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Effect of an Agri-environmental Measure on Nitrate Leaching from a Beef Farming System in Ireland

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Abstract

Agricultural Nitrogen (N) management remains a key environmental challenge. Improving N management is a matter of urgency to reduce the serious ecological consequences of the reactive N. Nitrate (NO_3^--N) leaching was measured under suckler beef production systems stocked at two intensities: 1. Intensive, 210 kg organic N ha^{-1} with two cut silage harvests; and 2. Rural Environmental Protection Scheme (REPS), 170 kg organic N ha^{-1} with one cut silage harvest. Three replicate plots of each treatment were instrumented with ceramic cups (8 per plot), randomly placed within each plot at a depth of 1 m to collect soil solution for NO_3^--N at 50 kPa suction to collecting vessels one week prior to sampling. Samples were taken on a total of 53 sampling dates over 3 winter drainage periods (2002/03, 2003/04 and 2004/05). Over the course of the experiment the mean annual soil solution NO_3^--N concentration exceeded the MAC twice out of 15 means (5 treatments over 3 years). The REPS grazing and silage sub treatments had significantly lower mean annual soil solution total oxidized N (TON) concentrations than the respective intensive treatments in years 2 and 3. Annual total NO_3^--N losses over the three years in Intensive and REPS systems ranged from 55 to 71 and 15 to 20 kg N ha^{-1}, respectively. Mean N surpluses in Intensive and REPS systems were 210 and 95 kg ha^{-1}, respectively with the corresponding mean N inputs of 272 and 124 kg N ha^{-1}. The reduction in N inputs under the REPS system results in lower N leaching losses and contributed to a significant reduction in pressures on water quality.

Keywords: Nitrate leaching, drainage, beef farming, REPS, agri-environment, water quality

1. **Introduction**

Improving water quality in Ireland, in particular for the eutrophication in lakes, rivers and coasts, remains one of the key environmental challenges (Fenton et al., 2011; Toner et al., 2005). Among the substances responsible for eutrophication, nitrate (NO_3^--N) leaching from agricultural soils is by far the most important contributor (Nguyen et al., 2010). There has been considerable legislation, at the European and national levels, which has lead to the introduction of the Nitrates Directive (1991/676/EC) and the Water Framework Directive (2000/60/EC). Both of these legislative instruments require mandatory actions and measures to be introduced to ensure good water quality (Stark and Richards, 2008). The 2007-2009 biological surveys (McGarrigle et al., 2010) has shown another slight improvement in overall surface water quality, with 69% of river channel length classified as unpolluted. On the other hand national groundwater quality is still under threat as 40% of the monitoring locations showed 10-25 mg NO_3^- L^{-1}, 16% of the monitoring locations exceeded 25 mg L^{-1} NO_3^- and 3% exceeded 50 mg L^{-1} NO_3^- (Craig et al., 2010).

In Europe, Agri-Environmental Measures (AEMs) were established to reduce agricultural impacts on the environment and positively contribute to environmental protection and enhancement. They were introduced through a number of EU regulations such as 797/85 EC and 2078/92. The implementation of AEMs is compulsory at the national level and was optional for farmers within member states. The Rural Environmental Protection Scheme (REPS) was established in 1994 as Ireland’s AEM. The scheme was designed to financially reward farmers for carrying out their farming practices in an environmentally friendly manner and to ensure good environmental practice on farms. REPS places compulsory limits on inorganic fertiliser N rates, application timing and the overall farm stocking rate must be below 170 kg organic N ha^{-1}. It also contains a large range of other compulsory and optional measures with a particular focus on enhancement of biodiversity. A comprehensive study of the environmental impacts of REPS has been absent in Ireland (Finn and hUallacháin, 2011).

The REPS scheme in Ireland was attractive to farmers, an estimated 31% of Irish farms received REPS payments in 2004 (Connolly et al., 2005). Almost 74% of farms which participate in REPS are in the three dry stock systems, namely Cattle Rearing, Cattle Other and Mainly Sheep (Connolly et al., 2005). Reduced fertiliser N inputs to grazed permanent grassland should lead to decreased NO_3^- leaching rates. Over an 8 year period, NO_3^--N leaching was 38 and 129 kg N ha^{-1} on a clay loam soil (Scholefield et al., 1993) receiving fertilizer inputs of 200 and 400 kg N ha^{-1}. Watson et al. (2000) reported a significant positive relationship between fertilizer N application rate (100-500 kg N ha^{-1}) and load of NO_3^--N leached. Published schemes on NO_3^--N leaching in Irish agricultural system is scarce and the studies highlighted the potential threat of NO_3^--N to surface and groundwater pollution. There has been no evaluation of the efficacy of REPS in reducing nutrient loss to water. Ryan et al (2006) estimated mean NO_3^- and NH_4^+ concentrations of 8.2 and 0.30 mg N L^{-1} leachate, respectively at 1 m bgl (free draining soil) under dairy systems where mean N input and stocking density were 319 kg ha^{-1} and 2.38 LU ha^{-1}. Similar to grass, cereal-growing on recently ploughed grassland on well drained soils receiving 75-100 kg N ha^{-1}, poses a significant risk to water quality from leaching of NO_3^- (Ryan et al., 2001). Farmers and regulators urge the need to improve N recovery in agricultural systems. For example EU directives impose pressure on agriculture to make more efficient use of N. The objective of this study was to examine the effect of reduced animal stocking rate and associated fertiliser N inputs on NO_3^- leaching under suckler beef production on a moderately well drained clay loam soil in Ireland.

2. Materials and Methods

2.1 Study site description

The study was carried out at Teagasc, Grange research centre which is located in Dunsany, Co. Meath, Ireland (53°32` N, 6°31` E) at 60 m above sea level. The research farm focuses on beef and suckler production and is mainly comprised of permanent grassland. The soils on the farm were mapped in detail by Gardiner (1962). The area is underlain by gravely, limestone boulder clay with occasional sorted sands and gravels. The soils are derived from the boulder drift cover and vary between clay loam and clays. The plots investigated comprised of moderately well drained, brown earth, clay loam soils of high base status. The FAO classification of the soil underlying the site is an Orthic Luvisols (Kurz et al., 2006).

2.2 Farming systems

Nitrate leaching was quantified under two suckler beef production systems in the final 3 years of an 8 year agronomic systems experiment. The agronomic systems experiment was conducted from 1997 to 2005. Drennan and McGee (2009) described the agronomic design of the experiment in detail. Spring-calving beef suckler cows were introduced in 2001 and 2002 which consisted of Limousin × (Limousin × Holstein-Friesian), purebred Limousin and purebred Charolais. The suckler beef systems were stocked at two intensities: 1. Intensive: 211 kg organic N ha^{-1}; stocking rate (SR) 1.8 and 1.4 for bull and steer production, respectively and 2. REPS: 170 kg organic N ha^{-1}; SR 1.4 and 1.1 for bull and steer production, respectively. Number of silage harvests was 2 and 1 for Intensive and REPS, respectively. Both treatments were managed as systems and grazing/silage plots were allocated in a randomised block design. A summary of the treatments, system intensity, grassland management and nutrient source applied to treatments was outlined in Table 1.

Animals were grazed on permanent grassland plots from April to October/November depending on weather and soil conditions. The grazing events during the whole grazing period in every year took place for 7, 5 and 4 times at every 4 week interval for grazing only, one cut silage and 2 cut silage, respectively. During the winter period animals were housed in slatted floor sheds and offered grass silage conserved from within their respective systems. Silage was harvested in both systems for feeding during the winter housing period. In the intensive system there were two silage harvests, May and August each year. Silage was harvested in once in the REPS system in late May/early June. The total annual fertiliser and manure N application rates for each system during the 3 years of the study are outlined in Table 1. Manure was applied (33 m^3 ha^{-1}) to the silage plots in spring and summer before or after first cut and after second cut silage and the manure N application rates are shown in Table 1. All plots received recommended rates of P and K fertiliser each year based on annual soil test results.

2.3 Soil solution sampling

Three replicate plots of each treatment were instrumented with ceramic cups (Soil Moisture Inc., California, USA); there were 8 cups per plot inserted at a depth of 1 m having a bentonite seal, 150 mm below ground surface, around the connecting tube. Ceramic cups were randomly placed within each plot as described by Ryan et al. (2006). Soil solution was sampled by applying 50 kPa suction to collecting vessels one week prior to sampling. Samples were taken on a total of 53 sampling dates over 3 winter drainage periods 2002/03 (year 1), 2003/04 (year 2) and 2004/05 (year 3). The samples were stored and transported at 4 °C to the analytical laboratories in Teagasc, Johnstown Castle. Soil solution samples were analysed within 48 hours of sampling for NO_3^--N colorimetrically by hydrazine reduction (USEPA, 1983a) with a Konelab 30 discrete autoanalyzer (Konelab Corporation, Espoo, Finland). Quality checks were also carried out where tolerances for high and low values were within 90% and 10% of top standard.

2.4 Water balance

Meteorological data collected at the experimental site was used to calculate effective rainfall or drainage which is an estimate of the quantity of water that percolates through soil to groundwater. Potential evapotranspiration was calculated using the FAO Penman-Montieth equation (Allen et al., 1998) and this was converted to actual evapotranspiration using an Aslyng scale recalibrated for Irish conditions (Schulte et al., 2005). Effective rainfall was calculated by subtracting daily actual evapotranspiration from daily rainfall.

2.5 Nitrate leaching loads

Load of NO_3^--N leached was calculated using the trapezoidal rule (Lord and Shepherd, 1993). The area under the plot of NO_3^--N concentration against drainage was calculated as the sum areas of the trapezia resulting from successive pairs of sampling occasions

(c_1, c_2 mg L^{-1}) and the drainage volume between sampling occasions (dv mm). The total N leached (kg ha^{-1}) in each sampling interval was: kg N leached = 0.5 ($c_1 + c_2$) dv/100.

2.6 System N balance

A nitrogen balance was calculated for each of the suckler systems. Farm gate N inputs quantified include inorganic fertiliser and concentrated feed; atmospheric deposition was estimated using data from Ryan et al. (2006). Nitrogen outputs measured include animal uptake (live weight gain) and leaching; estimated losses include NH_3 and N_2O. The N surplus was calculated by subtracting total outputs from total inputs.

2.7 Statistical analysis

2.7.1 Analysis of annual average NO_3^--N concentrations in plot drainage water:

The annual average NO_3^--N concentration was analysed using a repeated measures analysis over each of the three years. The data consisted of 45 values for each N type (5 treatments x 3 replicates x 3 years). These aggregated data were not normally distributed. A generalized linear mixed model was fitted that assumed a Gamma (positively skewed) distribution and incorporated a log link and allowed for the repeated measures nature of the data (Littell et al., 1996; Ryan et al., 2006). An appropriate correlation structure was used to describe the relationship among the repeated values across years.

2.7.2 *Analysis of weekly average N concentrations in plot drainage water:*

Within each year a repeated measures analysis on the average concentration (over 8 cups) per plot per week, using the modelling strategy described for the annual concentration data, was performed.

2.7.3 Analysis of annual NO_3^--N loads leached

The annual calculated NO_3^--N load leached was analysed using a repeated measures analysis over each of the three years. The data consisted of 45 values for each N type (5 treatments x 3 replicates x 3 years) and the data were analysed as outlined for the analysis of annual average N concentrations in plot drainage water above.

Statistical analysis was carried out using the GLIMMIX procedure in the SAS/STAT software Version 9.1 of the SAS System for Windows (SAS Institute Inc., Cary, NC, USA). Means predicted from models with a log link are back-transformed to give means for presentation on the scale of measurement. A Least Significant Ratio (LSR) is used to compare significant differences between the mean treatment soil solution NO_3^--N concentration and NO_3^--N load leached. If the ratio of the larger mean to the smaller mean is greater than the LSR, then the two means differ at the 0.05 (or as specified) confidence level.

3. **Results**

3.1.1 Rainfall and effective rainfall

Cumulative rainfall in 2002, 2003 and 2004 was 1066, 743 and 864 mm per year, respectively. The average annual air temperature was very similar during the year 2002, 2003 and 2004; and was 10.6, 9.9 and 10.2 °C, respectively. The long term (1971-2001) average annual rainfall and temperature at the site are 849 mm and 9.1 °C. In contrast to the cumulative annual rainfall, the cumulative rainfall patterns during the 3 winter drainage periods were broadly similar, with 439, 490 and 430 mm in years 1, 2 and 3, respectively. There were larger differences apparent in the calculated drainage volumes over the 3 winter period with 303, 226 and 251 mm drainage during year 1, 2 and 3, respectively (Fig. 1). The majority of drainage was calculated to have occurred during the ceramic cup sampling period with only small amounts occurring outside these sampling periods.

3.1.2 Annual soil solution NO_3^--N concentrations

The mean annual NO_3^--N concentrations observed within all the treatments ranged 2.1 to 8.4, 1.7 to 20.3 and 0.7 to 15.5 mg N l^{-1} in years 1, 2 and 3, respectively. The mean annual soil solution NO_3^--N concentration exceeded the EU MAC twice out of a total of 15 means (5 treatments by 3 years). There was a significant ($p<0.01$) year by treatment interaction observed in the NO_3^--N data. Significant differences between the mean annual soil solutions NO_3^--N concentrations are summarised for all treatments in Table 2. No significant differences were observed within the mean annual NO_3^--N between any treatments in year 1. Within the grazing only treatments T4 had a significantly ($p<0.01$) lower mean annual soil solution NO_3^--N concentration than T1 in years 2 and

3. Mean annual NO_3^--N concentrations within the silage areas were significantly lower in T5 than in both T2 and T3 for years 2 and year 3. The LSRs were slightly lower in years 2 and 3 (3.5 and 3.7, respectively) compared to 4.0 in year 1.

3.1.3 Mean weekly soil solution NO_3-N concentrations

The temporal variation of weekly soil solution NO_3^--N concentrations is presented in Figure 3a to 3c. Within the grazed only treatments, T4 had consistently lower mean weekly NO_3^--N than T1. Over the three years of the study the mean weekly NO_3^--N concentrations in T4 were mostly <5 mg L^{-1}, on 4 sampling dates in year 2 the concentrations were > 5 mg L^{-1}. Whereas in T1 the mean weekly NO_3^--N concentrations over the 3 years was generally between 5 and 10 mg l^{-1}, the mean on 5 dates was <5 mg L^{-1} and on 4 dates >10 mg L^{-1}.

Nitrate leaching was generally lower in the silage area in comparison to the grazed only. In T2 the range of mean weekly NO_3^--N concentrations varied over the three years of the study; the ranges were <5 mg N L^{-1} year 1, 5-10 mg N L^{-1} in year 2 and >10 mg N L^{-1} in year 3. The same pattern was also evident in T3 where the mean weekly NO_3^--N concentrations ranged <5 mg N L^{-1} in year 1, >10 mg N L^{-1} in year 2 and 5-10 mg N L^{-1} in year 3. Significant interactions were observed between sampling date and treatment in year 1 ($p<0.0001$), year 2 ($p<0.05$) and year 3 ($p<0.01$). The number of sampling dates, within a year, on which the mean soil solution NO_3^--N concentrations were significantly different between selected treatments are summarised in Table 3.

Within the grazed only plots, the mean weekly NO_3^--N concentration was significantly lower in T4 compared to T1 on 55% of the sampling dates in year 1, 10% of the sampling dates in year 2 and 60% of the sampling dates in year 3. Overall T4 had significantly lower mean NO_3^--N concentrations than T1 on 43% of all sampling dates (23 of 53 dates). For the silage and aftermath grazing treatments, T5 had significantly lower weekly NO_3^--N concentrations than T2 on 11, 38 and 95% of the sampling dates in years 1, 2 and 3, respectively. In total the mean weekly NO_3^--N concentrations in T5 were significantly lower than T2 on 51% of all sampling dates. Weekly mean NO_3^--N concentrations were significantly lower in T5 than T3 on 16, 100 and 100% of the sampling dates in years 1, 2, and 3, respectively. Over all mean weekly NO_3^--N concentrations were significantly lower in T5 than T3 on 70% of all sampling dates.

3.1.4 Annual loads of NO_3^--N leached

The calculated mean annual NO_3^--N load leached (kg N ha^{-1} yr^{-1}) by treatment and year, the annual least significant ratio and the statistical summary comparing treatment means are presented in Table 4. In year 1, the mean annual NO_3^--N loads leached ranged from 6.6 to 24.2 kg N ha^{-1} y^{-1} with being 7-24 kg N ha^{-1} y^{-1} in Intensive and 7-10 kg N ha^{-1} y^{-1} in REPS. In year 2, the mean annual NO_3^--N loads leached ranged 3.5 to 44.9 kg N ha^{-1} y^{-1}; leaching under REPS treatments were <10 kg N ha^{-1} y^{-1} and Intensive treatments were >10 kg N ha^{-1} y^{-1}. In year 3, mean annual NO_3^--N loads leached ranged from 1.9 to 41.4 kg N ha^{-1} y^{-1}; the REPS treatments had leaching losses <5 kg N ha^{-1} y^{-1} whereas Intensive treatments had >15 kg N ha^{-1} y^{-1}. Over the 3 years of the experiment, the total load of NO_3^--N leached ranged from 15 to 70.7 kg N ha^{-1} y^{-1}. The 3 year total losses from the two REPS treatments were each <20 kg N ha^{-1} y^{-1} and the Intensive treatments were each >50 kg N ha^{-1} y^{-1}. Total NO_3^--N leached over the three winter drainage periods were significantly lower in REPS compared to Intensive (p=0.012). The average for different managements over the three years loads of NO_3^--N leached were 63.1 and 17.3 kg ha^{-1} (SED=14.9) for intensive and REPS, respectively.

There was a significant year by treatment interaction ($p<0.05$). In year 1, no significant differences were observed between the treatments mean NO_3^--N loads leached (Table 4). Within the silage + grazing treatments, mean NO_3^--N loads leached under T5 were significantly lower than T2 in year 2 ($p<0.05$), year 3 ($p<0.01$) and T5 was significantly lower than T3 ($p<0.01$) in both years 2 and 3 (Table 4). In the grazed only treatments, in year 3, T4 had significantly lower mean NO_3^--N loads leached than T1.

3.1.5 System N balance

Total N inputs and outputs were much higher in the intensive system than the REPS. Over the 3 year period inputs ranged from 253 to 288 kg N ha^{-1} and 124 to 125 kg N ha^{-1}, respectively in intensive and REPS systems (Table 5). Lower N inputs in REPS system resulted in a lower losses of N by volatilisation, denitrification and leaching (Table 5). The annual N surpluses were approximately 50% lower in the REPS than the Intensive systems. The REPS system appeared to have shown a significantly lower N surplus in the environment. Even though the mean output in the Intensive system was higher than the REPS system, the N output via live weight gain were higher in Intensive systems only by 2-3 kg ha^{-1}.

4. **Discussion**

4.1 Annual NO_3^--N leaching in REPS and Intensive systems

The observed NO_3^--N leaching losses from all the treatments in this study are generally lower than the EU MAC. Over the course of the experiment the mean annual soil solution NO_3^--N concentration exceeded the MAC twice out of 15 means (5 treatments over 3 years). The moderately well drained clay loam soil would not be as susceptible to NO_3^--N leaching and even under high annual fertiliser inputs of up to 245 kg N ha^{-1}. Similar soil solution NO_3^--N concentrations between treatments in year 1 could be attributed to the higher drainage in this year than other two years; and the residual NO_3^--N effects from the previous years. However, the significant differences in soil solution NO_3^--N between treatments in the latter two years of the study (Year 2 and 3) rather indicate the consistency in higher NO_3^--N leaching under Intensive system than the REPS. There was an association between N fertiliser input and mean annual NO_3^--N concentration but this was not significant (p=0.007). The relationship between fertiliser input and NO_3^--N leaching is probably confounded by a variation in stocking rate between the treatments. The stocking rate in Intensive system was 0.25 higher than the Extensive system (Drennan and McGee, 2009). Higher stocking rate would require higher N inputs which will eventually increase N leaching to groundwater. However, impact of grazing and N management practices on N leaching in grazing system is complicated by many factors: site weather conditions, sources of N (organic vs inorganic), N application time and grazing intensity (Huebsch et al., 2013). **In this study in 2002/03 NO_3^--N leaching in T2 and T3 was acceptable but not in the later years (Table 4). This could be attributed to high rainfall in the immediately previous year which have flushed out soil pore water NO_3^--N to groundwater and reduced NO_3^--N leaching in the following year.** High rainfall events coincide with major mobilisation of NO_3^--N (Drew and Hotzl, 1999). Bartley (2003) showed that groundwater NO_3^--N concentrations were highest in the areas of highest organic N loadings. Switching application time can significantly increase N use efficiency and thus can reduce NO_3^--N leaching (Huebsch et al., 2013). Increased grazing intensity can increase NO_3^--N leaching in the vulnerable soil conditions (Huebsch et al., 2013). With regards to all these aspects of N management and animal number, the REPS system has higher potential than the Intensive system to reduce NO_3^--N leaching.

Participation in the REPS scheme by farmers increased steadily to 45% of the total farms in 2006 after its initiation in 1994. The REPS systems appeared to have shown a significant reduction in total NO_3^--N leaching over the three years. Total annual losses of NO_3^--N over the three years in various managements ranged from 55- 71 kg N ha^{-1} under Intensive system and from 15-20 kg N ha^{-1} under REPS system. This reduction in NO_3^--N leaching implies that the REPS system can be an environment friendly beef production system in Ireland. Lawes et al. (2000) reported that reducing fertiliser N use reduces the N surplus in beef systems. However in beef systems, the reduced stocking density and fertiliser N in an extensive system do not affect the performance of individual animals. So in accord with previous findings, Peyraud and Astigarraga (1998) suggested that lowering the levels of N fertiliser with a concurrent reduction in stocking density reduces N losses of ruminants with little or no change in their nutrition or in individual performance. Drennan and McGee (2009) found a similar performance of individual bull in two systems: 1) Intensive (stocking density 0.56 with fertiliser N 211 kg ha^{-1}) and 2) Extensive (stocking density 0.69 with fertiliser N 97 kg ha^{-1}), indicating that substitution of fertiliser N with additional land would not affect the beef production. Their Extensive system was compatible with the REPS systems in this study with regards to N losses to the environment. After a review of available publications on the impact of REPS on water quality, Finn and hUallacháin (2011) concluded that REPS system appears to have shown very significant improvements in the management and storage of nutrients and agro-chemicals, which would contribute to a significant reduction in pressures on water quality. The leached N concentrations were generally below the MAC and overall leaching was substantially lower than the IPCC (30% default value).

The limits placed on farmers by the REPS scheme could be seen as reducing the farmers potential for innovation as they have to operate within stringent fertiliser and stocking rates. The scheme was attractive to less intensive farmers who could operate within these limits due to the reduced productivity on their farms. This input control based agri-environmental policy pays farmers for the completion of actions rather than the benefits that arise from actions. Input control policies are often viewed with resentment and put farmers off participation in such schemes (Vickery et al. 2004). The rewarding of farmers for performing actions can reduce rather than promote motivation and innovation (Deci et al. 1999). At the EU level there has been a moved towards results oriented agri-environmental schemes which encourage results or outcomes rather than actions or behaviours. These result oriented schemes would reward farmers for the provisions of environmental goods and services but they have two limitations. Firstly the difficulty of developing the monitoring indicators to evaluate schemes against and secondly there is an increased risk of the scheme to the farmer (Burton and Schwarz 2013). The financial incentives linked to results oriented schemes directly links to the desired environmental objectives but encourage innovation for the farmer to choose the most efficient way to achieve the objectives. The move to results oriented agri-environmental schemes has been shown to be cost effective (Matzdorf and Lorenz, 2010). For example catchment level reduction of N surpluses could be achieved through cooperative incentivisation as part of the results oriented scheme.

4.2 System N balance

In Irish grassland system, studies have shown that annual N surpluses increased with increasing N inputs but recovery in products were declined (Humphreys et al., 2008). This Intensive grass-based farming contributes to large inputs of fertilizer N and thus indicates the potential risk of NO_3^--N delivery to groundwater and surface. More efficient N use is involved lower N inputs and in particular lower N concentrations in grazed herbage (Humphreys et al., 2008). In terms of the N surplus (input - output), REPS system had significant reduction in the environmental NO_3^--N loads. Drennan and McGee (2009) reported N surplus of 216 and 95 kg N ha^{-1} with an Intensive (216 kg N ha^{-1}) and Extensive (97 kg N ha^{-1}) systems, respectively which was in agreement with the present study. The relatively lower N inputs in REPS system resulted in a lower N outputs than the intensive systems, because N losses by physico-chemical and biological processes were lower in REPS (Table 5). Therefore, REPS system had shown the high potential to a reduced N delivery to the environment. The estimated N input data in the Intensive system were comparable with the previous findings of beef farming in Ireland. Treacy et al. (2008) estimated the mean fertilizer N application rate of 223 kg ha^{-1}. The N surplus data in the Intensive system was also in agreement with the other studies carried out in Irish grassland system. In Europe, grass based animals excrete 80%, on average, of the N that they consume (Oenema, 2011). Jahangir et al. (2012) estimated an N surplus range of 137-263 kg N ha^{-1} in Irish grazed grassland systems. From a survey in 21 dairy farms during 2003-2006, Treacy et al. (2008) estimated the mean N surplus of 232 kg N ha^{-1}. The lower rate of N surplus in REPS demonstrates the potential of the system to be a sustainable beef production practices with a corresponding low N polluted environment. The low N release in the environment in turns will help reduce eutrophication in lakes, rivers and coastal waters.

Conclusion

The REPS system significantly reduced N use and the total NO_3^--N leaching over the study period. The REPS grazing and silage sub treatments had significantly lower mean annual soil solution NO_3^--N concentrations than the respective intensive treatments in years 2 and 3. The reduced stocking rate and fertiliser inputs in REPS significantly reduced NO_3^--N leaching on this site. Mean N inputs and surpluses were significantly lower in REPS than the Intensive system. This reduction in NO_3^--N leaching implies that the REPS system can be an environmentally friendly beef production system. Therefore, the REPS system can be considered as an improved N management system that will help achieve and maintain the 'Good Ecological Status of Irish Water Bodies' and thus the target of EU Water Framework Directive and Nitrate Directive.

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Table 1 Summary of the treatments, Stocking rate (No. animal ha^{-1}), system intensity, grassland management, grazing events (No. grazing time per year), nutrient source and rates applied (kg ha^{-1}) to each treatment

Treatment	Intensity	Stocking rate	Grassland management	Grazing events	Nutrient applications					
					Fertiliser			Manure		
					Y1	Y2	Y3	Y1	Y2	Y3
T1	Intensive	1.8 (bull);	grazed only	7	269	188	212	-	-	-
T2	Intensive	1.4 (steer)	cut once for silage, grazed	5	247	222	273	129	86	102
T3	Intensive		cut twice for silage, grazed	4	220	245	245	129	86	102
T4	REPS	1.4 (bull);	grazed only	7	57	57	57	-	-	-
T5	REPS	1.1 (steer)	cut once for silage, grazed	5	114	114	114	98	70	102

Table 2 Summary of the Least Significant Ratio comparison of individual treatments, identifying the year (Y) when the mean annual soil solution NO_3^--N concentrations were significantly different

	Treatment				
Treatment	T1	T2	T3	T4	T5
T1					
T2	n.s				
T3	n.s.	n.s.			
T4	Y2 & 3	Y3	n.s.		
T5	Y2 & 3	Y2 & 3	Y2 & 3	n.s.	

n.s. no significant difference between mean treatment annual TON concentration.
Annual LSRs were 4.0(Y1), 3.5 (Y2) and 3.7 (Y3).
Y signifies the year when the mean annual soil solution TON concentrations were significantly different (P<0.01)

Table 3 Comparison of the number of sample dates (%), within a year, that the mean soil solution NO_3^--N concentrations above the specified LSR for the following comparisons. a. T4 and T1, b. T5 and T2 and c. T5 and T3 and the total number of sample dates each year

Treatment comparison	**Year 1 %)**	**Year 2 (%)**	**Year 3 (%)**	**Total**
a. T4 < T1	55	10	60	23
b. T5 < T2	11	38	95	27
c. T5 < T3	16	100	100	37
L.S.R.	3.8	3.9	3.8	
Probability	<0.0001	<0.05	<0.01	
No. of sampling dates	19	13	21	53

Table 4 Mean annual NO_3^--N load leached (kg N ha^{-1} y^{-1}) by treatment and year, the annual least significant ratio and the mean annual leaching load statistical summary comparing the means of T4 and T1; T5 and T2; and T5 and T3

	Year				
Treatment	1	2	3	Total	FracLeach (%)
T1	24.2	13.0	17.6	54.8	8.2
T2	8.7	13.8	41.4	63.9	6.0
T3	6.7	44.9	19.1	70.7	6.9
T4	6.6	8.4	4.6	19.7	11.5
T5	9.6	3.5	1.9	15.0	2.5
LSR†	4.2	3.7	3.7	2.9	2.8

	Year			
Statistical comparisons Treatment	1	2	3	Total
T4 v T1	n.s.	n.s.	*	n.s.
T5 v T2	n.s.	*	**	*
T5 v T3	n.s.	**	**	*

†Least significant ratio; If the ratio of the larger mean to the smaller mean is greater than the LSR, then the two means differ significantly at the reported p-value; Treatment means are significantly different $p<0.05$ (*) and $p<0.01$ (**)

Table 5 Comparison of the nitrogen balance for the Intensive and REPS beef suckler systems over the 3 year study period

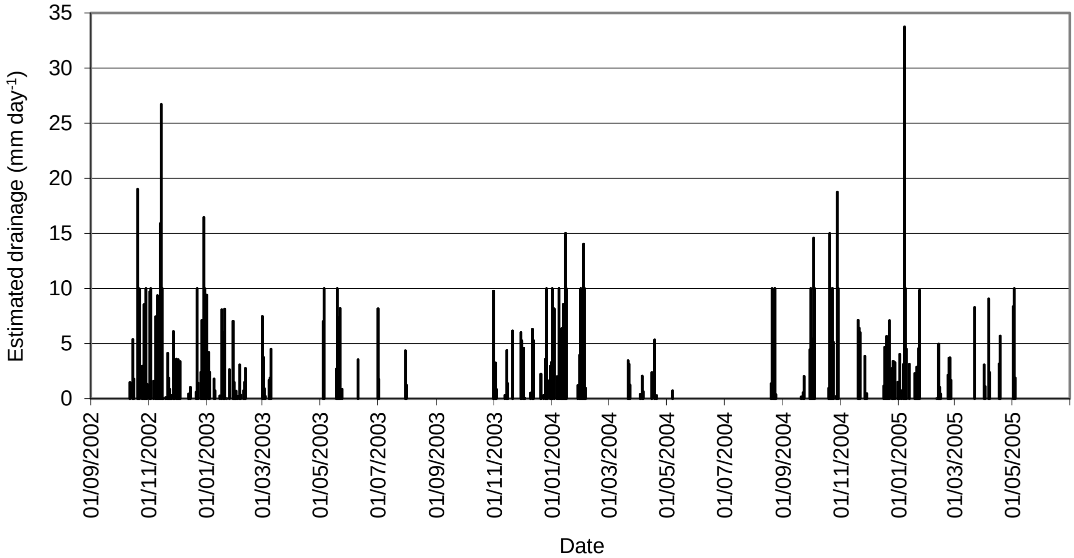
	Intensive			**REPS**		
Inputs	Y 1	Y 2	Y 3	Y 1	Y 2	Y 3
Fertiliser (kg N/ha)	248.3	214.0	235.7	90.1	90.1	90.1
Concentrate feed (kg N/ha)	30.5	30.5	31.6	24.5	24.9	26.0
N deposition (kg N/ha)*	9.0	9.0	9.0	9.0	9.0	9.0
Total Inputs (kg N/ha)	288	253	276	124	124	125
Outputs						
Animal live weight gain (kg N/ha)	11.4	12.0	13.0	9.2	9.6	10.6
Ammonia volatilisation (kg N/ha)**	28.8	25.3	27.6	12.4	12.4	12.5
Denitrification (kg N/ha)** *	3.1	2.7	2.9	1.1	1.1	1.1
Leaching (kg N/ha)	13.2	23.9	26.0	8.1	6.0	3.3
Total Outputs	58.5	63.7	66.7	31.0	28.7	27.3
N not accounted for (input - output)	229.3	189.8	209.6	92.6	95.3	97.7

*Calculated according to Ryan et al., 2006; **Calculated as 10% of total input; ***Calculated according to the IPPC, 1.25% of total N fertiliser input

Figure 1 Temporal variation of estimated daily drainage (mm d^{-1}) from 01/09/02 to 30/06/05.

Figure 2a-2c Temporal variation of mean weekly soil solution NO_3^--N concentration (mg l^{-1}) in year 1 (a) year 2 (b) and year 3 (c) for T1 Intensive grazing (■), T2 Intensive one cut silage + grazing (▲), T3 Intensive two cut silage + grazing (◆), T4 REPS grazing (☐) and T5 REPS 1 cut silage + grazing (△).

Fig. 1


Estimated drainage (mm day-1)
35
30
25
20
15
10
5
0
01/09/2002
01/11/2002
01/01/2003
01/03/2003
01/05/2003
01/07/2003
01/09/2003
01/11/2003
01/01/2004
01/03/2004
01/05/2004
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01/09/2004
01/11/2004
01/01/2005
01/03/2005
01/05/2005
Date

Figure 2a Year 1

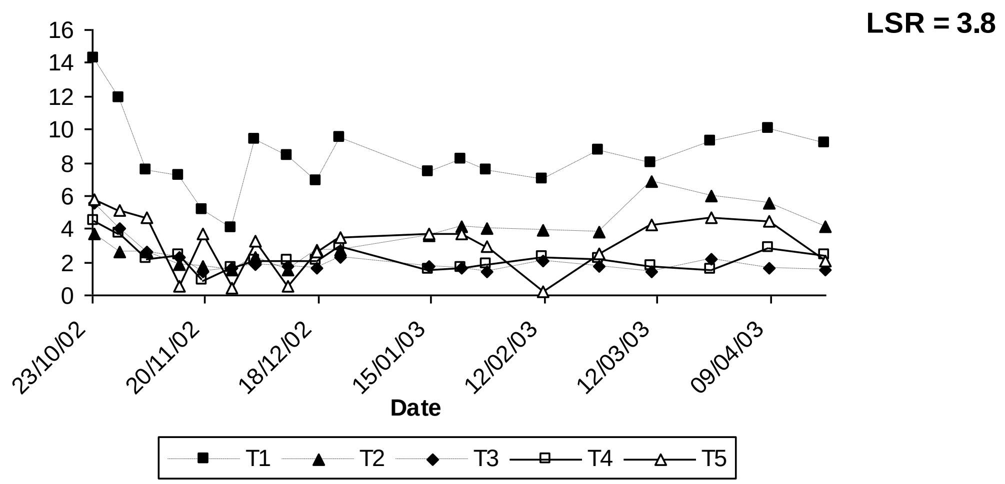

Figure 2b Year 2

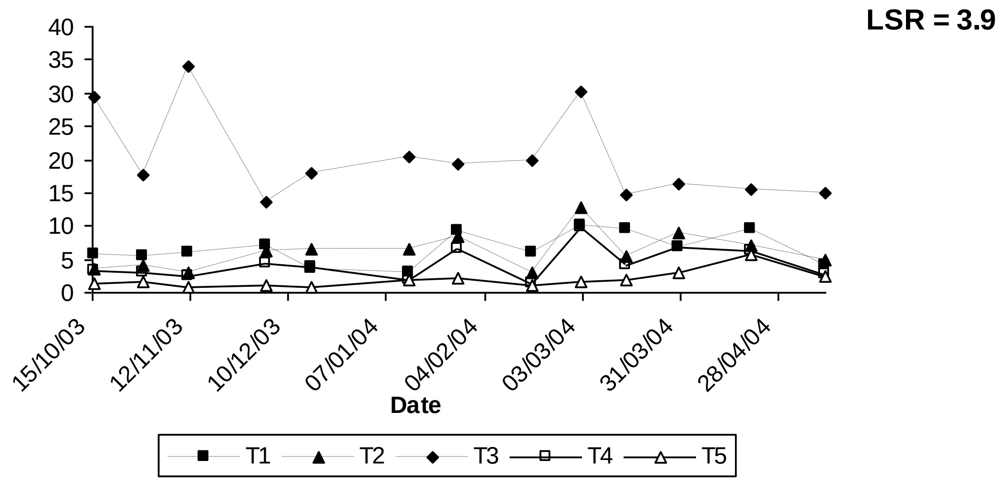

Figure 2c Year 3