milk yield categories. The corresponding chemical nitrogen was 149kg/ha, 181kg/ha and 201kg/ha for the three milk yield categories.

Table 4.6 shows the emissions for the different systems. Total methane and overall GHG emissions increased with milk yield. GHG intensities excluding sequestration reduces as milk yield increases with a dramatic difference between the low category and the medium and high milk yield categories. The inclusion of sequestration counteracts some of the effects and reduces the extreme differences. When sequestration is included the GHG intensity are the same between the mid and high milk yield categories.

Table 4.6. Effect of banding organic N excretion rates on GHG emissions

Milk production per cow	<4,500kg	4,501-6,500kg	>6,500 kg
Methane, kg per cow	95	111	127
Methane belched, % GEI lost	6.93	6.86	6.75
GHG Emissions per dairy cow, t CO_2e /cow	4.64	5.46	6.82
GHG intensity- kg CO_2e per kg FPCM excl Seq	1.28	1.04	1.02
GHG intensity- kg CO_2e per kg FPCM incl Seq	1.03	0.88	0.88

4.5 Summary organic N excretion rates

Organic N excretion rates are increasing over time and will require updates periodically. As milk yield increases organic N excretion rates increases. The introduction of a banding system would allow the organic N excretion rates to better reflect the nitrogen output per cow and its relationship to milk yield. While the average stocking rate of dairy farmers in the band with a milk yield of >6,500 kg is less (2.12 cows/ha) (NFS), individual farms that are stocked higher will be severely affected and would require appropriate lead in times.

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