MultiSward

Multi-species swards and multi scale strategies for multifunctional grassland-base ruminant production systems

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Table of contents

1. Introduction ......................................................................................................................3
2. Materials and Methods..................................................................................................3
   2.1 Dairy cow grazing experiments.................................................................................3
      2.1.1 France..................................................................................................................3
      2.1.2 Ireland..................................................................................................................4
2.2 Model description .......................................................................................................6
   2.2.1 The MDSM Bio-economic model..........................................................................6
   2.2.2 The GHG Model..................................................................................................10
3. Results ..........................................................................................................................17
   3.1 France......................................................................................................................17
   3.2 Ireland....................................................................................................................20
4. Conclusions ...................................................................................................................24
5. References.....................................................................................................................25
1. **Introduction**

Whole farm simulation models in association with systems experiments allow a multidisciplinary approach to studying grass based ruminant production systems. The use of models makes it possible to study the behaviour of a large range of virtual systems, providing dynamic information on many variables difficult to measure for technical and economic reasons. Therefore, models now have a major role to play in research to improve systems of production. In grassland systems the breed and/or strain of dairy cow must be robust, easy care and able to meet their feed requirement from grassland. In Task 4.3 of WP4, MultiSward examined the suitability of cow breeds for grass based milk production systems in France and Ireland. In Task 4.4 of WP4 whole farm models were assessed in terms of their suitability to model aspects of grass based milk production systems within MultiSward. The results are presented in D4.4. it was decided by the consortium to use the Moorepark Dairy Systems Model (Shalloo et al., 2004) and the greenhouse gas sub-model of the MDSM (O’Brien et al., 2010) to evaluate the long term dairy cow grazing experiments in WP4 Task 4.3. Using whole farm simulation modelling with data from these long term grass based dairy cow production systems allows a more holistic evaluation of the systems, including production, some economic and some environmental evaluation.

2. **Materials and Methods**

2.1 *Dairy cow grazing experiments*

2.1.1 France

The experiment was undertaken at the Le Pin-au-Haras dairy farming system experimental farms which are part of the INRA research unit. The farms are located in the north west of France in Normandy (48.44°N, 0.09°E) on a drained clay-loam soil and benefit from an oceanic climate suitable for grass production. From 2001-2005 research was carried out on the farms to analyse the effect of cow breed and feeding strategy on the milk and reproductive performance of winter-calving (December to February) dairy cows. Delaby et al. (2009) previously outlined the experimental design of this study and reported the results, which were used in this analysis to simulate GHG emissions.
In brief, Delaby et al. (2009) evaluated the physical performance of the most popular breeds of cow in the Normandy region, namely Normande and Holstein. Overall, 167 Holstein dairy cows and 158 Normande dairy cows were used in the analysis. Each year, before winter-calving Normande and Holstein dairy cows were assigned to one of four feeding treatment.

The four feeding treatments comprised of two winter feeding strategies applied indoors and two levels of concentrate offered to cows while grazing. The first winter feed treatment (High treatment – H) had a diet composed of 65% maize silage, 5% hay and 30% concentrate. The second winter feed treatment (Low treatment – L) was based on a diet comprising 45% first cut grass silage, 40% second cut big bale grass silage and 15% concentrate.

At turn-out to pasture in April and throughout the grazing season, half of the animals on the first and second winter feed treatments received 0 kg of concentrate/cow per day (low concentrate – l), while the other half received 4 kg of concentrate/cow per day (high concentrate – h). In autumn (mid-November) after re-entry to the cattle shed, but prior to next calving, grazed grass was replaced by grass silage, but without modification of the concentrate allowance. Therefore, 8 farms, comprising of 2 breeds and 4 feeding treatments named High/high (Hh), High/low (Hl), Low/high (Lh) and Low/low (Ll) were assessed.

2.1.2 Ireland

a. Jersey, Holstein-Friesian and Jersey × Holstein-Friesian

Moorepark controlled research study

Forty-five Holstein-Friesian (HF), 45 Jersey (J) and 45 Jersey × Holstein-Friesian (F1) animals were randomly assigned, within each genetic group, to one of three stocking rates in a completely randomised design in the Spring of 2010. The HF and F1 animals were stocked at 2.5, 2.75 and 3.0 cows/ha while the J animals were stocked 0.25 cows/ha higher at 2.75, 3.0 and 3.25 cows/ha. Each group was balanced for parity. Nine farmlets were set out for the nine groups of cows. Stocking rates were set to account for total farm production, including conservation of winter forage. Groups were moved to a fresh paddock when the required post grazing sward height was reached - 3.00-3.75, 3.75-4.5 and 4.5-5.5cm for the high, medium and low stocking rates, respectively, as measured using the Rising Plate Meter (Jenquip, Feilding, New Zealand). Concentrate supplementation averaged 627, 614 and 643 kg per cow
for the High, Medium and Low stocking rate (SR) groups, respectively. Milk yield was recorded daily; milk composition and bodyweight (BW) was determined weekly; and body condition score (BCS) was measured once a month on a scale of 1-5.

*Relative breed and heterosis effects obtained from national data set*

The production extract file used in the routine genetic evaluations containing 305 day milk yields was provided by the Irish Cattle Breeding Federation (ICBF). Production data from lactation 1 to lactation 5, and survival data to lactation 6, were available.

The fact that the Holstein and the Friesian are considered different breeds within Irish genetic evaluations, and due to the intertwined nature of the two breeds within the national cow population, it is considered appropriate to examine the relative breed and heterosis effect among the three breeds. Friesian genetics can be further categorised as Kiwi (or New Zealand Friesian, KF) and British (or European Friesian, BF), hence all three were included as individual breeds in the genetic analysis.

*b. Norwegian Red, Holstein-Friesian and Holstein Friesian×NorwegianRed dairy cows*

Walsh et al. (2007) indicated in a study carried out at Teagasc Moorepark, Ireland, that the Norwegian Red (NR) breed had a slightly lower milk yield capacity but exhibited superior udder health and reproductive efficiency (Walsh et al., 2008) compared to Holstein-Friesian (HF) cows. These results, however, were based on small sample size. Therefore, a larger farm participatory study involving commercial dairy farms was established to further evaluate the merits of the NR breed and to determine the potential suitability of crossbreeding with the NR for Irish dairy farmers.

*Commercial on-farm study*

The design of the farm participatory study was a contemporary comparison design, whereby both parent breeds as well as crossbreds would be present on each farm. Norwegian Red semen from each of 10 proven AI sires was distributed to 55 commercial dairy herds for the purpose of generating NR crossbred females. In June 2004, 393 purebred NR heifer calves were imported to Ireland. These animals were sired by the same 10 proven NR AI sires used to generate the NR×HF animals. Detailed animal performance data subsequently became
available from 46 of these herds. Initial results published from this study by Begley et al. (2009) confirmed the relative milk differences between HF and pure NR. Over the two lactations the predicted 305 day milk yield of the NR cows was 95% of that produced by the HF cows. Norwegian×Holstein-Friesian cows appeared to exhibit a capability to produce to a similar production level to the HF. A clear fertility advantage, however, was evident with both pure NR and NR×HF.

Relative breed and heterosis effects obtained from national data set
The on-farm study was augmented using additional herds containing both HF and NR genetics identified from the national data base. Data spanning lactation 1 to lactation 5 was included. The production extract file used in the routine genetic evaluations containing 305 day milk yields was provided by ICBF.

2.2 Model description

2.2.1 The MDSM Bio-economic model
The MDSM is a stochastic budgetary simulation model of a dairy farm and was developed to allow investigation of the effects of varying biological, technical, and physical processes on farm profitability. The model is described in detail by Shalloo et al. (2004). An overview of the model is given here.

The model is formulated in an Excel spreadsheet. The model simulates over a 12 month period, or over a number of years. The basic element of the MDSM is the dairy cow.

Simulation of herd performance is based on cow calving data and is broken down by month of calving. The worksheet displays the following information for each month of calving over the 12 months - livestock movement (culling, purchases, and sales) at the start and end of each month, livestock valuations (cows, male and female calves, and male and female yearlings) at the start and end of each month, expected milk production, and feed requirement. The amount of milk sold off the farm can be constrained by milk quota or land area depending on the scenario which is being simulated.
Both seasonal and all year round calving can be modelled. For a seasonal calving pattern breeding starts on a fixed calendar date and continues for a prescribed period of time. Once breeding starts, every cow detected in oestrous is served using AI, regardless of number of days since calving. The key objective is to achieve the highest pregnancy rate in the shortest period of time. The milk production system is spring calving grass-based (Dillon et al., 1995; Kennedy et al., 2002), which is representative of the production system on most Irish dairy farms. It is very dependent on the efficient utilization of grazed grass (Stakelum, 1991). Calving date is targeted to commence at the start of the grass-growing season. The objective of the system is to optimize grazed grass as a proportion of the total diet of the lactating dairy cow, allowing high cow performance while, at the same time, minimizing the cost of additional feed to produce milk. Feeding and management are based on best practices in seasonal spring calving grass-based systems (O’Donovan, 2000). The proportion of feeds offered (grass, grass silage, and concentrate) is altered to meet the net energy requirement for milk production, maintenance, and body weight change (Jarrige, 1989). A fixed feeding system is used for young stock as per Teagasc guidelines (Teagasc, 2002).

The model displays the number of cows at the start and the end of each month and the number of cows culled. It assumes that cows are dried off two months before the next calving, and replacements are introduced as in-calf 2-year-old heifers to replace culled and dead cows. The culling percentages (voluntary plus involuntary) per month of lactation are inputted to the model. The model also includes the purchases and sales of livestock in each month. The valuation of cows and other livestock is also calculated at the start and the end of each month. The model assumes that 45% of the female calves are reared for replacements, but these animals are sold at 23 months of age. It is assumed that these replacements are purchased into the dairy herd for the same price. This simulates the practice among dairy farmers to consider young stock rearing as a separate enterprise; it also allows for the flexibility at farm level to sell surplus replacements, which, for example, calve at a more suitable time. All male and surplus female calves are sold at one month of age. Therefore, the MDSM allows the flexibility to consider rearing replacements as a separate enterprise or part of the dairy enterprise, depending on the sale date of young stock.

The average milk production, milk fat and milk protein of the herd are inputs to the model, as is the lactation curve. Milk yield and milk composition are modelled for an average group for each month of calving rather than for individual cows. Similarly, the average body weight
and body weight change can be inputted to the model, or calculated from Moorepark (or other) studies.

The feeding regime modelled has fixed ratios of grazed grass, grass silage, and concentrate for each month of the year. These ratios are not influenced by milk yield, but the amount of feed offered is altered to meet the NE system (Jarrige, 1989). The NE content of feeds is determined using the feed unit for lactation (UFL) content of the ingredients (O’Mara, 1996). The NE content of the herbage is related to its chemical composition (Jarrige, 1989).

Total yearly grass production and its supply across the year are inputted to the model. Grass utilisation is assumed to be 85%, unless it is known and can be inputted. Grass growth is dependent on nitrogen application and farm location. Teagasc nutrient management guidelines were observed; these allow the recycling of phosphorous and potassium produced on the farm in the form of slurry (Teagasc, 2008).

The financial reports are derived from equations linking the farm receipts, costs, and capital investment.

Land area is treated as an opportunity cost; additional land is rented in when required or leased out when not required for on-farm feeding of animals. Grazing management, silage harvesting, and grass production are similar to the Moorepark blueprint (Dillon et al., 1995) or can be altered as prescribed by the user. The land areas for first and second cut silage (ratio 3:2, respectively) and for grazing are optimized to meet silage and grass requirements. Costs for fertilizer application, reseeding, and silage making (contractor, additives, and polythene) are based on the actual area required for silage and grazing.

Land improvements and buildings are depreciated at 10%/year using the straight line method, and machinery is depreciated at 20% using the reducing balance method (O’Mahony, 1992). Provision is made for the purchase and depreciation of new fixed assets during the year. A 15-year bank term loan was used to fund the cost of land improvements and buildings.

Labour requirements are based on the results of a comprehensive farm labour efficiency study on 143 Irish dairy farms (O’Donovan et al., 2003). Total farm labour requirement is divided into 8 main categories (milking, maintenance, grassland, management, calf care,
cleaning, veterinary, and miscellaneous). In the model, labour requirement is divided between time associated with the cow and other farm tasks. The labour cost is calculated assuming 1848 hours equates to one labour unit/year.

The gross milk price is inputted into the model and is based on a reference milk fat and protein content. The calf and cull cow prices are also inputted into the model, and can be based on current process or an average over a number of years. Similarly, cull cow valuation is inputted to the model and can depend on the month of disposal and lactation stage.

The worksheet holds information month-by-month for each of the operating costs, such as fertilizer application, silage making, veterinary medicine, etc. All variable costs (concentrates, fertilizer, reseeding, machinery hire, silage making, veterinary medicine, and AI) are based on current prices (Teagasc, 2013). Reseeding costs are based on 5% (or the actual area reseeded if known) of the farm being reseeded each year at current reseeding costs. Veterinary costs include routine animal treatments as well as compulsory annual tuberculosis and brucellosis testing of animals and drugs involved in correction of infertility problems in cows. Artificial insemination costs are based on 1.7 inseminations per conception.

As for variable costs, all fixed costs (car, electricity, machinery operation and repair, telephone, insurance) are based on current prices (Teagasc, 2013).

The outputs from the model include physical outputs such as feed budget, nutrient balance sheet, and physical ratios, and financial indicators (operating cash flow, profit and loss account, and balance sheet).

The physical outputs from the model include GHG emissions, nitrogen balances, and milk production. Physical outputs also contain a tornado feed-budget graph of the requirements of grass, grass silage, and concentrate for each month of the year on an individual cow basis.

Operating cash flows are summarized for each month of the year and indicate the cash surplus or deficit in each month. The estimated farm profit and loss account is presented on a total farm basis as well as on a hectare, per cow calving, and per kilogram of milk produced. Farm net profit includes total receipts less total costs, including full labour costs. The fixed
cost distinguishes interest costs on an overdraft account from term liabilities. Interest earned on the cash flow in the current account is distinguished from other farm receipts. The farm balance sheet summarizes the assets and the liabilities of the business, and it estimates net worth.

A key and innovative part of the development of MDSM is the inclusion of stochastic simulation modelling. Stochastic features were introduced into the budget. Stochastic simulation was carried out in the MDSM using the computer software @Risk (Palisade, 2000), which works by a process, of “Monte Carlo Sampling”. Monte Carlo risk assessment (also called Monte Carlo uncertainty assessment) specifies a probability distribution for each sensitivity parameter, draws a set of those parameters, and repeats the conventional analysis for multiple draws (Phillips and Maldonado, 1999; Phillips, 2000). A sufficiently large number (10,000) of simulations are run with the same input distributions so that the probability distribution functions of the outputs are adequately described (Isukapalli et al., 1998).

2.2.2 The GHG Model
A cradle to farm-gate attributional LCA model was developed by O’Brien et al. (2012). The model is described in detail by O’Brien et al. (2012). An overview of the model is given here.

The GHG model estimates all known GHG emissions from dairy production: CO₂, CH₄, N₂O, and fluorinated gases (F-gases). The model quantifies on and off-farm GHG sources (e.g. fertilizer, pesticide and fuel manufacture) associated with milk production up to the farm gate. The GHG model operates in combination with Moorepark Dairy System Model (MDSM; Shalloo et al., 2004). The MDSM is a whole farm simulation model, which provides input data (e.g. animal inventory, feed intakes etc.) for the GHG model. The MDSM uses the net energy (NE) to determine feed requirements (Jarrige, 1989). Calculated feed requirements were validated using actual intake data from the Le Pin-au-Haras research herds (Delaby et al., 2009).

The GHG model calculates on and off-farm GHG emissions by combining farm input data from the MDSM with literature GHG emission algorithms (Table 1). On-farm emission algorithms for CH₄, N₂O and CO₂ emissions from sources such as manure storage and crop residues were obtained from Intergovernmental Panel on Climate Change (IPCC) guidelines.
(IPCC, 2006) and national inventory reports (e.g. Duffy et al. 2012 a,b). Enteric CH$_4$ emissions were estimated as a function of feed intake, using a fixed factor of 6.5% of gross energy intake (GEI) for all cattle diets in the analysis of French dairy systems. For Irish dairy systems, a regression equation from Yan et al. (2000) was also used to estimate enteric CH$_4$ emissions, but only when cattle were indoors consuming grass silage and concentrate.

On-farm emissions of CO$_2$ were limited to fossil fuel combustion, urea and lime application. Short-term biogenic sources and sinks of CO$_2$ such as animals, crops and manure were considered to be neutral with respect to GHG emissions given that the IPCC (2006) and International Dairy Federation (IDF, 2010) guidelines assume all carbon absorbed by animals, crops and manure to be quickly released back to the atmosphere through respiration, burning and decomposition.

Generally, most studies report that soils have a limited capacity to store carbon (Jones and Donnelly, 2004), but recent reports suggest that managed permanent grasslands soils are an important long-term carbon sink e.g. Conant et al. (2001), Janssens et al. (2005) and Soussana et al. (2010). Thus, the effect of including carbon sequestration is also tested. According to the review by Soussana et al., (2007, 2010) of permanent European grassland soils carbon sequestration rates vary between regions partly due to management practices. Therefore, to compare dairy systems, we used an average annual European value of 0.87 t/CO$_2$ per ha to calculate carbon sequestration by permanent grassland soil.

Off-farm GHG emissions associated with production and supply of non-agricultural products (e.g. fuel manufacture) were estimated using emission factors from the Ecoinvent database and data from literature sources (Table 2). Emission factors for on-farm sources and purchased non-agricultural products were used in combination with physical data from national statistics and literature reports to quantify emission factors for growing and harvesting purchased feedstuffs (Jungbluth et al., 2007; Vellinga et al., 2012). Emissions from processing and transporting feedstuffs were estimated using emission factors from Ecoinvent (2010) and Vellinga et al. (2012). Average sea, rail and road transportation distances and load factors were estimated based on Searates (2012), Jungbluth et al. (2007) and Nemecek and Kägi (2007). Emission factors for importing feedstuffs were estimated by summing emission factors for the farm, processing and transportation stages (Table 2).
Emissions from land use change were estimated for South American soybean and South-East Asia palm fruit. The approach used to calculate land use change emissions from these crops was taken from Jungbluth et al. (2007) and involved dividing the total land use change emissions for a crop by the total crop area to estimate the average land use change emissions per crop. This resulted in average land use change emissions per ha from South American soybean of 2.6 t of CO₂ and South-East Asia palm fruit 5.5 t of CO₂.

Outputs of the dairy farm GHG model were a static account of annual on-farm and total (on and off-farm) GHG emissions in CO₂ equivalents (CO₂-eq). The IPCC (2007) global warming potentials (GWP) were used to convert GHG emissions into kg of CO₂-eq using a 100-yr time horizon, where the GWP of CO₂ = 1, CH₄ = 25, and N₂O = 298. The GHG model expresses total GHG emissions as the carbon footprint of milk in kg of CO₂-eq per t of energy corrected milk (ECM), which per kg of milk is equivalent to 4% milk fat and 3.3% milk protein (Sjaunja et al., 1990).
Table 1. Emission factors from the IPCC (2006) guidelines used in the dairy farm greenhouse gas model (O’Brien et al., 2011) for quantification of on-farm agricultural emissions

<table>
<thead>
<tr>
<th>Emission and source</th>
<th>Emission factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Methane (CH$_4$)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enteric fermentation</td>
<td>$0.065 \times \text{GEI}^1$</td>
<td>MJ/d</td>
</tr>
<tr>
<td>Manure storage</td>
<td>$\text{Manure VS}^2 \times 0.24 \times 0.67 \times (\text{MSa}^3 \times 0.17 + \text{MSb}^4 \times 0.02 + \text{MSC}^5 \times 0.001 + \text{MSd}^6 \times 0.01)$</td>
<td>kg/year</td>
</tr>
<tr>
<td>Grazing returns$^7$</td>
<td>$\text{Manure VS excreted on pasture} \times 0.24 \times 0.67 \times 0.01$</td>
<td>kg/year</td>
</tr>
<tr>
<td><strong>Ammonia (NH$_3$-N)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synthetic N fertilizer</td>
<td>$0.1 \times \text{N fertilizer}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Slurry storage</td>
<td>$0.4 \times \text{slurry N stored}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Solid manure storage</td>
<td>$0.3 \times \text{solid manure N stored}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Manure application</td>
<td>$0.2 \times (\text{N stored} – \text{NH$_3$ storage loss})$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Grazing returns$^7$</td>
<td>$0.2 \times \text{N excreted on pasture}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td><strong>Nitrate (NO$_3$-N)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N leaching</td>
<td>$0.3 \times \text{N applied}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td><strong>Nitrous oxide (N$_2$O-N)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing returns$^7$</td>
<td>$0.02 \times \text{N excreted on pasture}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Synthetic N fertilizer</td>
<td>$0.01 \times \text{N fertilizer}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Manure application</td>
<td>$0.01 \times (\text{N stored} – \text{N storage loss})$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Crop residues</td>
<td>$0.01 \times \text{N Crop Residues}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Slurry storage</td>
<td>$0.005 \times \text{slurry N stored}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Solid manure storage</td>
<td>$0.005 \times \text{solid manure N stored}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Dry lot</td>
<td>$0.02 \times \text{dry lot manure N stored}$</td>
<td>kg/kg N</td>
</tr>
<tr>
<td>Nitrate leaching</td>
<td>$0.0075 \times \text{N leached}$</td>
<td>kg/kg NO$_3$-N</td>
</tr>
<tr>
<td>Ammonia re-deposition</td>
<td>$0.01 \times \text{sum of NH$_3$ emissions}$</td>
<td>kg/kg NH$_3$-N</td>
</tr>
<tr>
<td><strong>Carbon dioxide (CO$_2$)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>$2.63 \times \text{diesel use}$</td>
<td>kg/l</td>
</tr>
<tr>
<td>Gasoline</td>
<td>$2.30 \times \text{gasoline use}$</td>
<td>kg/l</td>
</tr>
<tr>
<td>Kerosene</td>
<td>$2.52 \times \text{kerosene use}$</td>
<td>kg/l</td>
</tr>
<tr>
<td>Lime</td>
<td>$0.44 \times \text{lime application}$</td>
<td>kg/kg lime</td>
</tr>
<tr>
<td>Urea</td>
<td>$0.73 \times \text{urea application}$</td>
<td>kg/kg urea</td>
</tr>
</tbody>
</table>

$^1$ GEI = Gross energy intake.
$^2$ VS = Volatile solids.
$^3$ MSa = Proportion of manure volatile solids stored in slurry system.
$^4$ MSb = Proportion of manure volatile solids stored in solid storage system. Solid manure dry matter content >20%.
$^5$ MSc = Proportion of manure volatile solids spread daily.
$^6$ MSd = Proportion of manure volatile solids stored in dry lot.
$^7$ Manure excreted by grazing cattle on pasture.
Table 2. Emissions factors used in the dairy farm greenhouse gas (GHG) model (O’Brien et al., 2011) for quantification of off-farm GHG emissions from manufacture and transport of key purchased inputs in g of CO2 equivalents.

<table>
<thead>
<tr>
<th>Item</th>
<th>Emission factor^2</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>French Electricity, kWh</td>
<td>108</td>
<td>Ecoinvent (2010), Defra (2011)</td>
</tr>
<tr>
<td>Diesel, kg</td>
<td>359</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>Gasoline, kg</td>
<td>455</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>Kerosene, kg</td>
<td>341</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>Ammonium-based fertilizer EU, kg N</td>
<td>5,164</td>
<td>Ecoinvent (2010), Leip et al. (2010)</td>
</tr>
<tr>
<td>Ammonium-based fertilizer US, kg N</td>
<td>5,164</td>
<td>Snyder et al. (2009), Ecoinvent (2010)</td>
</tr>
<tr>
<td>Urea EU, kg N</td>
<td>2,627</td>
<td>Ecoinvent (2010), Leip et al. (2010)</td>
</tr>
<tr>
<td>Lime, kg</td>
<td>43</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>P fertilizer, kg P_{2}O_{5}</td>
<td>1,926</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>K fertilizer, kg K_{2}O</td>
<td>363</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>Pesticide, kg active ingredient</td>
<td>7,421</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>Milk replacer, kg</td>
<td>1.38</td>
<td>Ramirez et al. (2006), Ecoinvent (2010)</td>
</tr>
<tr>
<td>Barley, kg DM</td>
<td>373</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Corn grain Europe, kg DM</td>
<td>412</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Beet pulp^3, kg DM</td>
<td>61</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Corn gluten, kg DM</td>
<td>1,078</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>DDGS^4, kg DM</td>
<td>929</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Rapeseed meal, kg DM</td>
<td>482</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Soyabean meal South America^5, kg DM</td>
<td>1,472</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Soyabean meal USA, kg DM</td>
<td>299</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Straw, kg DM</td>
<td>41</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Molasses, kg DM</td>
<td>149</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Irish dairy concentrate^6 16% CP^7</td>
<td>501</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>French dairy concentrate^8 16% CP</td>
<td>477</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>French dairy concentrate^9 25% CP</td>
<td>623</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>French dairy concentrate^10 32% CP</td>
<td>895</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
<tr>
<td>Heifer concentrate^10 16% CP</td>
<td>451</td>
<td>Ecoinvent (2010), Vellinga et al. (2012)</td>
</tr>
</tbody>
</table>
1 Carbon dioxide = 1; methane = 25; nitrous oxide = 298 (IPCC, 2007).
2 Emissions algorithms from the current IPCC (2006) guidelines were used to estimate emissions from agricultural GHG sources related to the production of feedstuffs.
3 Emissions were allocated between co-products based on their economic value using national data, EcoInvent (2010) and Vellinga et al. (2012).
4 DDGS = Dried distillers grains with solubles.
5 Based on EcoInvent (2010), 62% of South American soybean was from Argentina and 38% was from Brazil.
6 Concentrate formulation on a DM basis, Irish wheat feed 17%, German corn grain 16%, USA dried distillers grains 15%, USA soy hulls 12%, French rapeseed meal 9%, USA corn gluten feed 8%, Cuban molasses 6%, USA citrus pulp 5%, Irish barley 5%, vegetable oil 2%, Irish lime 3%, minerals and vitamins 2%.
7 Crude protein.
8 Concentrate formulation on a DM basis, French wheat feed 20.8%, French barley 20.8%, French corn grain 20.7%, French beet pulp 21.4%, South American soybean meal 12%, South American soybean oil 2.3%, molasses 0.9%, salt 1.1%.
9 Concentrate formulation on a DM basis, South American soybean meal 36.1%, French beet pulp 12.9%, French wheat feed 12.6%, French barley 12.5%, French corn grain 12.5%, minerals 10.6%, molasses 1.7%, South American soybean oil 1.1%.
10 Concentrate formulation on a DM basis, South American soybean meal 54.4%, French beet pulp 9.6%, French barley 9.3%, French wheat feed 8.4%, French corn grain 8.3%, minerals 7.2%, molasses 1.7%, South American soybean oil 1.1%.
11 Concentrate formulation on a DM basis, French rapeseed meal 17%, USA soy hulls 15%, Irish wheat feed 14%, USA dried distillers grains 12%, German corn grain 11%, USA corn gluten feed 8%, Cuban molasses 6%, USA citrus pulp 5%, Irish barley 4%, South American soybean meal 2%, vegetable oil 2%, Irish lime 2%, minerals and vitamins 2%.

Besides producing milk, dairy farms may also export crops, manure and produce meat from culled cows, male calves and surplus female calves. Thus, the carbon footprint of dairy systems should be distributed between these outputs. Several methods are recommended by various LCA and carbon footprint guidelines to allocate GHG emissions among the co-products of multifunctional systems (ISO, 2006a,b; IDF, 2010; BSI, 2011). The dairy farm GHG model applies different allocation approaches based on the various guidelines and previous LCA studies of milk.

Allocation of GHG emissions to exported crops was avoided by delimiting the dairy farm GHG model to consider only emissions from crops grown for dairy cattle reared on-farm. The system expansion method recommended by the IDF (2010) LCA guidelines was followed to attribute emissions to exported manure. The method assumes exported manure displaces synthetic fertilizer emissions, but allocates no storage emissions to exported manure. There are several methods to distribute GHG emissions between milk and meat. The following allocation methods can be evaluated:

1) Milk – No allocation to meat all GHG emissions attributed to milk.
2) Mass – The GHG emissions of the dairy system was attributed between co-products according to the mass of milk and meat sold.

3) Protein – Edible protein in milk and meat was used to allocate GHG emissions. The protein content of milk was based on research results and the protein content of meat was assumed to be 20% of carcass weight equivalent (CW; Flysjö et al., 2011).

4) Economic – Allocation of GHG emissions between milk and meat was based on revenue received for milk and meat (sales of culled cows and surplus calves). Prices of milk and animal outputs were estimated using present market values.

5) Biological – The GHG emissions of the dairy system was allocated based on feed energy required for producing milk and meat. The IDF (2010) guidelines and the MDSM (Shalloo et al., 2004) were used to estimate feed energy required to produce milk and meat.

6) Emission – The GHG emissions associated with producing surplus calves, dairy females <24 months and finishing culled cows were allocated to meat with the remaining emissions assigned to milk (O’Brien et al., 2010; Dollé et al., 2011).

Allocation of GHG emissions is also required for concentrate feeds that are co-products e.g. linseed meal. The economic allocation procedure described by IDF (2010) LCA guidelines was used to allocate GHG emissions between concentrate co-products. National reports, Vellinga et al. (2012) and Ecoinvent reports (Jungbluth et al., 2007; Nemecek and Kägi, 2007) were used to estimate concentrate co-product yields and average prices.

3. Results

3.1 France

Table 3 shows the technical description of the Le Pin-au-Haras dairy farm systems (Delaby et al. (2009). Regardless of feeding system, milk production was greatest for the Holstein breed. Replacement rate and therefore culling rate was greater for the Holstein breed compared to the Normande breed. The live weight of the Normande breed was, on average, 44 kg greater than the Holstein breed (694 and 650 kg, respectively).
Table 3. Technical description of Le Pin-au-Haras dairy farming systems

<table>
<thead>
<tr>
<th>Breed</th>
<th>Feeding strategy1</th>
<th>Holstein</th>
<th>Normande</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High-</td>
<td>Low-</td>
<td>High-</td>
</tr>
<tr>
<td></td>
<td>high</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>On-farm size, ha</td>
<td>36</td>
<td>45</td>
<td>39</td>
</tr>
<tr>
<td>Off-farm size2, ha</td>
<td>12</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Grassland, ha</td>
<td>32</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>Milking herd, # cows</td>
<td>34</td>
<td>39</td>
<td>37</td>
</tr>
<tr>
<td>Milk yield, kg/cow</td>
<td>8,400</td>
<td>7,850</td>
<td>7,560</td>
</tr>
<tr>
<td>ECM3 yield, kg/cow</td>
<td>8,107</td>
<td>7,309</td>
<td>7,422</td>
</tr>
<tr>
<td>Milk fat, %</td>
<td>3.81</td>
<td>3.62</td>
<td>3.94</td>
</tr>
<tr>
<td>Milk protein, %</td>
<td>3.25</td>
<td>3.11</td>
<td>3.26</td>
</tr>
<tr>
<td>Calving interval, days</td>
<td>380</td>
<td>380</td>
<td>380</td>
</tr>
<tr>
<td>Replacement rate, %</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Cull rate, %</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Average BW, kg</td>
<td>666</td>
<td>648</td>
<td>657</td>
</tr>
<tr>
<td>Concentrate, kg DM/cow</td>
<td>1535</td>
<td>1065</td>
<td>830</td>
</tr>
<tr>
<td>Grass4, kg DM/cow</td>
<td>3,338</td>
<td>3,283</td>
<td>3,254</td>
</tr>
<tr>
<td>Grass silage, kg DM/cow</td>
<td>1300</td>
<td>2950</td>
<td>1300</td>
</tr>
<tr>
<td>Maize silage, kg DM/cow</td>
<td>1800</td>
<td>0</td>
<td>1800</td>
</tr>
<tr>
<td>Total intake, kg DM/cow</td>
<td>7,973</td>
<td>7,298</td>
<td>7,184</td>
</tr>
<tr>
<td>On-farm N fertilizer, kg/ha</td>
<td>166</td>
<td>196</td>
<td>166</td>
</tr>
</tbody>
</table>

1 The four feeding treatments comprised of two winter feeding strategies crossed with two concentrate supplementation strategies at pasture. The diet of the High winter feed treatment was 65% maize silage, 5% hay and 30% concentrate and the diet of the Low winter feed treatment was 85% grass silage and 15% concentrate. The high concentrate feed level at pasture was 4 kg/cow per day and the low level was 0 kg/cow per day.

2 Off-farm land area required to produce purchased forage and concentrate feedstuffs.

3 ECM = Energy corrected milk = \((0.25 + 0.122 \times \% \text{fat} + 0.077 \times \% \text{protein}) \times \text{kg milk}\) (Sjaunja et al., 1990).

4 Forage intakes were estimated with the Moorepark Dairy System Model (Shalloo et al., 2004) using milk production, animal BW, concentrate supplementation and feed ration composition data.
Economic analysis

Economic analysis of the French systems was previously published by Delaby and Pavie (2008). Briefly, Regardless of feeding system, the Holstein breed was more profitable than the Normande breed. This was largely due to the greater milk output per cow from the Holstein breed. The Holstein breed was more reactive to feed input, and at a high feeding level had a greater response in terms of milk production and hence profitability. The advantage of the Holstein breed over the Normande in economic terms is largely due to the fact that less cows and heifers are required for the same quota due to the higher milk yield of the breed and so less land is required for grass. The additional land for the Holstein breed is then converted to cereal crops. The higher the cereal price, the greater the benefit associated with intensification of the milk production system (Holstein, maize silage and concentrates). The possibility of substitution between forage area and cereal area influences farm profitability.

Carbon profiles and footprints of milk for the Le Pin-au-Haras dairy farming systems

The carbon footprints and profiles of milk with all GHG emissions allocated to milk of the eight Le Pin-au-Haras dairy systems differing in breed and feeding strategy were quantified. Averaged across feed treatments, the carbon footprint of milk from Normande cows was 6% greater than Holstein cows. The main sources of GHG emissions for both breeds were enteric CH$_4$ (<50%), followed by CO$_2$ and N$_2$O emissions from fertilizer application and production, and then N$_2$O and CH$_4$ emissions from manure storage and spreading and N$_2$O emissions from manure excreted by grazing cattle. On average, enteric CH$_4$ emissions per ton of energy corrected milk (ECM) were 5% greater for the Normande breed relative to the Holstein breed, and N$_2$O emissions from manure excreted by grazing cattle was 11% greater for the Normande breed.
Averaged across cow breed, the Ll feed treatment had the lowest carbon footprint of milk for the two winter feeding strategies crossed with two concentrate supplementation strategies at pasture. The HI feed treatment had the highest carbon footprint of milk followed by the Lh and Hh feed treatments. However, compared to the difference between the average carbon footprints of milk for cow breeds, the carbon footprints of milk for the Ll and HI feed treatments were similar. For instance, the Holstein breed had their lowest carbon footprint of milk on the HI feed treatment and highest on the Lh treatment. Conversely, the Normande breed had their highest carbon footprint of milk on the HI feed treatment and lowest on the LL treatment.

The carbon profiles of the four feed treatments, averaged across breeds, showed that the HI feed treatment had the highest enteric CH\(_4\) emissions per t of ECM followed by the Ll, Lh and Hh feed treatments. The high concentrate winter feeding strategies (Hh and HI) also sequestered less carbon from grassland per ton of ECM and increased GHG emissions from concentrate production per ton of ECM compared to the Lh and LI feed treatments. The Lh and LI feed treatments, however, had higher CO\(_2\) and N\(_2\)O emissions from fertilizer application and production per ton of ECM compared to the Hh and HI feed treatments.

2 Ireland

a. Jersey, Holstein-Friesian and Jersey × Holstein-Friesian

*Moorepark controlled research study*

Yield of milk solids per cow was highest for the Medium and Low SR groups. The HF and F1 cows had similar milk solids yield. Milk solids per ha were highest for the medium SR group. Body weight was lowest for the J group and BCS lowest for the HF group. Body
weight and BCS were lowest for the High SR group with the Medium and Low SR groups being similar.

Comparative performance based on national data set
The JE breed expressed a lower propensity for milk, fat and protein yield (305 d) compared with pure HO cows, but milk fat and protein content is higher. Estimates for SCS demonstrate slightly inferior udder health with JE compared with HO. On average, however, JE×HO cows, are expected to produce slightly lower milk yields but higher yields of fat and protein compared to pure HO cows.

Breed effects for survival (SURV) were favourable for JE relative to HO. The breed effect for calving interval was less for JE compared with HO.

Economic Analysis
The performance data generated demonstrates that crossbred (Jersey×Holstein-Friesian) dairy cows are capable of production levels per cow at least similar to their Holstein-Friesian contemporaries on low cost systems, but fertility and survival levels are markedly improved, e.g. six week in-calf rates were increased with crossbreds

Initial economic analysis with the MDSM (Shalloo et al., 2004) using the biological data generated from this study, indicates a substantial profit benefit per lactation with the Jersey × Holstein-Friesian cows. Analysis presented by Prendiville et al. (2011) indicated a substantially higher benefit to crossbreeding with Jersey (+€18,000 annually
Breed and heterosis effects on carbon footprint of milk

Across the different methods applied to allocate GHG emissions between milk and meat, the JE breed had the lowest carbon footprint of milk using the nationally extrapolated dataset. The combination of greater reproductive efficiency and higher protein and fat content of the JE cow’s milk resulted in the breed requiring the least feed per unit of milk (feed conversion efficiency). Therefore, the JE breed emitted the lowest enteric CH4 emissions, which is the main component (45-50%) of carbon footprint of milk from grass-based systems.

However, excluding attributing GHG emissions only to milk, the proportion of GHG emissions allocated to milk varied by breed. This was because of differences between breed’s economic values for surplus calves and culled cows, GHG emissions from the replacement herd and the total energy required for producing milk and meat. As a result, the relative differences between breed’s carbon footprints of milk were not consistent between allocation methods.

Nevertheless, regardless of allocation method, the JE×HO cross also had a lower carbon footprint of milk than the HO breed. This was mainly because the reproductive efficiency and solids content of the milk of the JE×HO cross was greater than the HO breed. However, the JE×HO cross had a slightly higher carbon footprint of milk than the JE breed using all allocation methods, except economic allocation. The carbon footprint of milk of the JE×HO cross was similar to the JE breed when allocation was based on economics, because surplus JE calves were assumed to have no economic value and the price of culled JE cow was half that of JE×HO cows.
b. Norwegian Red, Holstein-Friesian and Holstein Friesian×NorwegianRed dairy cows

**Genetic differences and heterosis estimates**

The NR expressed a lower propensity for milk volume (305 d milk yield) compared with pure Holstein cows. Although NR milk on average had higher fat and protein content compared to Holstein, they produced lower 305 d yields of fat and protein. The production characteristics of NR appears similar to pure BF but inferior to pure KF. Estimates for SCS demonstrated a genetic propensity for superior udder health with NR, compared with HO, BF and KF. From a practical perspective, in line with the previous findings of Begley et al. (2009), NR×HO cows are capable of milk production levels not dissimilar to that of pure HO cows.

**Economic Analysis**

Initial economic analysis using the MDSM (Shalloo et al., 2004) conducted using the data extrapolated from the national data set incorporating data up to 6th lactation suggests that the profit generating potential of Norwegian×Holstein-Friesian is similar to pure Holstein under Irish conditions. This is in contrast to previous analysis by Buckley and Shalloo (2009) which indicated a €130 per cow advantage to the Norwegian crossbreds as a result of markedly improved reproductive efficiency compared with the Holstein-Friesian contemporaries. When the data was extrapolated to the national dataset the fertility benefits of the Norwegian Red×Holstein-Friesian were not apparent when compared to research results. In the analysis included it was assumed that all cows milked for 305 days irrespective of calving date when at farm level these cows would tend to have a shortened lactation as cows are dried off before Christmas.

**Breed and heterosis effects on carbon footprint of milk**

The analysis of GHG emissions from dairy farming systems differing in breed using nationally extrapolated data showed that the NR, BF and KF breeds caused a minor to moderate (1-5%) increase in the carbon footprint of milk compared to the HO breed. However, for 4 of the 6 allocation methods (protein, economic, biological and emission allocation methods) the proportion of GHG emissions attributed to milk varied by breed. This was because of differences between breed’s economic values for surplus calves and culled cows, GHG emissions from the replacement herd and the total energy required for producing milk and meat. Thus, the relative
differences between breed’s carbon footprints of milk were not consistent between allocation methods.

The NR×HO cross exhibited positive heterosis for survival and calving interval, but depending on allocation method, caused a minor decrease (-1%) or increase (2%) in the HO breeds carbon footprint of milk. This was principally because the HO breed produced more milk/cow.

4. Conclusions

The most profitable genotype or breed is the one that returns the highest profit per unit of the most limiting input.

In France, on average across feed treatments, the Holstein breed produced the most milk per cow and required the least feed per unit of milk. Regardless of feeding system, the Holstein breed was more profitable than the Normande. As a result of the higher milk yield and lower feed requirement per unit of milk, the Holstein breed had the lowest carbon footprint of milk. However, the relative difference between Holstein and Normande breeds carbon footprints of milk varied from 4-8% depending on allocation method. This can be explained by differences between breed’s for surplus calves and culled cows prices, GHG emissions from the replacement herd and the total energy required for producing milk and meat.

In Ireland the impending removal of EU milk quotas will result in land becoming the most limiting resource. The analyses undertaken therefore assume that fat adjusted milk quota will not be a constraint at farm level in the future. The results from the Jersey crossbreeding study indicate that with a fixed land base Jersey crossbred dairy cows can offer immediate substantial improvements to farm profit and moderately mitigate the carbon footprint of milk. In addition, the results highlight that losses resulting from reduced cull cow and male calf value are clearly overshadowed by the overall performance of the Jersey×Holstein-Friesian. The results suggest that on a per ha basis HF, J and F1 cows can produce similar yields of milk solids when grazed to similar post-grazing intensities. The results from the Norwegian Red crossbreeding study indicate that Norwegian Red crossbred dairy cows can offer immediate and substantial improvements in fertility and survival, but had little influence on the carbon footprint of milk. The herd profitability may be different under a scenario where the herd was dried off on a fixed date rather than the herd milking for 305 days.
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