Identification and mitigation of the environmental impacts of out-wintering beef and dairy cattle on sacrifice areas

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Executive summary

Out-wintering cattle offers a number of economic benefits compared to housing over the winter months. However, out-wintering may have undesirable consequences, mainly in terms of air and water pollution. In addition, there are a number of other issues related to out-wintering, specifically related to economic impact, animal health and welfare and public safety. Various studies have been commissioned to analyse some of these impacts. This research project has extended these to cover the use of grass sacrifice fields and to explore options for mitigating negative environmental effects of out-wintering. It has three main objectives, namely:

1) to identify parameters that quantify the impacts of out-wintering cattle in social, economic and environmental terms;
2) to establish the sensitivities of impacts from out-wintering, which emerge from various bio-physical and management strategies; and
3) to evaluate the barriers and potential for adoption of strategies to mitigate against these negative impacts

In order to meet these objectives a range of approaches were employed within a multi-disciplinary team. Specifically, 6 farms were recruited to conduct monitoring over a two-year period (2009/2010) & (2010/2011). A range of stocking intensities and feeding systems were employed on these sites and environmental effects were compared against a similar control field within the same farm boundary. Environmental data collected covered the main pollutants to air (nitrous oxide, carbon dioxide and methane emissions), water (N-leaching, phosphate loss and sediment loss) and soil (poaching, compaction and erosion). This was coupled with long term economic records for the 6 sites to understand labour and other fixed costs. This was complemented by a series of workshops on outwintering with farmers in a number of locations to identify both the perceived risks to outwintering and the mitigation measures they would be most likely to adopt.

Monitoring, economic and social data were used to parameterize a series of environmental and bio-economic models. The aims of these models was to examine the sensitivities of the sacrifice system to environmental and economic parameters under the variable weather effects experienced within the winter period. A range of management scenarios were explored with these models, which were predominantly identified by workshops with farmers which ran in the third year of the project (2012/2013). It was felt that farmer-led scenario development would help to encourage uptake of best practice measures. These scenarios covered pre and post sacrifice, as well as options for management during the sacrifice period.

i) the impact of site choice for sacrificing a field: Nitrous oxide emissions, relative to organo-mineral soils, are greater under both dry and wet weather conditions, but less under average conditions. For organo-mineral soils, soil texture had the greatest influence on leaching losses of N, with ammonia and nitrous oxide emissions being less responsive. Generally most nitrogen was lost from free-

draining sandy soils, irrespective of the prevailing weather conditions. Gaseous losses of N were smaller from soils with greater clay contents.

ii) Management of water pollution via field drains: This study has shown that outwintering of beef and dairy cows will lead to significant levels of water body pollution by ammonium, phosphorus and other particulate contaminants. Such pollution arises due to rapid transport of components of deposited excreta to tile drains through macropores in saturated soil during or after rainfall. Saturated soil conditions arise around the periphery of any field areas which have become compacted due to trampling by animal hooves, and this situation is almost inevitable during outwintering. Saturated soil can also arise in a second situation after prolonged rainfall if the tile drainage system is inadequate so in effect the water table rises to the surface. In this situation, there is a significant additional level of pollution further to that arising from soil compaction due to trampling. It is very obvious when this second situation arises as it is associated with surface runoff and ponding.

iii) the impact of sacrificing a field on farm level economics: The profitability of suckler cattle herds with out-wintering management is particularly sensitive to increasing feeding cost and heifer rearing/purchasing cost that can negatively affect the feeding levels and hence the environment, body condition score and animal welfare. Results show that in the no-outwintering scenario purchased concentrate and forage as well as pasture grazing are the main sources of energy for the optimum number of animals. Winter, where the grazing of the pasture area is restricted in winter months, more forage was purchased to cover the deficit. By increasing stocking density more feed was purchased in winter and even in summer months and also aftermath grazing was necessary to provide required nutrition for the animals

iv) the impact of post-sacrifice treatment of the field: The highest risk period emerges in the four months after sacrifice (1 April – 31 July) and N-losses are minimised if farmers reseed rather than rely on natural regeneration. In contrast, with ploughing and reseeding with grass, the nitrogen losses associated with conversion to arable were little different from those arising if the existing grassland was maintained and grazed over the summer.

v) the impact of intensifying activity at the field level: Losses associated with outwintering show a linear response to increasing stocking rate, but in numerical terms, the amount of additional N lost is relatively small. Increasing the stocking rate by 117% from 1.15 cattle per hectare to 2.50 cattle per hectare increases the total amount of N lost by ~5.5 kg ha^{-1}, which is just under a 9% increase.

Recommendations

Sacrificing an area requires planning and management to minimise the environmental damage from outwintering cattle. Increasing pressures on costs at the farm level will lead to the continuance of this practice within UK farming. The main areas of concern relate to choice of field, choice of stocking density, and feeding management. We therefore suggest key areas based around good planning for the farmer and possible future strategies for research, policy and support.

Monitoring environmental impact during the winter is challenging given the possibility of extreme temperatures. However, we have developed a number of protocols to ensuring both robust monitoring and attribution of pollutants. Further work would investigate the capture of emissions of N_20 through insulated chambers to meet the extremes of weather. In addition, this work would ideally be referenced against indoor systems, which offer more control over environmental parameters. Policy makers and researchers are recognising the need to address dual objectives, or at least to understand the trade-offs between environmental damage and economic performance. In this research we explored scenarios which required joining up of results between environmental and bio-economic modelling as a means to address this research need.

A range of best practice management measures were also identified and then tested with farmers in a second round of workshops in the final year (2013/2014) to assess their likelihood of adoption. The most attractive to the farmers were:

1. *Provision of visual soil assessment aids:* Soil types are critically important in affecting the level of damage within a sacrifice area and we have developed a visual guide to understanding soil type in relation to sacrificing a field.

2. *Visual poaching assessment aids:* A method was developed and tested to objectively measure the amount of poaching within a particular area. We are exploring options for linking this to mobile phone camera technology.

3. *Drainage management*: Outwintering should not take place in any field which is subject to frequent ponding or surface runoff due to the inadequacy or degradation of the tile drainage system. Misiewicz (2014) has described measures for inspecting and refurbishing old field drainage systems. This might allow outwintering in a field previously unsuitable due to frequent ponding.

4. *Potential for rainfall collection and monitoring:* In a field in which ponding occurs infrequently, there would be a benefit from recording rainfall and moving cows out of the field if the weighted mean past rainfall reaches a certain value. Only a small number of farmers (from a sample of 90) were actively recording rainfall. Investment in both rain collection equipment and provision of 'ready-reckoner' type cards or software may be beneficial to controlling pollution in a sacrifice area.

Note also that weather provides context for these results and strategies need to adjust for extreme wetter winters. This may raise the issue of providing temporary shelter or the use of pads/webbing to minimise damage. However, this is outside the scope of the present project.

Opportunities for further work

We utilised a novel technique for objectively identifying the level of poaching within a particular level. In discussion with farmers, it was felt that this would be potentially useful and could be actionable through the use of mobile phone technology.

A simple spatial model of the field and herd dynamics was developed using rule based methods. The aim was to provide a visual assessment of decisions and weather effects on economic and environmental parameters. Further work is needed to link to the bio-economic models developed for this project to indicate long-term financial performance and, hence, address the need for dynamic these with environmental damage, stocking density and welfare tradeoff indicators at the field level..

1.0 Objectives

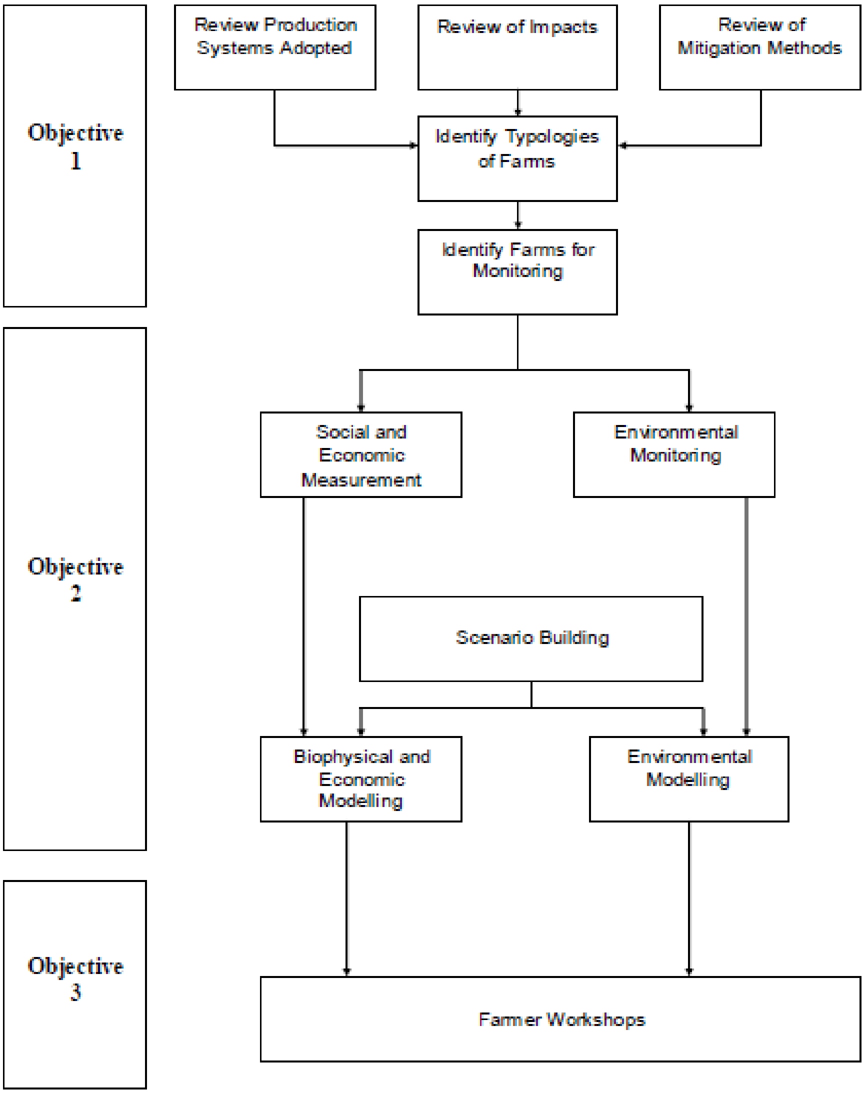
1) to identify parameters that quantify the impacts of out-wintering cattle in social, economic and environmental terms;

2) to establish the sensitivities of impacts from out-wintering, which emerge from various bio-physical and management strategies; and

3) to evaluate the barriers and potential for adoption of strategies to mitigate against these negative impacts

In order to achieve the objectives, a multi-disciplinary approach was used, with each aspect of the project being conducted as outlined in Figure 1.

Figure 1: Research plan and corresponding objectives



2.0 Methods

Objective 1: To identify parameters that quantify the impacts of out-wintering cattle in social, economic and environmental terms

i) Literature review

Key parameters were identified through a review of the literature and then agreed under discussion with Defra and Natural England. The literature review was completed (and previously submitted to Defra within the first year report). This work on sacrifice fields is entwined within a number of high profile policies related to climate change, air and water pollution as well as soil.

The farm practices survey (Defra, 2008) found high numbers of English and Welsh livestock farmers were conducting some form of outwintering of cattle, the most prevalent being both less favoured areas (LFA) grazing farms, where 88% of farmers claimed to have conducted some form of outwintering, and 70% of lowland grazing farms also conducted some form of outwintering. This falls to 46% for dairying enterprises. On average 26% of holdings who outwinter do so on sacrifice fields. The most likely to outwinter are medium to smaller farms, where incomes are lower and managing costs within the system are a priority.

Grassland livestock production causes a number of potentially serious environmental problems. These encompass water, air and soil degradation issues and can be framed in terms of the UK Government's growing interest in averting the impact of climate change. A variety of mitigation measures are available for livestock policy. However, these will have spin-off impacts and are politically sensitive, for example reducing stocking densities in remote rural areas may not be socially desirable. The role of grasslands and how they are managed is also proving particularly important to the climate change debate as they have potential to offset some emissions of carbon. Consequently, management of grasslands over the winter period is critically important to maximising sequestration of carbon. In addition, the preservation of grasslands is becoming increasingly visible within recent debates on reform of the Common Agricultural Policy.

Outwintering on grassland can be classified with respect to animal type and approach to field restoration. Generally, animals put out to sacrifice fields cover various categories of dairy, dairy beef and suckler beef animals. Grassland on which they outwinter could be classified as semi-natural grazing or reseeded grass, where the grass is naturally regenerated or restored respectively. A typology of outwintering systems (provided in the year 1 report) gave a total of 27 possible types of grazing sacrifice strategies dependant on animal type and approach to field restoration.

Generally, the literature review found large gaps in our understanding towards outwintering on sacrifice fields and work in other areas, e.g. grassland science, had to be used to infer possible impacts from over-poaching soil. Outwintering strategies, when combined with changes in feeding regimes seem to reduce costs on several case study farms. Very little economic data and modelling has taken place on sacrifice fields but this could be used to capture the complexity between biophysical factors and economic pressures. The data gaps and research needs found within the literature review informed the identification of key variables for monitoring within the project.

ii) Identify a list of indicators to fully understand the impacts of out-wintering on grass sacrifice fields

A list of indicators were compiled and discussed, revised and agreed with various stakeholders and project partners at Defra at a meeting in London on 24 February 2009. Table 1 shows the agreed indicators collected over the period of the contract.

		When measured				
		09/10	10/11	11/12	12/13	13/14
Environmental						
soil	poaching	x	x			
	compaction	x	x			
	erosion	x	x			
water	N-leaching	x	x[*]			
	phosphate loss	x	x			
	sediment loss	x	x			
air	*GHG exchange*	x	x			
	carbon dioxide	x	x			
	nitrous oxide	x	x			
	methane emissions	x	x			
Social	animal welfare	x[**]	-			
	farmer attitudes			x[$]		x[$]
Economic	gross margins	x[~]				
	fixed costs	x[~]				
	productivity	x[~]				

[*] IBERS/SRUC sites only; [**] SRUC site only; [$] Workshops; [~] Farmer Survey

iii) Selection of farms for monitoring

Indicators were mostly collected through on-farm monitoring over a two-year period (*2009/2010 – 2010/2011*). Farms that were out-wintering cattle on grass sacrifice fields were identified through the English red meat levy board, EBLEX and Hybu Cig Cymru (Meat Promotion Wales, HCC). Six farms were short-listed from the farmers provided by industry partners according to their ability to meet the requirements for taking on-farm measurements. There were 3 beef and 3 dairy farms in the study, including the dairy research farm at IBERS and the beef research farm at SRUC, Edinburgh. The remaining 4 sites were commercial farms based across England and Wales, chosen to include different farm types, soil and climatic conditions, ranging from an upland beef farm in Northumberland to a lowland dairy farm in Cornwall.

Several issues emerged after the first year of data collection. Given the limited choice of site availability water data collection was changed in the second year to control for exogenous variables on the two sites of IBERS (Trawsgoed) and SRUC (Easter Howgate). Given the need for monitoring animal welfare data and lack of access to animal health records on the farm site, welfare indicators (weight and condition score) were only collected for one year at the SRUC site.

Objective 2: To establish the sensitivities of impacts from out-wintering, which emerge from various bio-physical and management strategies

Sensitivities were established through i) analysis of on-farm environmental monitoring data, and ii) scenario analysis through environmental and bio-economic modelling. These are discussed in detail below.

i) Field and farm level monitoring

Monitoring of the environmental indicators was conducted over a two year cycle. The dates of the site visits were dependent on the management plan for each farm, with measurements being taken at each site as soon as possible prior to and after cattle were removed from each out-wintering site. At each site, measurements were made within the out-wintering area and in a comparable area of grassland which was ungrazed over the winter period. Background field management data were collated from the farmers at each site, requesting details of the livestock type, age, number of days grazing the measurement site, field stocking rates and age of the pasture. Further information on any liming, nutrient inputs (fertiliser / slurry applications) and grazing records from the previous growing season were also obtained wherever possible.

Gaseous emissions and ammonia measurements were made as soon as possible prior to and after cattle were removed from each out-wintering site. Static and dynamic chambers for the gaseous emissions and ammonia emissions measurements were located side by side in the field, with the chambers being placed in the field in a randomised manner. Within the grazed and ungrazed areas at each site, replicate dynamic chambers were used for the assessment of ammonia emissions. The technique used was based on the field sampler method of Kissel et al. (1977), where air is pumped from a volatilisation chamber through an acid trap to catch the ammonia as modified by Ball *et al* (2006) to run for a relatively long (up to 24 h) periods. The chambers were left in place for a minimum of 20 hours and the measurement period was recorded in minutes so that the volume of air could be calculated from the period of pump operation and the flow rate of the pump, to allow the flux of ammonia to be calculated. This technique worked well at most of the farm sites visited. However, a cold spell which lasted over a four week period meant that consistently low temperatures led to the acid trap freezing overnight on two occasions, despite adding salt to the acid solution. This was modified for the second year's sampling. Within the grazed and ungrazed areas at each site, static chambers were used to determine nitrous oxide, methane and carbon dioxide emissions measurements. Static chambers were placed on the soil for approximately 1 h and the gases collected drawn into a glass syringe. One sample per chamber were used to determine nitrous oxide, methane and carbon dioxide emissions. Samples were analysed by gas chromatography.

A hand-held soil corer was used to collect soil from depths of 0-30 and 30-60, 60-90 cm (where possible) to determine soil texture (clay, silt, sand) for each field site in the project. From November/December, and January to March, soil bulk density was determined using core rings to a depth of 5 cm. Soil samples were taken using a spade to a depth of 5 cm.

Prior to grazing in the autumn of each year, forage analysis was determined from six 0.5 x 1 m quadrats, cut to ground level, within the grazed and ungrazed field sites. Post-grazing, in the spring of 2010 was not possible to collect forage samples due to the nature of the study and therefore forage observations have been recorded as photographic images collected from each site.

Where possible, replicate stream water measurements were made from nearby watercourses at each farm site. In autumn 2009 and spring 2010, samples were collected from both the out-wintering site and the ungrazed control site and analysed for nitrate, ammonium, dissolved organic carbon, phosphate, faecal indicator organisms and sediment load. These data were found to be highly variable and a consequence of exogenous issues. In 2010/2011 this monitoring protocol was changed to focus on the two experimental sites in Wales and Scotland in order to control for non-outwintered pollutants.

Poaching assessments were undertaken initially as visual observations. Using GPS markers, an assessment of the area during each site visit was made by using a grid with 40 x 40 m divisions of each field site. The degree of poaching in each area of each field was recorded visually by the same person on each occasion. Using Google earth™ and GPS locations recorded, a map of each field was collated and the percentage of land area for each parameter calculated. In addition, reference photographs were taken around each gas sampling point and after visual assessment a range of these from each site were investigated using image analysis techniques to see if a more objective method of poaching assessment could be achieved. The aim of this was to overcome the lack of a standardised method for evaluating the degree of poaching within sacrifice fields. Initial approaches were based on colour analysis, either using all three channels (red, green or blue) or conversion to *L*a*b* colour representation, which by analysis of *a* and *b* terms only reduces the effects of variation in intensity of illumination. In both cases classification of images was based on K-Means analysis working in the chosen colour space and summing the pixels in the colour classes representing soil and vegetation. The second approach was to convert the images to greyscale and then use a texton based approach (Varma & Zisserman, 2005) which essentially quantifies the differences in textures in an image between grass and bare soil. The differences between various levels of poaching were detected using Multidimensional Scaling of the texton variables (Vickers, 2013).

ii) Scenario analysis

Two models were used for environmental modelling because, in our judgment, no one model could provide optimal predictions of gaseous exchange and diffuse pollutant losses to water. The models were DNDC (DeNitrificationDeComposition) (Li *et al.* 2006; Li *et al.* 1992; Saggar *et al*. 2004) and MACRO (Jarvis *et al*., 1993). These are discussed in more detail in the year 3 report.

DNDC is a sophisticated process based model of soil C and N turnover that allows management activities such as fertiliser use, stocking density and manure applications to be used in conjunction with daily climate and site conditions to simulate greenhouse gas emissions and C sequestration. The model has been applied extensively to agro-ecosystems in a range of systems and is widely acknowledged as a state-of-the-art model for use in assessing nutrient fluxes in farming systems (Li *et al.* 2006; Li *et al.* 1992; Saggar *et al*. 2004). It has two components; firstly there is a sub-component that simulates soil climate and decomposition; secondly there are sub-models for nitrification, denitrification and fermentation which predict emissions of CO_2, N_2O and CH_4 emissions. Inputs to the model are weather data, soil descriptions, crop physiology parameters and descriptions of the farm management practices. UK-DNDC has been developed from DNDC and validated against field-based observations for the UK (Jarvis *et al*. 2001; Brown *et al.* 2002; Wang *et al.* 2012). For site-scale modelling, as performed in this study, the principal difference between DNDC and UK-DNDC is additional functionality enabling simulation of daily C and N inputs from grazing animals and applied animal waste (Gilhespy *et al.* submitted).

MACRO is a physically based computer model that describes the water and contaminant transport processes in the soil. The model has been used to describe leaching of ammonium (McGechan, 2003b), colloidal P (McGechan et al., 2002) and microorganisms (McGechan & Vinten, 2003) from excreted material. The soil is divided into layers, but the soil pore space in each layer is further subdivided into macropore and soil matrix pore domains. Ammonium, colloidal P and microorganisms from excreted material pass rapidly by surface and macropore flows, but colloids are physically trapped (McGechan, 2002a) and ammonium is sorbed then rapidly converted to nitrate (McGechan, 2003b) if they enter the soil matrix. A special colloid transport version of MACRO (Jarvis et al., 1999) has previously been calibrated and tested for a range of scenarios for phosphorus (McGechan et al., 2002), McGechan (2002b, 2003a) and E.coli microorganisms (McGechan & Vinten, 2003, 2004).

The effects of poaching around a feeder was considered by sub-dividing the field into three ‘zones’, with separated simulations for each. In Zone 1 around the feeder where cows spend a large proportion of their time, the soil becomes so severely compacted by hooves (‘poached’) that no water can infiltrate the surface. Rainfall leads to contaminated water accumulating as puddles in hoof-prints, and the only route by which water can leave Zone 1 is by surface runoff into the peripheral area which is described as Zone 2 (Fig. 2). Zone 2, which varies in area with rainfall intensity and can drop to zero area in dry periods, is where saturated soil conditions occur so rapid transport of water and contaminants to tile drains takes place. Zone 3 is the remainder of the field which is almost undamaged by poaching and where deposition of excreta is at a low intensity. The three-zone field representation of a situation where the feeder remained in one position throughout the outwintering period, was further modified to represent the situation where the feeder was moved at regular intervals throughout the period. MACRO simulations for each field zone were carried out to represent the feeder position (fixed or moving location), soil type and weather at the Easter Howgate and Trawscoed locations for the two winters (2009-10 and 2010-11) corresponding to the monitoring at each site. By way of scenario testing, further simulations were carried out assuming a fixed location feeder at Trawscoed and moving location feeder at Easter Howgate. Further scenario testing was carried out in simulations using weather records over longer periods (10 winters) at each site to test the effect of a poorly functioning (partially blocked) or inadequate field drainage system. In each case, the overall contaminant loss via tile drains for the whole field was calculated as a weighted mean (taking account of the area of each zone) of the simulated losses from each zone.

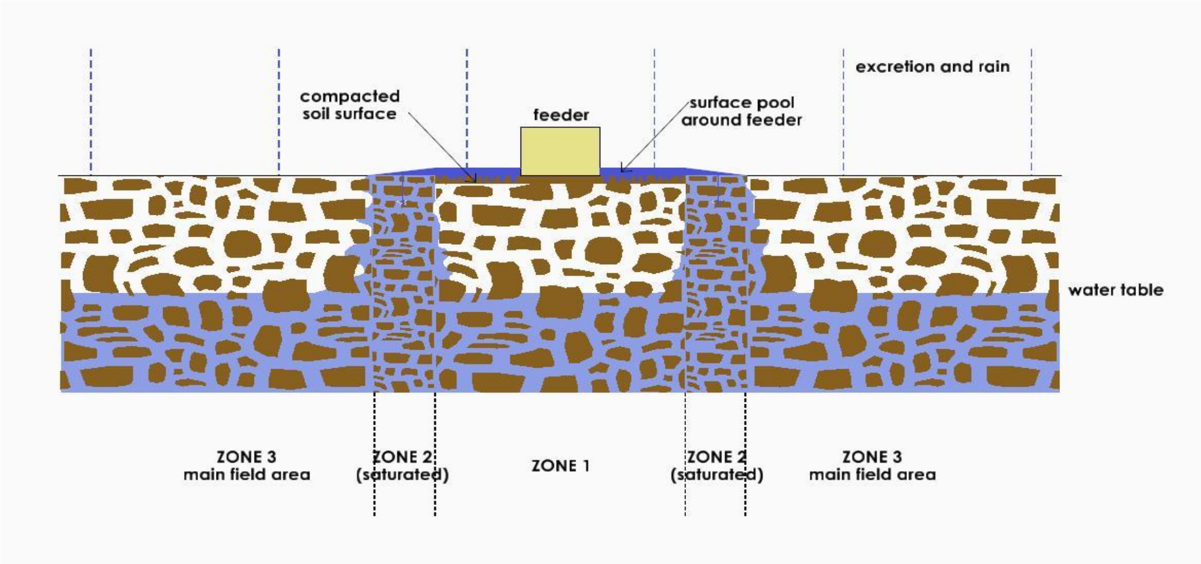


Figure 2. Sub-division of field into three zones based around the feeder

Two bio-economic models were developed to mimic farmer decision making with respect to outwintering on a sacrifice field. These models were used for identifying the synergies and trade-offs between economics, animal welfare and environmental goals of out-wintering systems. A dynamic programming (DP) model and a linear programming (LP) model were developed using farm and production data collected from this study. The objective of the DP was to maximise the expected net margins (i.e. expected net present value (ENPV) of returns expressed as an annuity) from a current suckler cow and future cows, by making appropriate replacement decisions. Ultimately, this models the outwintering decision with respect to the farmer and the beef or dairy enterprise he/she manages. The objective of the linear programming model (LP) was to predict the impact of out-wintering and sacrifice field management strategies on feeding/grazing management, profit per head and farm profit for specialised breeding suckler cattle farms.

The LP model establishes the profit maximising farm management strategy subject to constraints that reflect the main resource limitations, local environment and climatic situations, strategic goals of farmers and the welfare needs of the suckler cattle. Feed energy supply (from grazing grass and/or feeding forage and concentrate) and animals' daily energy demand during their annual production cycle, as well as the supply and demand of labour were matched in the model to maximise farm gross margin (GM) or farm net margin (NM). The grass feed energy supply component of the model was linked to a dynamic mechanistic crop model (COUP) (Eckerstena H, *et al,* 2001) with the aim of accounting for the variation in grass development due to changes in weather and fertiliser applications. This enabled the LP to establish the average annual profit maximising grazing/feeding strategy month by month for a specific farm. This also helped with estimating the economic performance of out-wintering systems under alternative bio-economic assumptions and management options and relating these to the range of uses of sacrifice fields in commercial practice.

Objective 3: to evaluate the barriers and potential for adoption of strategies to mitigate against these negative impacts

Two rounds of workshops were conducted with farmers across England and Wales in years 3 (2010/2011) and 5 (2013/14) of the project. Farmers were recruited using HCC and EBLEX mailing lists. The workshops were chosen for regions which were indicative of the most dense livestock areas. These were held in both years in the same venues (Dorset, Wales, Northumberland).

The purpose of the first workshop (held in 2011/12) was to identify perceptions of risks towards outwintering and sacrifice fields as well as identify the most applicable mitigation strategies and hence inform modelling. Results of these workshops are reported in the year 3 report and Barnes et al. (2013). A maximum of 90 farmers attended the 3 workshops. Whilst ideally more workshops would be desirable, we are confident that attendees of the workshops were reasonably representative of outwintering activity and sacrifice grazing in particular.

The second round of workshops aimed to raise awareness of the risks from sacrificing fields and test the recommendations developed from the modelling exercise to inform best management practice. In addition, for both rounds of workshops a survey of farmer's pre and post-workshop was conducted to understand general trends towards sacrifice field management and the impact of the project on raising awareness of environmental risks.

3.0 Results

i) Field and farm level monitoring

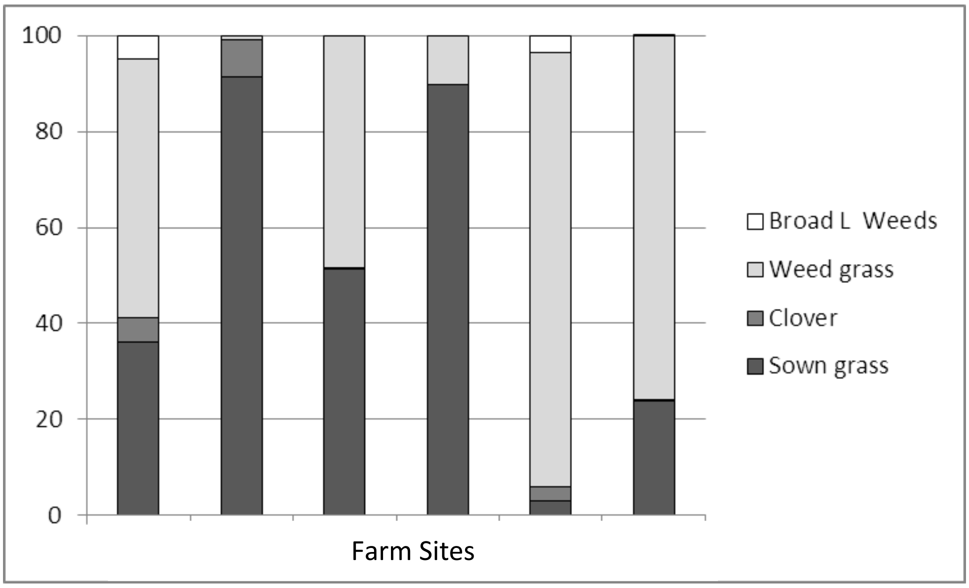
On-farm field data on grazing management and stocking rates (see Table 2) were collected from each of the six project farm sites. Data on the soil, sward composition and environmental parameters (i.e. greenhouse gas emissions from soil) were also collected across all six sites and used to validate the data generated through modelling. For brevity, just a few examples of data collected are presented here. The reporting related to monitoring is given in the year 1 and year 2 reports delivered to Defra. In addition the whole data are archived on a MS SharePoint site hosted by SRUC but with shared access for members of the research team from IBERS.

For example, the data shows the range of out-wintering practices which varied in relation to grazing days and stocking rates across the farm sites studied (Table 2). Figure 3 shows the botanical composition of the swards on each farm at the start of the outwintering period in Year 1, with results showing there was relatively little clover present in most of the swards. These data were then used to inform and validate their effects on the soil gaseous emissions data collected for the scenario modelling.

Table 2. Example of field data collected (Year 1) on outwintering practice on sacrifice fields across project farms

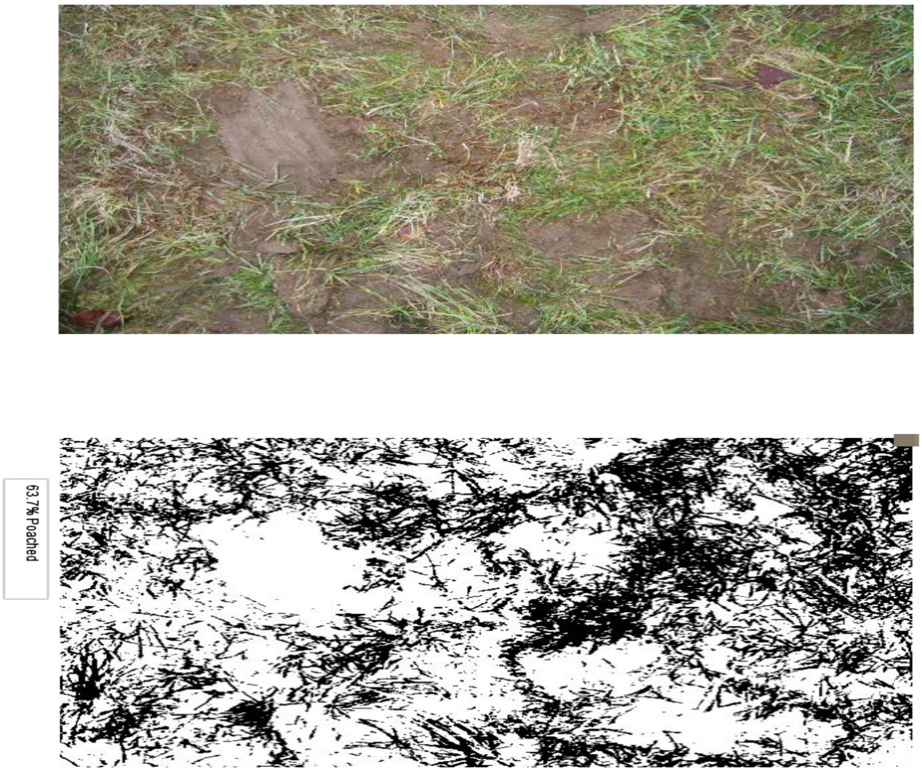
Type	Number of Cattle *(average over period)*	Area *(Ha)*	grazing overwinter *(days)*
Beef	14	5.8	168
Beef	40	7.5	91
Beef	12	1.8	84
Dairy	10	2.0	52
Dairy	48	7.0	72
Dairy	245	4.8	9

Figure 3. Sward Composition of sacrifice fields used for data collected from on-farm sites during Year One



Poaching was assessed both visually and through the development of a computerised approach coupling digital images with MATLAB visual assessment routines to measure the degree of poaching on sacrifice fields An example of the images produced is provided in Figure 4 where poaching could be objectively quantified using imaging software.

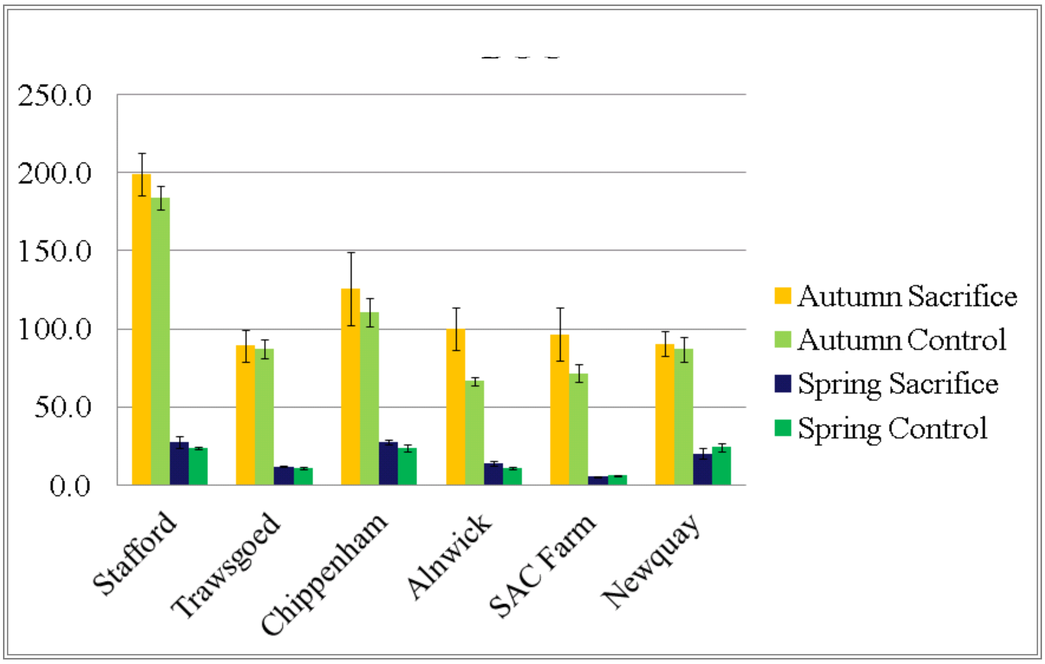
Figure 4. Example of the approach to measuring poaching, giving a poaching index of 63.7%



Poaching ranged from 16 to 28% of the sacrifice area for the beef farms, which had stocking rates of between 2.4 to 6.4; whereas dairy farms had higher poaching levels on the sacrifice area, ranging from 32% to 38% of the area poached, though stocking rates were marginally higher on these farms.

Soil profiles for each field at each site was taken. Some patterns could be clearly determined over the two sampling periods. Figure 5 shows the results of the Dissolved Organic Carbon content for the six sites across the sampling strata.

Figure 5. Dissolved Organic Carbon (DOC) sampling over the six farm sites



There is clearly a decline in DOC but it is difficult to determine the impact of outwintering on soil impact. This was true of most of the soil sampling, which indicated some changes over the autumn to spring time frame but no obvious outliers were noted in the data and, hence, little indication of a significant effect of outwintering activity compared to the sacrifice sites.

ii) Environmental and Bio-economic modelling

The modelling focused on a range of scenarios mostly identified from discussion with farmers from within the workshops. A further scenario was added due to an increasing policy interest over the time of the project into sustainable intensification. This was because it was felt as models had been established to measure economic, environmental and biophysical parameters these could be tested against various increasing levels of stocking density to examine the effects at the field level. The five scenarios and modelling results are discussed below.

a) Site choice for the sacrifice field

This dictates the impact of environmental damage and affects the parameters of damage from sacrifice fields for the environmental indicators, which are N-leaching, P-loss, gaseous emissions and soil loss. These parameters therefore relate to soil type and topology, as well as drainage and ponding issues.

Nitrous oxide emissions, relative to organo-mineral soils, are greater under both dry and wet weather conditions, but less under average conditions. For organo-mineral soils, soil texture had the greatest influence on leaching losses of N, with ammonia and nitrous oxide emissions being less responsive.

Generally most nitrogen was lost from free-draining sandy soils, irrespective of the prevailing weather conditions. Gaseous losses of N were smaller from soils with greater clay contents.

The N_2O data that has been collected for the 2010-2011 sampling period has been analysed using the restricted maximum likelihood (REML) (Genstat 16). The data were logged transformed to meet the assumptions of normality. The results indicate that significantly more ($p<0.001$) N_2O was sampled in the spring period from the sacrifice and the ponded sacrificed areas than the control treatment (Figure 6). There was no difference between the ponded area and the sacrificed area. This suggests that outwintering cattle has increased the emissions. The results also indicate that site choice had a significant effect on emissions.

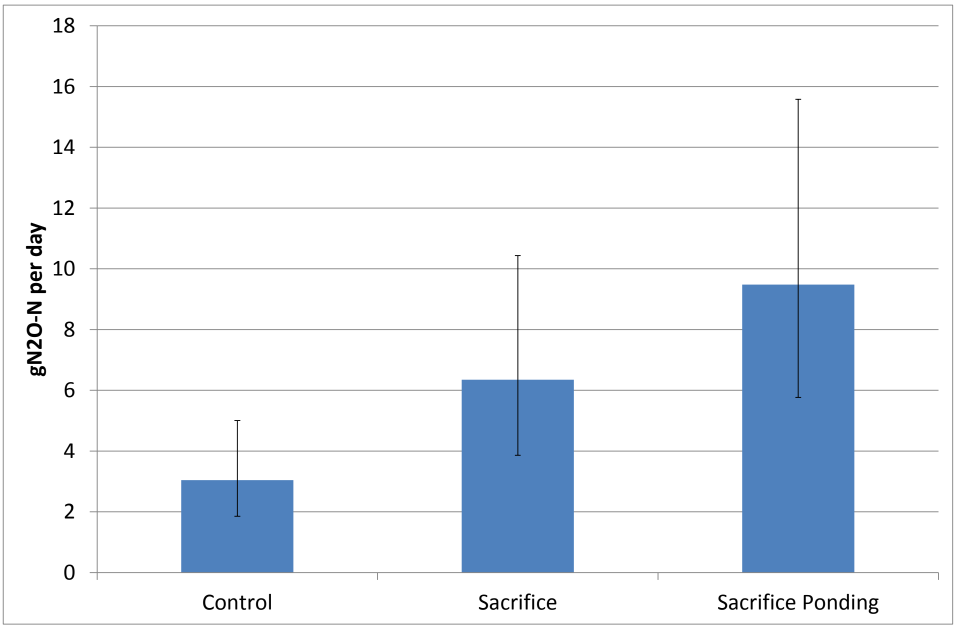
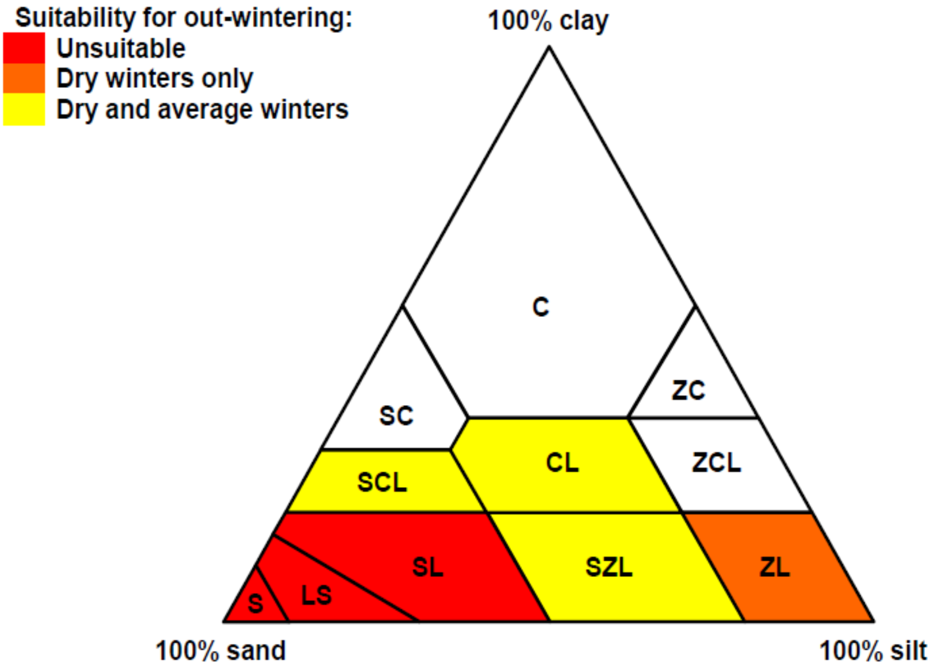


Figure 6. N_2O emissions for each of the treatments; the error bars indicate the least significant difference

Figure 7 shows an example of a visual soil decision making aid developed for site choice. Charts have also been constructed for NH_3 and N_2O emissions. These were presented at farmer workshops at the end of the project to emphasise the importance of site selection but also understand farmer responses to the use of such charts as a decision making aid.

Figure 7. Suitability of different soil textures for outwintering based on the loss of nitrogen leached



Key: S= sand; Z= silt; C= clay; LS= loamy sand; ZL = silt loam; SC = sandy clay; SL= sandy loam;

SZL= sandy silt loam; CL= clay loam; ZCL= silty clay loam; ZC= silty clay.

The UK-DNDC model does not contain dynamic routines describing soil compaction. Soil compaction (i.e. bulk density and porosity) are fixed input values. The effect of compaction during average weather conditions was therefore subject to a sensitivity analysis whereby bulk density and porosity have been simultaneously increased or decreased by 10%. Compaction of the soil reduces N losses through leaching but favours gaseous losses, particularly those for N_2O. The resultant range of emissions is, however, small in comparison with temporal variation.

Wet weather conditions favour nitrogen loss through leaching, but as soils become wetter, and the increasing proportion of denitrification losses occur in the form of nitrogen,, with reduced N_2O emissions. Reduced N_2O emissions associated with dry weather conditions are a function of reduced soil moisture. Ammonia emissions accounted for 66 – 90 % of nitrogen losses, irrespective of either out-wintering practices or prevailing weather conditions.

b) Management of water pollution via field drains

With the three-zone model losses of both contaminants were always high from Zone 2, except during extended dry periods when the area of this zone dropped to zero. However, when the whole field was considered to give the weighted mean loss, the overall loss was lower than in Zone 2 but still generally much higher than in Zone 3 (Table 3). This represents a pollution level which should be a cause of concern. Sampled ammonium concentrations at Trawscoed during outwintering in the second winter showed peak values around or soon after the dates of simulated high losses (Figure 8).

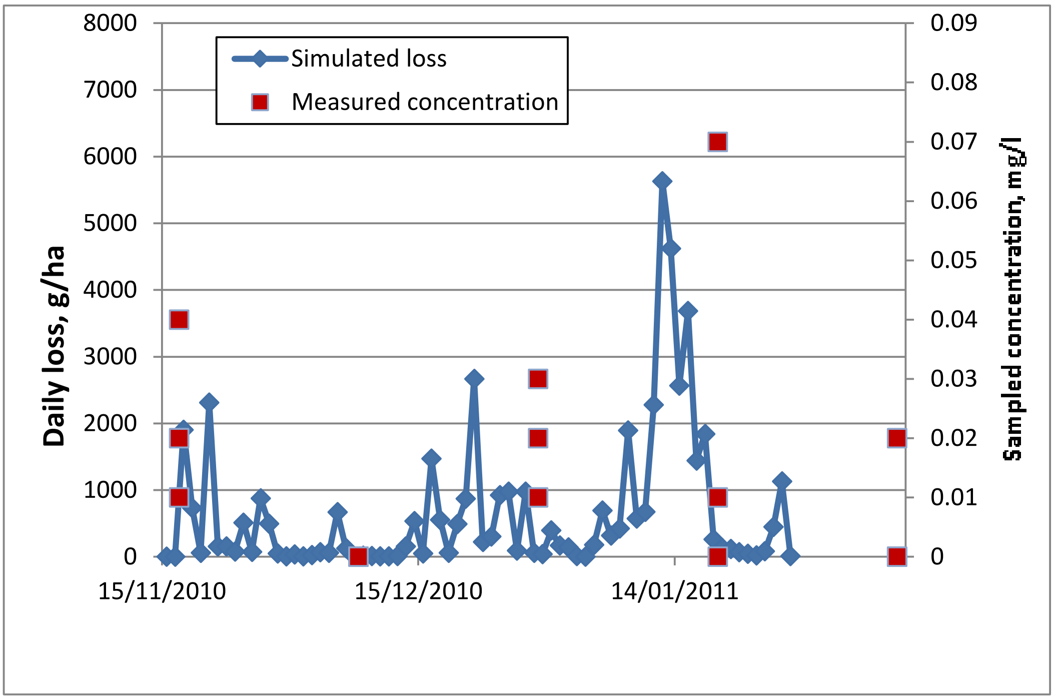
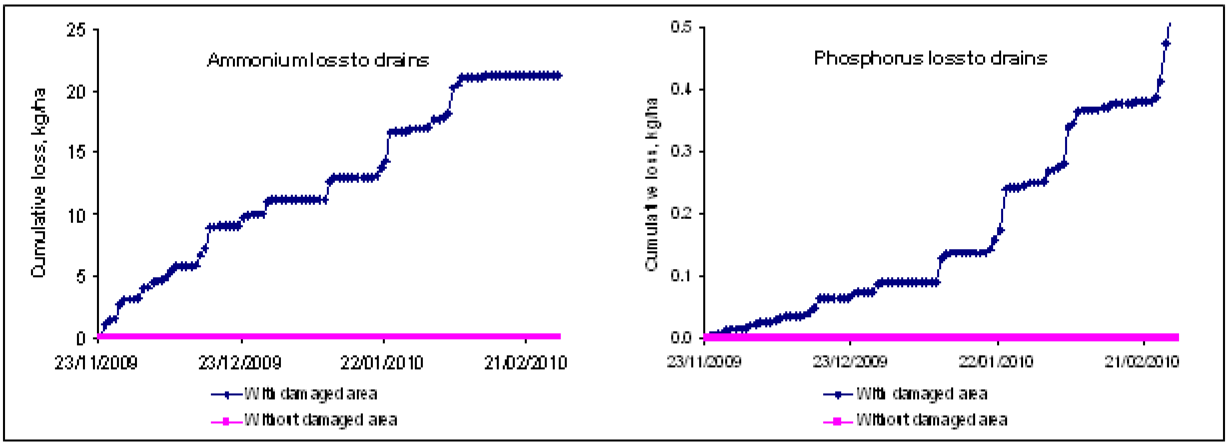


Figure 8. Ammonium loss to drains and sampled ammonium concentrate

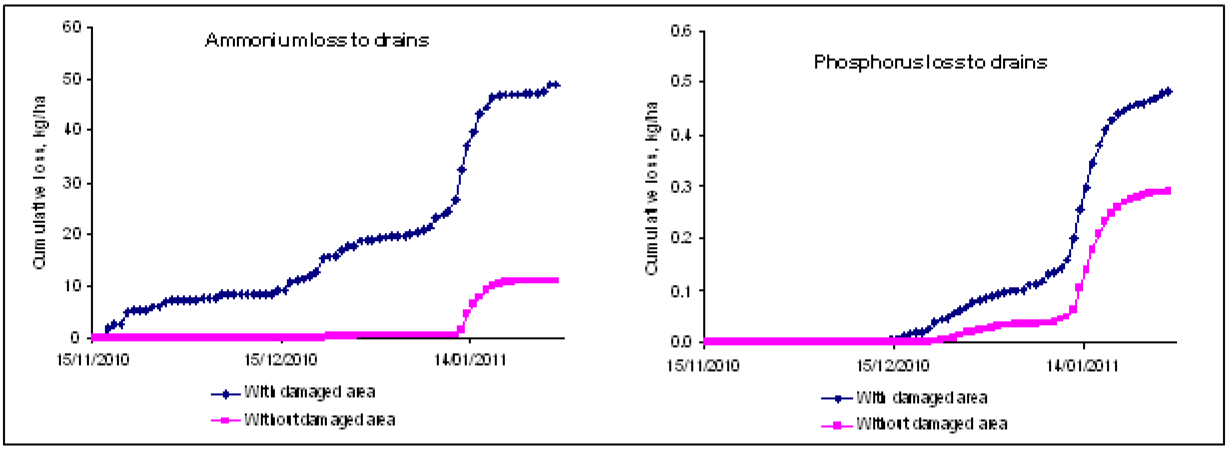
Simulated results for the actual situation at each site showed losses of both ammonium and phosphorus from the main part of the field (Zone 3) that were generally very low or zero (Fig. 9a). The exception was the second winter at the Trawscoed site where there was one extended rainfall event which caused some surface runoff and very high losses of both contaminants (Fig. 9b). In this case, cumulative losses of ammonium over the outwintering period exceeded 10 kgN/ha for ammonium, and were around 0.5 kg/ha^{-1} for inorganic phosphorus, with the losses occurring almost entirely during a single event lasting about 5 days. This informed best management practice guidelines to move and manage stock during extended periods of wet weather.

Figure 9. Simulated cumulative losses of ammonium and inorganic phosphorus over overwintering periods

a). First overwintering period at Easter Howgate, Scotland site



b). Second overwintering period at Trawscoed, Wales site



Results of the scenario test simulations with the feeder moved periodically at Easter Howgate, and a static feeder at Trawscoed, showed losses almost the same as those in simulations with the actual feeder position at each site. Results of the scenario simulation over 10 years showed no winter other than 2010-11 with high losses from Zone 3. However, if the specified drain spacing was increased from 7m (as at the experimental sites where the MACRO model was calibrated) to 20m (to represent a partially blocked field drainage system), losses from Zone 3 were high in most years. Simulations also indicated surface runoff and ponding at times corresponding to these high losses. This indicates that outwintering (or any winter grazing) should not be carried out in any field in which ponding is observed, even intermittently. This also informed best practice guidance with respect to clearing and inspecting drains to minimise environmental risk

Table 3. Cumulative pollutant losses for whole field over outwintering period at two experimental sites, kg/ha

Site	Trawscoed, Wales		Easter Howgate, Scotland	
Pollutant winter	*2009-2010*	*2010-2011*	*2009-2010*	*2010-2011*
Ammonium	22.5	48.8*	21.3 (20.7**)	45.9
Inorganic phosphorus	0.24	0.48*	0.47	0.70

* Overall losses include high losses from Zone 3

** Alternative scenario with feeder moved to three different locations during different periods throughout winter

The high loss event during the second winter at the Trawscoed site occurred after a period of near-continuous rainfall over several days. The possibility was investigated of devising a criterion describing rainfall which would indicate that cows should be removed from the field before the occurrence of the high loss event. The criterion selected was a weighted sum of past rainfall up to the current day (10% of the current day's rainfall plus 90% of the sum up to the previous day), which if exceeding a value of 10.0 mm indicates that cows should be removed from the field. This value was exceeded on 13 January 2011, but was not reached at any other time during the winter 2010-2011. A simulation in which cows were removed on 13 January 2011, and not put back in the field again until four days later, gave almost zero losses of both contaminants.

c) the impact of sacrificing a field on farm level economics

An increased cull cow price encourages a heavier culling rate to maximise the financial outcome compared to the baseline (business as usual) scenario (Figure 10). Because of a higher culling rate, more in-calf heifer replacements are required leading to a higher number of animals (i.e. higher stocking density) on farm. As many suckler farmers are rearing their own replacements, increasing the population of suckler cows and heifers because of different culling/replacement strategies, encouraged by a higher cull cow market prices, will be detrimental to the environment and imposes pressure on the land and the sacrifice areas. This may also negatively affect animal health and welfare if sufficient feed is not available for the heifers and if they are out-wintered on sacrifice fields.

This is particularly important as the Cross Compliance Regulations GAEC 9 (Defra 2011) prohibits overgrazing and unsuitable supplementary feeding on natural or semi-natural grassland, except where it is necessary for the purpose of animal welfare during periods of extreme weather conditions. Higher stocking densities on sacrifice fields particularly on poorly selected sacrifice areas and in extreme weather conditions, compromises animal health and welfare (e.g. higher risk of lameness, injury, contagious diseases, etc.) whereby the expected benefits of sacrifice areas could be outweighed by extra costs of health and welfare.

The dynamic programming model also predicted that an increase in the cost of feeding (due to higher market prices or higher quantities of bought in forage and concentrate) keeps the replacement rate at baseline (15%) but with a slightly lower financial outcome. However, it was estimated that a 10% increase in the purchase price of replacement heifers reduced the replacement rate from 15% to 13%. These results also show that the profitability of suckler cow enterprises is sensitive to cull cow price (£/kg), feed costs and heifer rearing/purchasing. These factors affect welfare indicators such as mean herd life.

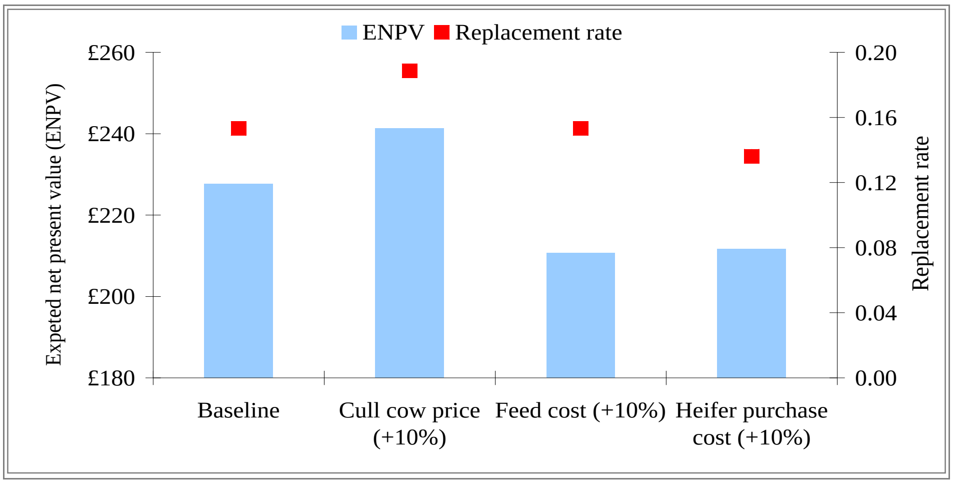


Figure 10. Graphical illustration of the long term expected net present value (ENPV) (£/cow) under the baseline and three alternative scenarios and the total replacement rate of the herd. The alternative scenarios were a 10% increase in cull cow price, a 10% increase in feed costs and a 10% increase in heifer purchase cost.

Using the COUP model the average daily dry matter of grass produced in SRUC's Easter Howgate farm in 2010 were predicted and used in the linear programming (LP) model using monthly steps. The LP predicted the cost of purchased concentrate and forage of £110 per year to feed the cattle from September to March whereas for the months of April to August only grazing pasture provided sufficient feed for the animals. Increasing the stocking rate increased the purchased feed in both winter and summer months and the annual feeding costs increased to £469 (Figure 11). By increasing the pasture area, the optimum-stocking rate increased that generated higher farm GM but with considerably greater quantities of purchased/consumed feed that will have both economic and environmental consequences. Assuming a fixed pasture area but imposing a higher stocking density rate resulted in a decreasing farm gross margin because of a greater dependency on purchased concentrate and forage mainly in the winter months.

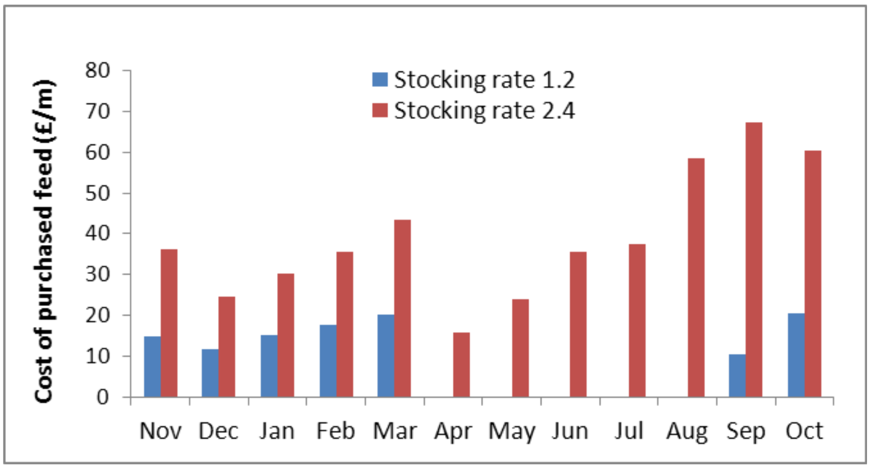


Figure 11. Costs of monthly purchased feed including concentrate and forage per month under two stocking rates of 1.2 (two cattle on 1.8ha) and 2.4 (four cattle on 1.8ha).

The LP model was run for an average small specialist suckler beef farm with an average farm size of 107 hectares (consisting of 102 hectares of pasture and 5 hectares of forage. The objective of the LP was to maximise farm net margin (NM), that is by including fixed and variable costs, by optimising the number of cattle and the feeding management. An output of £400/head, a fixed cost of £42,048/farm and a total subsidy of £37,948 were included in the net margin calculations (SRUC, 2012/13). In the baseline scenario (i.e. no out-wintering), it was assumed cattle are allowed all year round to graze in both pasture and forage growing areas (except May and June when the forage area was closed for grazing). In the out-winter 1 scenario, it was assumed that the grazing area is restricted for grazing in 6 months of winter. In the subsequent set of scenarios (2-4) the stocking density was increased over 0.5 increments. The financial results of the baseline and out-winter scenarios predicted by the LP are presented in Table 4.

Table 4. Predicted stocking density, net margin and feed costs in baseline and out-wintering scenarios (out-winter 1) and, predicted net margins and feed costs for the out-winter scenarios 2-4.

Scenarios	Stocking density	Net Margin (£)	Feed cost (£)
No out-winter*	1.15	19,335	-16,293
Out-winter 1**	1.15	12,864	-22,764
Out-winter 2***	1.50	9,599	-26,264
Out-winter 3***	2.00	21,394	-34,037
Out-winter 4***	2.50	-6,616	-42,940

* In the baseline scenario grazing allowed in all areas all year round.

** In out-winter 1 scenario grazing was restricted in pasture area during winter months.

*** In out-winter 2-4 scenarios grazing was restricted in pasture area during winter months and the stocking densities were increased by 0.5 increments.

Results showed that the optimum stocking density predicted by the model in the baseline scenario was 1.15 (i.e. 123 suckler cattle) that generated a farm net margin of £19,335. Restricting the grazing area in the winter months (out-winter 1) did not reduce the optimum stocking rate but the net margin dropped by 33% as a result of more feed purchased to fulfil the animals' demand. Further increasing the stocking densities dramatically reduced the net margins and imposed extra purchased feed costs that are not sustainable.

Environmental modelling explored this scenario further and found that, under prevailing dry conditions, N_2O emissions show a broadly linear response to both the number of out-wintered cattle and the duration of out-wintering. N_2O emissions were smallest when a small number of cattle were out-wintered for a long time, with the opposite resulting in the greatest loss of N_2O. For average and wet weather conditions the interactions between the number of out-wintered cattle and the duration of out-wintering were more complex, as would be expected. N_2O emissions increased sharply after 50 days of out-wintering.

d) Management of the field in the post-sacrifice period

A number of options were tested to reflect the impact of post-treatment of the field, namely

a) do nothing: regraze out-wintered land in the summer,

b) plough and reseed with grass in the early summer, lightly fertilize then lightly graze in late summer

c) plough, brief fallow, put down to spring barley.

In contrast with ploughing and reseeding with grass (b), the nitrogen losses associated with the conversion to arable were little different from those arising if the existing grassland was maintained and grazed over the summer (Fig. 12).

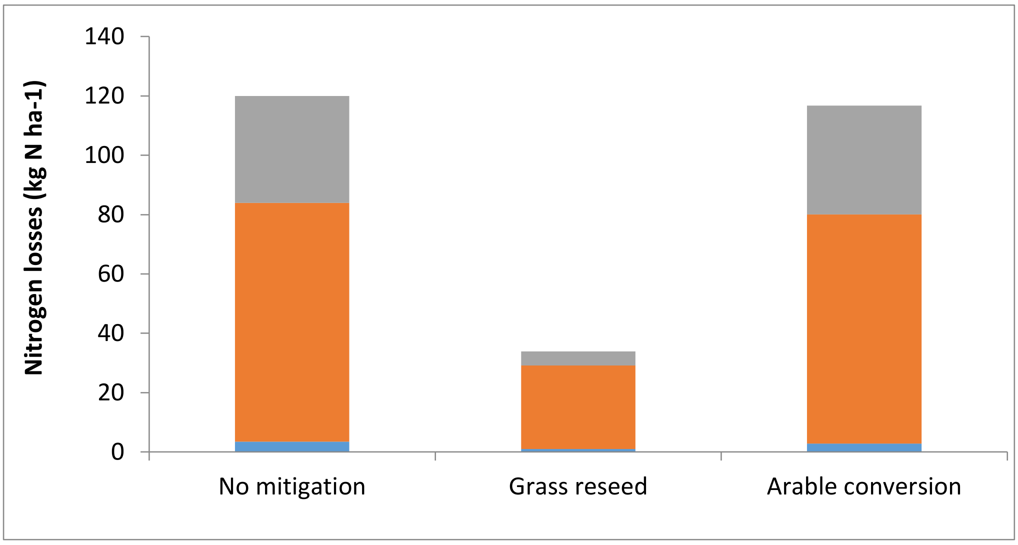


Figure 12. The effect of land use on nitrogen losses after out-wintering under average weather conditions. Losses attributed to N_2O are the lower blue portion of each column; NH_3 the red portion of each column and N-leaching the green portion of each column. Values are the sum of daily fluxes from after the out-wintering period until the end of the calendar year (~9.5 months). The conversion to arable was also associated with a net loss of soil C (Figure 13).

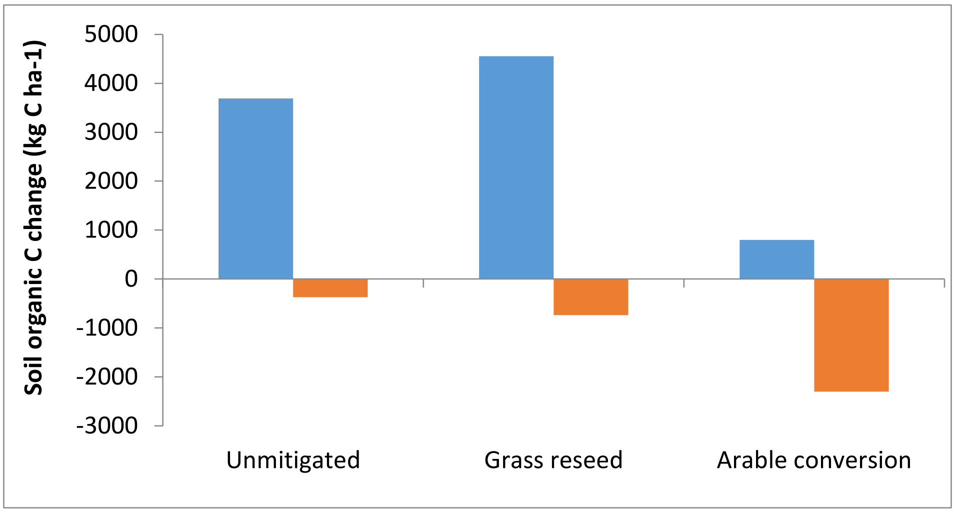


Figure 13. The effect of land use on soil organic C after out-wintering under average weather conditions.

e) The impact of intensifying within the sacrifice field

A number of options were explored with respect to intensifying the stocking rates within the field and comparing this with no or limited activity. The options explored were:

1. No grazing or cutting (referred to as No grazing)
2. Grazing in the summer only (1 April – 30 September), 1.15 cattle per hectare, no supplementary feeding (referred to as Summer grazing)
3. Outwintering on sacrifice area (1 October – 31 March) with 1.15 cattle per hectare plus supplementary feeding rations supplied by the economic model (referred to as WG 1)

3a Outwintering on sacrifice area (as above with 1.5 cattle per hectare (WG 2)
3b Outwintering on sacrifice area (as above with 2.0 cattle per hectare (WG 3)
3c Outwintering on sacrifice area (as above with 2.5 cattle per hectare (WG 4)

The scenarios were modelled for “average” weather conditions only. Based on the modelling of post-sacrifice field treatment (outlined in scenario (d) above), nitrogen losses were partitioned into two phases: i) the outwintering period: 1 October – 31 March, and ii) the high risk period: 1 April – 31 July (post-outwintering). Figures 14 and 15 show that the microbially-mediated losses (N_2O and NH_3) are greater during the high risk period when temperatures are greater.

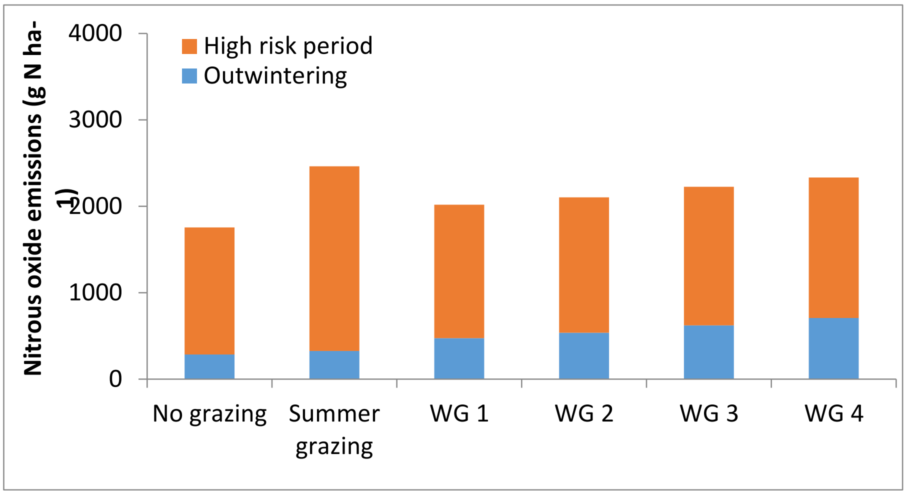


Figure 14. The effect of grazing regime on nitrous oxide emissions during the out-wintering period and the subsequent 4-month “high risk” period.

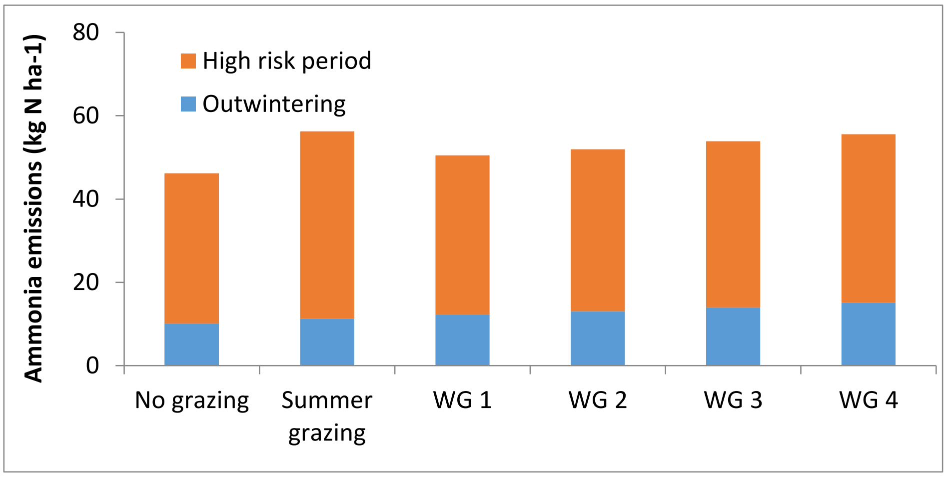


Figure 15. The effect of grazing regime on ammonia oxide emissions during the out-wintering period and the subsequent 4-month “high risk” period.

Leaching losses (Figure 16) are greatest during the outwintering period because of the greater rainfall during this time.

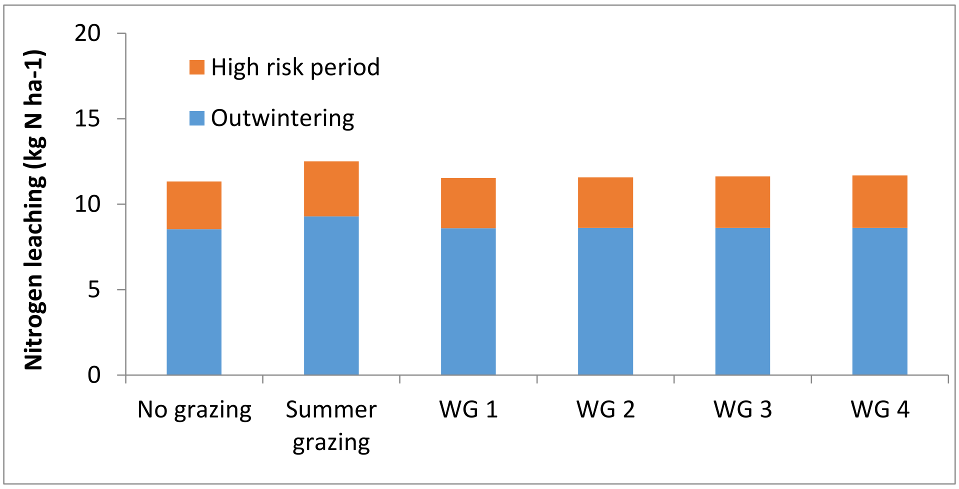


Figure 16. The effect of grazing regime on nitrogen losses via leaching during the out-wintering period and the subsequent 4-month "high risk" period.

N_2O emissions make the smallest contribution to N-losses (~3%), with ammonia emissions and nitrate leaching accounting for ~79% and ~18% of N losses respectively (Figure 17).

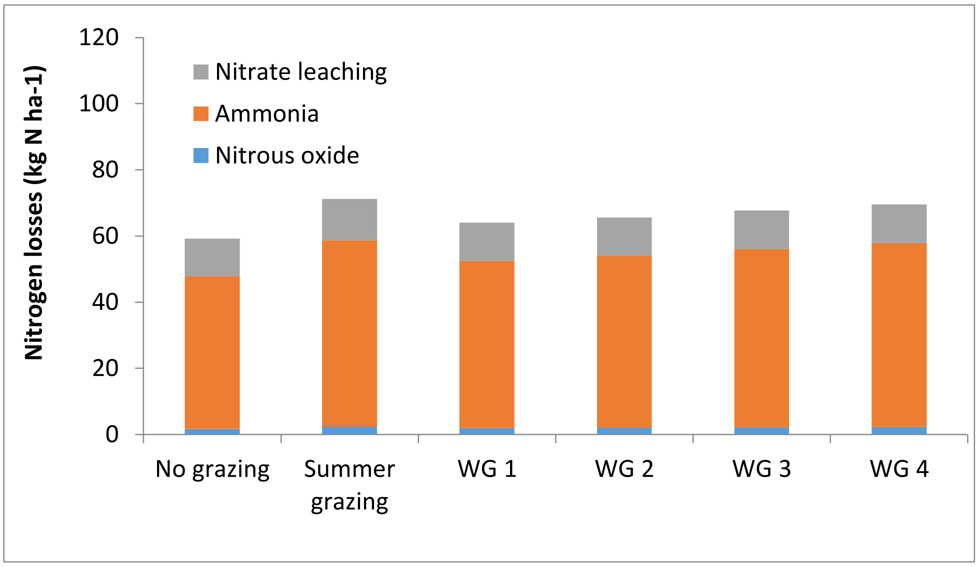


Figure 17. The effect of grazing regime on total nitrogen losses during the out-wintering period and the subsequent 4-month "high risk" period.

The range of variation in NH_3 and NO_3^- loss between the scenarios is 2 percentage points, i.e. very small, and the relative partitioning of N between the three routes of loss is consistent across the scenarios.

The total amount of N lost is determined by N inputs and the prevailing weather conditions at the time of input. The greatest loss of N occurs for summer grazing, due to the inputs of cattle manure and fertilizer when temperatures favour microbial activity. Losses associated with outwintering show a linear response to increasing stocking rate, but in numerical terms, the amount of additional N lost is relatively small, which increases the stocking rate by 117% from 1.15 cattle per hectare to 2.50 cattle per hectare increases the total amount of N lost by ~5.5 kg ha^{-1}, which is just under a 9% increase.

iii) Farmer workshops

Uptake of recommended measures is complicated by the heterogeneity of farming systems and the different types of outwintering that farmers have adopted. In order to maximise uptake of mitigation measures farmer workshops were used to identify the management scenarios (first round of workshops) and then results presented to farmers to discuss the practicality of options within a specific farming system (second round of workshops).

The first round of workshops (conducted in Winter 2012/13) examined practices and perceptions towards the risks of outwintering and, through workshop discussion, prioritised the practices that farmers would be willing to adopt. The results are discussed in the year 4 report and in Barnes et al. (2013). Under discussion with farmers the main risks from outwintering were classified as:

- economic risk (*"cross compliance breaches", "cost of field restoration")*
- production risk *("loss of production from land the following year", "loss of output" , "late sowing of following crop and yield loss")*
- social risk *("public perception", "animal welfare and public relations")*
- environmental risk (*"weather dependency ", "long term soil damage", "runoff pollution")*

Farmers were asked, through questionnaire, what are the main reasons for outwintering. The most frequent response was improved health but also lower labour and variable costs. These are shown below.

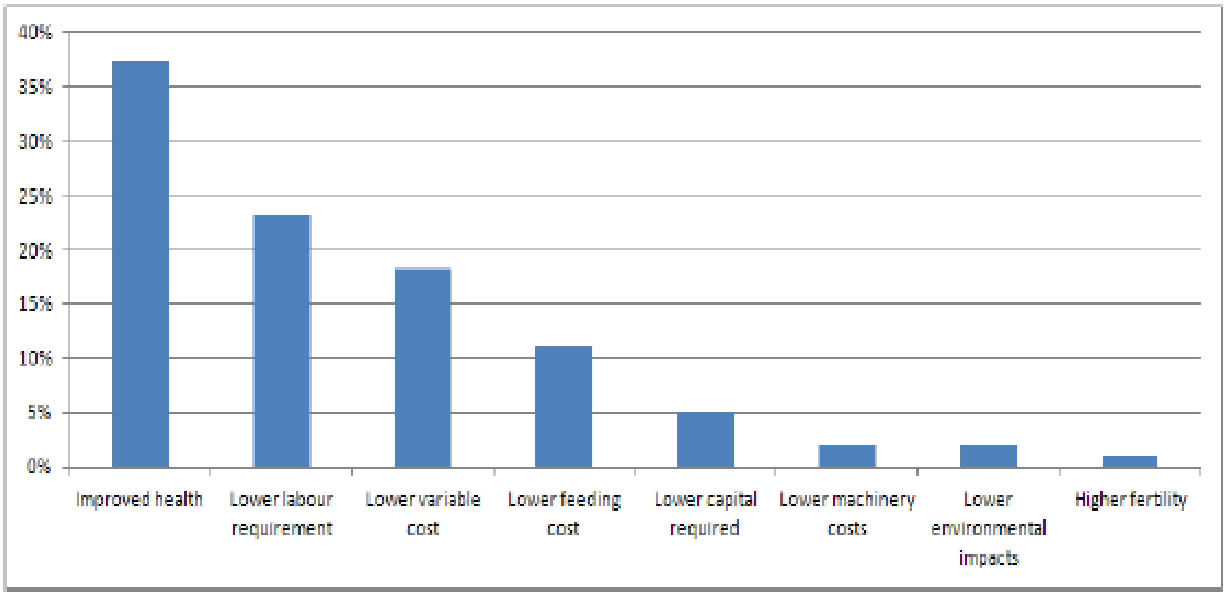


Figure 18. Main reasons for outwintering, percentages across total sample (*90 farmers*)

A second wave of workshops was conducted in January 2014 as a means of transferring the practical applications of these results to the farming industry. Again this was held at the same three locations and efforts were made to recruit the same farmers who attended the first wave of workshops. Farmers were presented with the background and results of the project and asked to discuss the recommendations for mitigation using visual aids (e.g. pictures of ponding in fields) to help discussion. These are discussed further in Section 7.0.

4.0 Reliability of results

Soil ammonia emissions were determined using a standardised technique using dynamic chambers. This technique worked well at most of the farm sites visited. However, the extreme low temperatures experienced during the samples period (minimum temperature was -7.5 on the measure of Central England) caused the acid traps to freeze overnight on 2 occasions, despite adding salt to the acid solution on the latter of these two occasions. This resulted in gaps in data collection on these dates.

Early indications from the development of a computerised image analysis to measure the degree of poaching on sacrifice fields showed potential for the application of this methodology. However, the work also showed limitations that need to be overcome through further work. One of the most obvious areas of difficulty was the variability in visual assessment of the degree of poaching in specific images by eye, and a much wider pool of images needs to be assessed by a number of experts to provide a more robust “ground truth” to allow quantitative comparison of various image analysis approaches. The development of definitions of poaching also need to be refined so that the contributions of relatively level ground with little vegetation, deep flooded or muddy hoof-prints, leaves or obvious dung patches are treated consistently. There are also some technical challenges to be overcome, particularly in dealing with images acquired in bright sunlight at low angles of incidence when rough vegetation results in deep shadows.

Validation studies comparing predictions of N_2O emissions with field-based measurements for grassland systems have shown that within DNDC the processes driving N_2O emissions are well represented resulting in daily predictions that more than adequately describe the episodic nature and seasonality of N_2O emissions (Saggar *et al.* 2004; Saggar *et al.* 2007; Abdalla *et al.* 2009). The predicted responses to management events such as fertiliser applications, periods of grazing and grazing intensity are generally in agreement with observations (Saggar *et al.* 2004; Saggar *et al.* 2007; Wang *et al.* 2012). However, having been developed for intensively managed (i.e. fertilised) agricultural systems the model performs poorly in the absence of fertiliser inputs (Abdalla *et al.* 2009). For the daily time-step users have found that DNDC either under- or over-estimates N_2O emissions, with consistent under-estimation of very large emissions (Saggar *et al.* 2004; Beheydt *et al.* 2007; Saggar *et al.* 2007). This has been attributed to the very high inherent spatial variability of fluxes caused by the heterogenic spatial distribution of excretal N inputs (Saggar *et al.* 2007). The cumulative effect is generally one where annual N_2O emissions are over-estimated (Hsieh *et al.* 2005; Beheydt *et al.* 2007). Although there may be systematic bias within DNDC, the relative differences between scenarios are congruent with those seen in vivo (Raffique *et al.* 2011). Therefore, scenario testing with process models is a valid and valuable approach when assessing the efficacy of potential N_2O mitigation options (Saggar *et al.* 2007).

In the absence of accurate field observations, assumptions were made for the MACRO modelling regarding the size of the poached area and how much time the animals spent in each of the ‘zones’ as defined in Figure 2. Simplifying assumptions had to be made in the representation of the feeder being moved to a newly unwrapped bale at the Trawscoed site. Also, measurements of poaching were made only at the end of each outwintering period, so there was some uncertainty about the time taken for the progressive build-up of poaching. Nevertheless, evidence of lack of infiltration and of surface runoff was observed in poached areas, and this will inevitably lead to a peripheral zone (described here as ‘Zone 2’) where saturated soil conditions occur so rapid transport of water and contaminants to tile drains takes place. The MACRO model has previously been calibrated and tested at sites with accurate measurement methods (Parkes et al., 1997, McGechan et al., 1997, 2002) showing rapid macropore flows, under near saturated soil conditions, to tile drains, of water and contaminants including ammonium and phosphorus. These previous studies also illustrate the event-driven nature of such contaminant losses. Even if there is doubt about the absolute vales of losses as simulated in the current study, there is strong evidence that loss levels will be significant when near saturated soil conditions occur, and also be periodic in nature. High losses associated with blocked or poorly performing drainage systems, as represented by widely spaced field drains in simulations, leading to saturated conditions, surface runoff and ponding, have also been previously noted (Lewis & McGechan, 1999); this observation is not dependent on assumptions about poaching as they arise from the main field area (Zone 3).

One issue with the economic modelling is the assumption of optimization of resources at the farm and herd level. In practice, farmers operate under a range of influences and factors which affect their approach to resource allocation. These were revealed and explored within the workshop aspects of the study. Nevertheless, the stated farmer desire to use 'best planning' from the first round of workshops gives some insight to how best planning, through optimisation, could be achieved.

5.0. Implications of the Findings

Monitoring environmental impact during the winter is challenging given the possibility of extreme temperatures. In addition, the variety of sacrifice field management systems in operation imposes restrictions on adequately representing the range of activities through on-farm monitoring. However, we have developed a number of protocols to ensuring both robust monitoring and attribution of pollutants. Further work would investigate the capture of emissions of N_20 through insulated chambers to meet the extremes of weather. In addition, this work would ideally be referenced against indoor systems, which offer more control over environmental parameters.

This study has shown that outwintering of beef and dairy cows will lead to significant levels of water body pollution by ammonium, phosphorus and other particulate contaminants. Such pollution arises due to rapid transport of components of deposited excreta to tile drains through macropores in saturated soil during or after rainfall. Saturated soil conditions arise around the periphery of any field areas which have become compacted due to trampling by animal hooves, and this situation is almost inevitable during outwintering.

Saturated soil can also arise in a second situation after prolonged rainfall if the tile drainage system is inadequate so in effect the water table rises to the surface. In this situation, there is a significant additional level of pollution further to that arising from soil compaction due to trampling. It is very obvious when this second situation arises as it is associated with surface runoff and ponding.

Policy makers and researchers are recognising the need to address dual objectives, or at least to understand the trade-offs between environmental damage and economic performance. In this research we explored scenarios which required joining up of results between environmental and bio-economic modelling as a means to address this research need.

Out-wintering management in suckler cattle farms may reduce fixed costs such as housing and machinery but without provision of high quality feed and increasing stocking density could also result a decreasing farm profit as a result of greater dependency on purchased concentrate and forage (i.e. higher variable costs) mainly in winter.

Commodity market prices (e.g. cull cow price, feed costs and heifer rearing/purchasing cost) influence optimal replacement rates and hence change the age structure of the herd and proportion of animals in various health and welfare states (i.e. fertility and body condition score). The profitability of suckler cattle herds with out-wintering management is particularly sensitive to increasing feeding cost. In addition rising heifer rearing and purchasing costs that can negatively affect feeding levels and hence the environment, body condition score and animal welfare.

Sacrificing an area requires planning and management to minimise the environmental damage from outwintering cattle. Increasing pressures on costs at the farm level will lead to the continuance of this practice within UK farming. This project's findings inform a number of current and future policy needs, specifically the current reform of the Common Agricultural Policy. This has embedded the principal of 'greening' payments linked to stricter cross-compliance, i.e. to protect grasslands to reflect preservation of carbon through pillar 1 payments. However, there has been no discussion at the EU policy level over the management of livestock on grasslands to minimise carbon emissions. These management measures may be exhibited through Pillar 2 payments and, whilst there are some current options which protect damage from outwintering activity, such as buffer strips, we would argue some support for clearing drainage may reduce ponding in fields and lessen the environmental risk of sacrificing a field.

A significant issue raised within the workshops with farmers was the importance of public perception in determining site location of cattle for outwintering. This aligns with several high profile debates surrounding intensification of livestock production systems and public criticism of large-scale indoor facilities. The majority of farmers in the workshops saw cows outdoors to be equated with higher health status. Accordingly, some of these findings align with issues currently being addressed within the newly established Defra Sustainable Intensification Platform (SIP). The establishment of farm research experimental sites from this platform may also allow further exploration of outwintering effects under intensified systems. The results here show that whilst the increase in pollutant load is marginal, the whole farm level cost of intensifying may be detrimental to future financial sustainability. Higher stocking densities on sacrifice fields particularly on poorly selected sacrifice areas and in extreme weather conditions, compromises animal health and welfare (e.g. higher risk of lameness, injury, contagious diseases, etc.) whereby the expected benefits of sacrifice areas could be outweighed by extra costs of health and welfare. This may inform the development of decision making tools as a means to negate environmental impacts whilst maximising profits and productivity, as has been explored within this project.

A further implication is the usefulness of maintaining farmer and industry contacts throughout the running of the research as means of directing research but also communicating to industry the outcomes of research. In this context the adoption of monitor farms, as demonstrated in New Zealand, which promote farmer to farmer knowledge transfer and offers practical demonstration of good practice to promote behavioural change, could be explored with respect to transferring the mitigation practices favoured within this project.

Practical Recommendations for best practice

A range of best management measures and recommendations were identified from this work and then tested with farmers in a second round of workshops in the final year (2013/2014) to assess their likelihood of adoption. These were:

Provision of visual soil assessment aids: Soil types are critically important in affecting the level of damage within a sacrifice area. If the farmer has a choice they should be on medium to heavy well structured soils and we have developed a visual guide to understanding soil and impact on main pollutants within the context of a sacrifice field management strategy.

Visual poaching assessment aids: A method was developed and tested to objectively measure the amount of poaching within a particular area. We are exploring options for linking this to mobile phone camera technology however, again, visual aids may be useful in identifying levels of ponding within a field at certain times of the year.

***Drainage management*:** Outwintering should not take place in any field which is subject to frequent ponding or surface runoff due to the inadequacy or degradation of the tile drainage system. Misiewicz (2014) has described measures for inspecting and refurbishing old field drainage systems. This might allow outwintering in a field previously unsuitable due to frequent ponding.

Potential for rainfall collection and monitoring: In a field in which ponding occurs infrequently, there would be a benefit from recording rainfall and moving cows out of the field if the weighted mean past rainfall reaches a certain value. Only a small number of farmers (from a sample of 90) were actively recording rainfall. Investment in both collecting equipment and provision of 'ready-reckoner' type cards or software may be beneficial to controlling pollution in a sacrifice area.

Use line feeding and balers: Soil compaction due to trampling leads to a significant base level of pollution which is unavoidable. We found there is no environmental benefit at all in moving the feeder to different locations periodically over the winter. Furthermore, this will cause further damage in extreme events both on the new site of the feeder ring as well as from the activity of moving this.

Post-treatment of the field: The highest risk period emerges in the four months after sacrifice (1 April – 31 July) and N-losses are minimised if farmers reseed rather than natural regeneration. Slot seeding, which over sows, may be an option for some farmers in terms of feeding provision and minimising damage.

Note also that weather provides context for these results and strategies need to adjust for extreme wetter winters. These may raise the issue of providing temporary shelter or the use of pads/webbing to minimise damage.

6.0. Possible future work

Comparison of outdoor systems with indoor systems would seem an important comparator for understanding the extent of the environmental and economic impact of outwintering systems. This may also be important, given the debate over intensification of livestock systems compared to extensive outdoor systems. In addition, developing a range of monitoring tools which can accurately capture environmental impact in extreme weather events would also be beneficial to future work in this area.

The impacts at field level require detailed spatial modelling. This has been conducted at field level and farm level. We would recommend further spatial modelling approaches. An exploratory spatial model was developed, based on rules and underlying geospatial characteristics. This could be developed further to understand the impacts of sacrifice fields at a catchment level, and accommodate differences in farmer behaviour and management within the catchment.

A profitable exercise within this project was the employment of participatory modelling techniques which allowed some integration across social science methods with environmental modelling. Whilst this was retrospective modelling, more dynamic scenario planning can be achieved by linking visual landscape mapping with computer modelling to give a 'real-time' demonstration of the effect of farmer decision-making at the field, farm or catchment level. The models presented here could be further linked with such software to allow more visual representation of these effects and elicit more detailed information on farmer decision-making.

Overall we see the area of visual poaching assessment as profitable for further work, and we have an excellent set of images on which this could be based. Initially this would proceed by expanding the ground truth assessments of the existing images using a number of experts. This could result in publication of standardised images of poaching which do not currently exist. The images would then be split into training, test and validation sets. The training set would then be used to asses a number of approaches to the image analysis, including the refining the colour analysis and texture based approaches tried so far and other more sophisticated approaches. It would also include dealing with images showing uneven illumination to minimise the constraints on image acquisition. The test set would then be used to confirm validity of the approach. Then, the performance of the algorithm would be checked against newly acquired images and the algorithm made widely available through a web based interface and application for mobile phones.

7.0 Action resulting from the research

The knowledge exchange part of this project was embedded within the research, to maximise relevance and uptake of recommendations within the farming industry. This was done through farmer workshops and with EBLEX and HCC levy boards.

Farmer workshops were held in January to discuss the acceptability of various mitigation techniques proposed for sacrifice field management. These were conducted in the following dates and locations:

10/1/2014 - The Raven Inn, Welshpool

14/1/2014 - Kingston Maurward College, Dorchester

29/1/2014 - Nafferton Farm, Stocksfield

A maximum of 90 farmers were consulted in this phase. A set of power point slides were prepared and presented to firstly highlight the project and the issues around environmental risks and sacrifice areas; secondly the results of the first round of farmer workshops was discussed; finally the recommendations for best practice (outlined in section 5.0) were presented with respective pictures and illustrations of the different ranges of environmental harm, such fields with light and heavy ponding. Throughout the workshop farmers were asked to discuss points in terms of how this applied to their farm. In addition, several farmers were invited to speak about the systems they had adopted to engage farmer network and utilise peer-to-peer type communication techniques. Responses have been collated and examined for tailoring an updated SRUC outwintering BMP blueprint.

Evaluation surveys were conducted at the end of each workshop. Specifically we asked whether the workshop was useful in raising information on the issues related to sacrifice areas and the majority (89%) either agreed or strongly agreed with this statement.

Several articles have been written for the farming press advertising the results of this research. Specifically, the farmer's guardian published on the 25th November 2013 and a forthcoming article on the workshop findings in Grass and Forage Farmer Magazine

Throughout the project discussion has been conducted with EBLEX, with a view to maximising outputs and informing policy and engagement with members. Indeed EBLEX and HCC were crucial to identifying farmers for the workshops conducted. Further afield, a visit from the Ag Research New Zealand farm allowed linking between UK scientists on this project and those involved in outwintering work in New Zealand. Discussion is ongoing regarding future research linkages.

In addition, a number of academic articles and presentations have been produced throughout the research project. These are listed in Section 9.

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