MODELING THE NITROGEN AND PHOSPHORUS INPUTS AND OUTPUTS OF FINANCIALLY OPTIMAL IRISH BEEF PRODUCTION SYSTEMS

P. Crosson, C. A. Rotz, P. O’Kiely, F. P. O’Mara, M. Wallace, R. P. O. Schulte

ABSTRACT. Challenges currently faced by beef producers in Ireland include reducing their adverse environmental impact and maintaining farm economic margins. Fertilizers are essential for productive farming but they can be harmful to the environment when inappropriately or excessively applied to crop and pasture land. A linear programming model was used to identify financially optimal strategies for calf-to-stocker and calf-to-finish beef cattle production in high- and low-price market scenarios. The high-price scenario resulted in an increase in gross margin of $1,700 and $13,000 on a 40-ha farm for the stocker and finisher options, respectively. The impacts of these systems on environmental indicators were investigated through farm simulation. In general, the high-price scenarios were more intensive and had greater environmental impacts when compared to the low-price scenarios. Nitrogen leaching losses were quantitatively the most important environmental indicator on well-drained soils with a maximum annual loss of 72 kg N/ha. Volatilization and denitrification losses of nitrogen (N) were also relatively high where more intensive production was practiced with annual losses of 48 and 23 kg N/ha, respectively, in the most intensive scenario identified. Predicted phosphorus losses were small although annual accumulations in the soil of up to 7.5 kg P/ha may lead to greater losses in the future. On poorly drained soils, volatilization losses were greatest with leaching losses in this case the lowest of the loss pathways investigated. Further reduction in inorganic nitrogen application has the potential to reduce N losses, but predicted concomitant reductions in farm gross margins were also considerable.

Keywords. Beef production, Linear programming model, Nitrogen, Phosphorus, Simulation model.

In many developed countries, much of commercial farming operates under the influence of society’s increasingly multifunctional expectations. Such farming must thus be sustainable within a range of economic, social, and environmental criteria. For example, the European Union (EU) Luxembourg Common Agricultural Policy (CAP) reform agreement provides direct payments [commonly referred to as single farm payments (SFP)] to farmers who comply with a range of requirements relating to the environment, animal welfare, and food safety. This involves major changes and uncertainty in business conditions and operating practices for many farmers.

Within the EU, the market framework provided by the Luxembourg Agreement (LA) is augmented by further agreements and regulations. The Nitrates Directive (Directive 91/676/EEC) requires that measures be taken with respect to farm practices to ensure that the EU standard for nitrates in potable water of 50 mg/L is not breached. The implications of this Directive are that farmers cannot exceed annual organic nitrogen (N) application rates of 170 kg N/ha. In addition, closed periods for application of organic manure together with at least minimum requirements for manure storage facilities are specified. In the longer term, World Trade Organization (WTO) agreements are expected to reposition cereal, milk, and beef prices closer to those on the world market (Westhoff et al., 2003). These changes will require each producer to carefully evaluate a range of options when formulating the most appropriate systems for their likely future conditions.

Beef produced in Ireland is sourced from the national cow-herd of 2.4 million of which approximately half are beef cows (CSO, 2004). This results in an annual calf-crop of 1.8 million calves to be raised for beef production. The output is predominantly derived from grazed and ensiled grass as these have been the cheapest forms of feed available (O’Riordan and O’Kiely, 1996). Many Irish farmers operate their beef production enterprise within the regulations of the Rural Environment Protection Scheme (REPS). REPS is a program operated by the Irish Government to provide annual incentives of up to $241/ha to farmers for producing food in an extensive and environmentally-friendly manner (Department of Agriculture, Food and Rural Development, 2000). An important requirement is a limit on annual land application of 170-kg organic N/ha and 260-kg total N/ha imposed on the area farmed.
Euthrophication of surface waters and contamination of ground water have increased concerns about N and phosphorus (P) applications in agriculture. It is important that farmers manage their production systems to minimize N losses between application to the soil and uptake by the plants (Humphreys et al., 2003). Farmers must also remain cognizant of P losses since small losses (of the order of 1 kg P per ha per year) are adequate to promote increased plant growth in rivers and lakes (Tunney et al., 2000). A suitable P application strategy (e.g. Culleton, 2000) is essential to minimize surpluses and the long-term accumulation of soil P on farms. Farmers must make decisions based on a complex matrix of criteria. These criteria are specific to each individual farm and include factors such as soil type, farm facilities, beef and input prices, and government regulations. Mathematical models provide the opportunity to identify optimal beef production systems within a set of farm constraints and management alternatives (Conway and Killen, 1987; Berentsen and Giesen, 1995; Nielsen et al., 2004; Veysset et al., 2005). A linear programming model, the Grange Beef Model (GBM), was developed to determine optimal Irish beef production systems (Crosson et al., 2006). In this model, beef production activities available to Irish farmers and the resources and constraints within which these farmers operate are identified. Based on the marginal revenue and cost associated with each activity, financially optimal systems are predicted. While this model permits the identification of optimal systems in terms of farm gross margin, the N and P fluxes are not addressed. A separate simulation model, the Integrated Farm System Model (IFSM; Rotz et al., 2005a) can be used to track these nutrients in agricultural production systems. The IFSM is a computer simulation model which integrates the various farm processes that control animal performance and nutrient flows in livestock production systems. It has been used to investigate nutrient losses on Dutch (Rotz et al., 2006) and German (Rotz et al., 2005b) dairy farms.

Therefore, our goal was to evaluate the environmental consequences of economically optimal beef production systems in Ireland. Specific objectives were to 1) use the Grange Beef Model to identify economically optimal systems of beef production given the physical and regulatory restrictions under which Irish farmers operate, and 2) use the Integrated Farm System Model to investigate the impact of these optimal systems on farm level N and P fluxes.

**PROCEDURE**

**GRANGE BEEF MODEL**

The Grange Beef Model is a linear programming model designed to identify financially optimal beef production systems in Ireland given a range of resource and economic parameters. It is constructed around a typical beef cow herd based on spring calving of Limousin × (Limousin × Friesian) cows (Drennan, 1999). Included are beef cow, replacement heifer, calf, stocker, and finishing animal groups. Cows are described as either young (first lactation) or mature (more than one lactation). Cows are artificially inseminated, so bulls are not included in the herd. Nutritional needs of each group are described in terms of energy requirements and intake capacity. Intake is energy driven, but it is potentially limited by physical fill (Crosson et al., 2006).

The feeds available are pasture, grass silage, corn silage, and concentrates. Due to the predominance of pasture-based systems in Ireland, the model specifies a detailed set of grazing options that are typical of those available to Irish cattle producers. A number of options are included to facilitate winter feeding and feeding in periods of temporary grass shortage during the grazing season. Forage production is based on historical Irish yield data with key nutritional variables taken from INRA (INRA, 2003). For the purposes of nutritional calculations, the growing season is divided into three periods; early, mid-, and late-season grazing. Yield is specified on a monthly basis.

Budgets are formulated for each activity using recent Irish price data (Teagasc, 2004). These budgets assign a cost or revenue to each activity and, based on these, the program identifies the optimal net farm gross margin. Costs for farm equipment, buildings, energy, etc. (with the exception of rented land and hired labor) are assigned based on farm type and size (Teagasc, 2004). Land rental and hiring of labor are established from the model-predicted land and labor resources required to operate each production system (Crosson et al., 2006).

**INTEGRATED FARM SYSTEM MODEL**

The Integrated Farm System Model is a simulation model which can be used to evaluate the long-term performance and environmental impact of beef production systems. Land use, inorganic fertilization rates, and animal production details must be specified by the model user. The beef herd is described by some combination of six possible animal groups including suckling calves, weaned calves, stockers, finishing cattle, replacement heifers, and beef cows (Rotz et al., 2005a). Animal breed characteristics such as mature weight, peak milk yield, and animal birth weight are specified. A feed allocation scheme is used to represent a farmer’s approach to making the best use of feeds. High-quality forage is fed to calves and finishing cattle with lower quality forage fed to other cattle. For finishing cattle fed a high concentrate diet, forage in the diet is set to supply 10% of the total energy requirement.

Diets for a representative animal of each animal group are formulated to meet four nutrient requirements: a minimum roughage requirement, an energy requirement, a minimum requirement of ruminally degradable protein, and a minimum requirement of ruminally undegradable protein (Rotz et al., 2005a). The energy and protein requirements of each animal group are determined using level 1 of the Cornell Net Carbohydrate and Protein System (CNCP; Fox et al., 2004). Ration balancing and performance prediction are accomplished by means of a linear program to determine a least-cost ration that meets the animal’s nutrient requirements. The calculated intake of nutrients is used to predict growth and body condition score.

Based on the diet fed, the quantity and nutrient contents of the manure produced are determined. The nutrient contents in fresh manure are calculated by means of a mass balance for all animal groups. Manure nutrients tracked are N, P, and potassium (K). Fecal dry matter (DM) is the total quantity of all feeds consumed by each animal group multiplied by the fraction of indigestible nutrients of each feed. Additional manure DM includes any bedding DM used and 3% of the feed DM intake that is lost into the manure. Urine production is a function of DM intake, crude protein...
intake, and milk production (Rotz et al., 2005a). Phosphorus loss from the farm through surface runoff and erosion is modeled as a function of manure P content and solubility and the techniques used for manure handling and incorporation into soil (Sedorovich et al., 2005).

Manure N is partitioned between organic and ammoniacal N. Organic N is considered stable during manure handling and ammoniacal N is susceptible to volatile loss as ammonia (Rotz et al., 2005a). Nitrogen losses during animal housing, manure storage, following field application, and during grazing are each modeled as functions of weather conditions and manure handling practices (Rotz and Oenema, 2006). Nitrogen movement and transformation within and among soil layers is modeled with functions from the Nitrate Leaching and Economic Analysis Package (NLEAP) model (Shaffer et al., 1991). Nitrate concentration in the leachate is the nitrate leached below the root zone divided by the moisture moving below the root zone in the soil profile. To calibrate IFSM for N losses in Ireland, parameters were adjusted to obtain losses similar to those obtained with a model, NCYCLE, developed in the UK (Scholefield et al., 1991) and adapted to Irish conditions (del Prado et al., 2005). With a dimensionless leaching coefficient of 0.85 and a denitrification rate of 0.125/d, IFSM accurately replicated NCYCLE in predicting N losses.

**Scenarios**

Two beef production strategies from within beef cow herd systems, calf-to-stocker and calf-to-finish, were specified with cows calving in March. In the calf-to-stocker scenarios, stocker heifers and steers were sold at 290- and 315-kg liveweight, respectively, at 9 months of age. In the calf-to-finish scenarios, finishing animals were finished at 24 months of age at 660 and 740 kg for heifers and steers, respectively. The land area farmed was 40 ha with all the land farmed as permanent perennial grassland. Additional land was available with an annual rental price of $300/ha. A loam soil was specified for all land. Grass silage was harvested in a one-cut system, with a single harvest taken in June, or as a two-cut system with an early harvest taken in May, and a second harvest taken 6 to 8 weeks later. Purchased concentrates completed the feed ration. Participation in REPS was assumed in all cases, and the annual SFP receipts were $361/ha.

Research by Binfield et al. (2003) indicates that implementation of the LA in the EU will result in an increase in beef prices due to a reduction in beef supply as suckler cow numbers decrease. Beef prices were predicted to rise by over 20% by 2010 relative to 2005 levels. Calf and stocker prices were predicted to rise accordingly although, not equally for heifers and steers. The negative price impact on steers of decoupling of premia, which was payable per steer, is such that the price increase was projected to be less for steers than for heifers (Binfield et al., 2003). Therefore, two price scenarios, high and low, representing 2005 and 2010 price scenarios were investigated (table 1). In the low-price scenario, cattle and beef prices were set to 2005 levels. In the high-price scenario, stocker steer prices were assumed to rise by 10% while stocker heifer prices and beef prices were assumed to rise by 20%. Since it was assumed that the low-price and high-price scenarios represented the market and policy conditions prevailing in Ireland in 2005 and 2010 respectively, input costs, including labor, concentrate, and fertilizer, were adjusted to account for inflation for the high-price scenario. An inflation rate of 2.8% per annum was assumed (Binfield et al., 2003).

Thus four scenarios were investigated; calf-to-stocker low price (SL), calf-to-stocker high price (SH), calf-to-finish low price (FL), and calf-to-finish high price (FH), all within beef cow herd systems. Soil drainage capacity is an important property determining N losses in Ireland (Schulte et al., 2006). Thus for the scenarios investigated, two soil drainage capacities were considered; well drained soils and poorly drained soils as defined by Schulte et al. (2005).

**Environmental Evaluation**

The importance of farming within the constraints of environmental regulation has been outlined. Therefore, the two scenarios investigated, environmental effects were predicted using the IFSM model. The two nutrients tracked were N and P. The mechanisms of N loss from soil have been well documented (Loehr, 1984; Rotz et al., 1999; Humphreys et al., 2003; Gibbons et al., 2005). Under conditions of high rainfall, nitrates are prone to be leached from the soil (Gibbons et al., 2005) whereas, with poor soil aeration and high oxygen demand, denitrification can occur resulting in N2O and N2 being released to the atmosphere (Loehr, 1984). Warm, sunny weather promotes the volatilization of ammonia gas, particularly during the application of slurry (Humphreys et al., 2003). Therefore, these forms of N loss were investigated for each of the optimal systems identified.

A key component of a sustainable P strategy as outlined by Culleton (2000) is to not exceed the replacement of P removed from the farming system once the optimum soil P level has been reached. Therefore, the P imported, exported, lost in runoff, and accumulated in the soil was investigated for each scenario using IFSM.

All animals were housed over the winter period of 4 to 5 months in free stall barns. Manure deposited in the barn was handled as slurry with a DM content of 8% to 10%. The slurry was assumed to be stored up to 6 months in a concrete tank with top surface loading. Slurry was applied using a splash-plate applicator without incorporation into the soil.

**Model Evaluation**

Prior to using both models, it was necessary to ensure that IFSM accurately replicated GBM results in terms of animal performance and forage yields on Irish beef farms. Therefore, a component-based comparison was undertaken. The forage yield and response to N fertilizer were first compared. Then GBM was solved to find the financially optimal system in the policy and market environment prevailing in 2005. The Integrated Farm System Model was subsequently run using

---

### Table 1. Cattle and beef prices for the high- and low-price scenarios solved using the Grange Beef Model.

<table>
<thead>
<tr>
<th></th>
<th>Low Price</th>
<th>High Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stocker steer price ($/head)</td>
<td>422</td>
<td>464</td>
</tr>
<tr>
<td>Stocker heifer price ($/head)</td>
<td>361</td>
<td>434</td>
</tr>
<tr>
<td>Fall beef price ($/kg carcass)</td>
<td>3.37</td>
<td>4.04</td>
</tr>
<tr>
<td>Spring beef price ($/kg carcass)</td>
<td>3.49</td>
<td>4.22</td>
</tr>
<tr>
<td>Cull cow price ($/kg carcass)</td>
<td>2.29</td>
<td>2.77</td>
</tr>
</tbody>
</table>

[a] $1 = 0.83 Euros.
the resulting optimal system parameters predicted by GBM in terms of land use, fertilization rate, and animal production. Animal intake and total feed use predicted by the two models were then compared.

**Forage Yield**

The Grange Beef Model specifies forage yield for the grazing area based on seven annual application rates of N; 0 to 300 kg N/ha in 50-kg N/ha increments. Simulations for each of these application rates were performed using IFSM. Initial results indicated that some yield adjustment was required. A yield adjustment factor is available in IFSM to adjust pasture yield for the effects of management practices such as crop variety, soil fertility, weed control and general pasture management. Following appropriate adjustments, simulations were run with the yields in reasonable agreement between the two models. Predicted yields for two fertilization strategies, 100 and 150 kg N/ha/year, are shown in Figure 1. Relative to the growth curves assumed in GBM (Crosson et al., 2006), IFSM underestimated production in spring and overestimated production in fall. However, the annual production across all fertilization strategies indicated a yield differential of only 2% between the two models.

**Intake Prediction**

To evaluate intake predictions, the two main categories of cattle were compared, cows and stocker through finishing cattle (fig. 2). Similar predictions of intake were obtained from both models. Some deviation was evident in the intake of beef cows at the start and at the end of the grazing season (the grazing season begins in February or March and finishes in October or November). This difference can be explained by a small deviation in calving dates between the models. In IFSM, the average calving date was the middle of the month selected, in this case March; whereas, in GBM, the average calving date was the beginning of March. Therefore, March energy requirements for beef cows were lower in IFSM than in GBM and consequently herbage intake was also lower. A similar situation occurred in November where IFSM requirements were higher. These different model specifications resulted in IFSM predicting annual average beef cow intakes 2% greater than GBM (fig. 2). For stocker through finishing cattle, intake predictions were closer throughout the year with IFSM predictions being a little greater than GBM during the finishing period (fig. 2).

**Feed Consumption and Beef Output**

In general, the production systems were similarly represented by the two models. A comparison of the total quantities of feed consumed is presented in figure 3. There was a modest difference between the two models with IFSM predicting 6% greater total feed consumed relative to GBM. Due to the cost advantage of grass, systems were based on grazed grass with grass silage and concentrates completing the feed ration. Beef output using GBM was 354 kg carcass beef per hectare with the equivalent value using IFSM being 360-kg carcass beef per hectare. It can be seen from these comparisons that model results were similar and thus, both models provided similar representations of the respective components of beef production systems.
Table 2. Optimal production systems for four scenarios investigated using the Grange Beef Model.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Calf-to-Stocker</th>
<th>Calf-to-Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Price</td>
<td>High Price</td>
</tr>
<tr>
<td>Land area farmed (ha)</td>
<td>40.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Land used for grazing only (ha)</td>
<td>35.1</td>
<td>32.1</td>
</tr>
<tr>
<td>Grazed grass consumed (t DM/year)</td>
<td>4.9</td>
<td>7.9</td>
</tr>
<tr>
<td>Grass silage consumed (t DM/year)</td>
<td>87.6</td>
<td>102.2</td>
</tr>
<tr>
<td>Total concentrates fed (t DM/year)</td>
<td>22.2</td>
<td>35.4</td>
</tr>
<tr>
<td>Inorganic N applied (kg N/ha/year)</td>
<td>14.2</td>
<td>22.6</td>
</tr>
<tr>
<td>Total N applied (kg N/ha/year)</td>
<td>72.3</td>
<td>95.4</td>
</tr>
<tr>
<td>Inorganic P applied (kg/ha/year)</td>
<td>36.9</td>
<td>62.6</td>
</tr>
<tr>
<td>Number of beef cows</td>
<td>24.3</td>
<td>30.4</td>
</tr>
<tr>
<td>Weanling heifers sold (9 months)</td>
<td>10.9</td>
<td>13.7</td>
</tr>
<tr>
<td>Weanling steers sold (9 months)</td>
<td>10.9</td>
<td>13.7</td>
</tr>
<tr>
<td>Heifers finished (24 months)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Steers finished (24 months)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 3. Annual financial performance of four optimal production systems as predicted using the Grange Beef Model.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Calf-to-Stocker</th>
<th>Calf-to-Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Price</td>
<td>High Price</td>
</tr>
<tr>
<td>Revenue, $[^a]</td>
<td>11,826</td>
<td>17,189</td>
</tr>
<tr>
<td>Animal sales</td>
<td>8,795</td>
<td>8,795</td>
</tr>
<tr>
<td>REPS[^b]</td>
<td>14,458</td>
<td>14,458</td>
</tr>
<tr>
<td>SFP[^c]</td>
<td>97</td>
<td>104</td>
</tr>
<tr>
<td>Direct costs, $</td>
<td>9,278</td>
<td>11,132</td>
</tr>
<tr>
<td>Forage production</td>
<td>50</td>
<td>71</td>
</tr>
<tr>
<td>Concentrate purchases</td>
<td>3,970</td>
<td>4,970</td>
</tr>
<tr>
<td>Replacement heifers</td>
<td>1,462</td>
<td>2,086</td>
</tr>
<tr>
<td>Gross margin</td>
<td>15,445</td>
<td>17,108</td>
</tr>
<tr>
<td>Other[^f]</td>
<td>4,972</td>
<td>5,179</td>
</tr>
<tr>
<td>Total</td>
<td>19,732</td>
<td>23,438</td>
</tr>
</tbody>
</table>

[^a] $1 = 0.83 Euros.
[^b] Payments received under the Rural Environment Protection Scheme.
[^c] Single farm payment receipts.
[^d] Interest earned on cash surpluses.
[^e] Expenses include veterinary, transport, breeding and miscellaneous animal costs.
[^f] Includes land rental payments, interest on overdrafts and depreciation.

RESULTS
ECONOMICALLY OPTIMAL SYSTEM

Key production and financial results of the optimal beef cow production systems as predicted by GBM are presented in tables 2 and 3. Both calf-to-stocker scenarios, SL and SH, were characterized by low N fertilizer rates receiving 14 and 23 kg/ha of inorganic N and 72 and 95 kg/ha of total N per year, respectively. The extensive nature of these systems is illustrated by land use where grazing land was predominant and only a small area of land was used for grass silage conservation. The small silage harvest area was also due to the sale of stocker animals prior to the wintering period. Since all stockers were sold at 9 months of age, concentrates fed in the stocker scenario were low. System intensity increased in the high-price scenario, SH, with beef cow numbers 25% greater than those of the low-price scenario. Despite the increase in production intensity, the high-price scenario only returned a modestly higher gross margin. In both cases, gross margin was only slightly greater than SFP receipts and lower than the sum of SFP and REPS payments. Thus, both production systems were greatly financially dependent on non-production based payments.

The calf-to-finish scenarios were considerably more intensive than the calf-to-stocker scenarios, particularly FH which was the most intensive of all scenarios investigated in terms of land area farmed, feed consumed, fertilizer use, and animal numbers. In this scenario, 28.2 ha were rented and cow numbers were increased by 70%. Nitrogen use for FL and FH was higher than either SL or SH and was restricted only by the REPS total N limit of 260 kg N/ha/year. The calf-to-finish scenarios had considerably greater gross margins than the calf-to-stocker scenarios due to the increase in animal sales. Despite this, REPS and SFP payments still represented a considerable proportion of gross margins, being 73% and 52% for FL and FH, respectively.

ENVIRONMENTAL IMPLICATIONS

Table 4 presents the environmental results for the four scenarios investigated. The N imported onto the farm included all N crossing the farm boundary including N fixed by pasture legume species and that deposited in precipitation. As expected, N imported was directly related to organic and total N application with the more intensive systems requiring the highest quantities of imported N. Nitrogen exported from the farm was that in animals sold off the farm. Therefore, similar to the N imported value, N exported was directly related to system intensity in the form of sales. It was apparent that the N exported was much lower than that imported and thus the potential for environmental losses was considerable, particularly for FL and FH where N imported was over nine times and almost eight times that exported, respectively.

In general, the greater inorganic and organic N fertilizer application rates of the calf-to-finish scenarios result in greater losses for these scenarios compared to the calf-to-finish scenarios. Of the three pathways for N loss investigated, leaching was greater than volatilization or denitrification for soils with good drainage. The nitrate concentrations in...
leachate were low in SL and SH, but in FL and FH they were much higher with concentrations of over 45 mg NO\textsubscript{3}/L. These values, although within the Nitrates Directive maximum allowable concentration in potable waters, approached this limit of 50 mg NO\textsubscript{3}/L. Further investigation of these data revealed that for the FL scenario, the nitrate concentrations in the leachate exceeded the MAC in 3 of the 15 years simulated. Corresponding figures in the FH scenario indicated that the MAC was exceeded in 4 of the 15 years simulated. Despite the difference in N exported and N imported, crop removal was between 71% for FL and 88% for SL which suggests that these scenarios were successful in capturing and using a major portion of available soil N.

The data for P losses and accumulation on the farm were similar to N in that P imported represented the P that crossed the farm boundary and P exported was that being in animals sold. Since all farm land was in permanent grassland, predicted total P loss in runoff was negligible in all scenarios. There was a sizable difference between P imported and P exported with the difference ranging from 6.2 kg/ha/year for SL and FH to 7.5 kg/ha/year for FL. Crop removal rates were between 70% and 91% for SL and FH with the remaining portion accumulating in the soil. This accumulation on the farm is a concern in that it may lead to higher P losses in the future due to increasing soil P levels.

**EFFECTS OF SOIL DRAINAGE CAPACITY**

Results presented thus far were for farms on soils with good drainage. Soil drainage has an important impact on the movement of N through the soil. Figure 4 presents the effect of soil drainage capacity on nitrogen losses within the four scenarios investigated. Two drainage capacities were considered: representing well-drained soils with volatilization and denitrification losses being greater and poorly drained soils with volatilization and denitrification losses being greater.

**EFFECTS OF DECREASING INORGANIC N USE**

From the results presented in table 4, it is apparent that finishing systems under both high- and low-price scenarios (FL and FH) were of most concern with regard to nutrient losses. In particular, N volatilization and leaching losses were high with denitrification losses also considerably greater than those found in either SL or SH. Thus, the impact of reducing inorganic N use for FH by placing a maximum threshold on the farm was explored. The effects on N losses and farm gross margin are presented in figure 5.

On average, for each 10 kg/ha/year reduction in applied inorganic N, total N losses were also reduced by 10 kg/ha/year. More specifically, the reduction in leaching loss was greatest with total annual leaching losses reduced by almost 40 kg N/ha over the range of application rates studied. However, concomitant with the reduction in N losses was a reduction in farm gross margin of over $1,000/year for each 10 kg/ha/year decrease in inorganic N applied. The total reduction in annual farm gross margin over the range studied was over $6,500.

**DISCUSSION**

The potentially conflicting targets of operating financially optimal and environmentally sustainable beef production systems in Ireland were measured using a linear programming model to identify financially optimal systems and a simulation model to quantify environmental indicators for these optimal systems. Financially optimal calf-to-stocker scenarios were found to be more extensive than calf-to-finish systems under both high- and low-price scenarios, in terms of land use and N application. However, calf-to-stocker scenarios were considerably less profitable than calf-to-finish scenarios in terms of gross margin earned. It is noteworthy that, although beef cow numbers for the SH scenario were greater than that of the SL scenario, farm gross margin increased by only $1,700. The low-price calf-to-stocker scenario (SL) resulted in less detrimental environ-
mental impacts for the indicators measured with total N loss 30% less than that of SH. Calf-to-finish scenarios were financially superior albeit with increased nutrient losses to the environment. In particular, leaching losses increased with losses almost five times greater in these scenarios when compared to the SH scenario. Thus, these results indicate that beef price increases encourage intensification of production leading to increases in N losses for the stocker scenarios with a relatively minor impact on nutrient losses in the finishing scenarios. Phosphorus losses were negligible in all cases although accumulation in the soil may be of concern. Long-term accumulation of soil P may lead to greater future

![Impact of soil drainage capacity on annual nitrogen losses by volatilization, leaching, and denitrification for the four scenarios investigated using the Integrated Farm System Model (IFSM). The four scenarios are calf-to-stocker low price (SL), calf-to-stocker high price (SH), calf-to-finish low price (FL) and calf-to-finish high price (FH).](image)

![Impact on annual N losses and farm gross margin of imposing an inorganic N limit on production as investigated using the Grange Beef Model and the Integrated Farm System Model for the calf-to-finish beef system under a high-price scenario on well drained soil.](image)
losses and the resulting eutrophication of surface waters (Tunney et al., 2000).

Nitrate losses are currently of much interest in Ireland, particularly with the recent implementation of the Nitrates Directive. Model predicted nitrate concentrations in leachate are driven by N use rates and rainfall. Predicted values in this study represent the average over 15 years of weather data and thus provide a robust average prediction. However, it should be noted that in some years where rainfall was lower than average, N concentrations in the leachate were greater and vice versa. This is particularly of consequence in the finishing scenarios where nitrate concentrations approach maximum allowable concentrations. Furthermore, subsequent legislation pertaining to surface waters and estuaries (e.g. the EU Water Frameworks Directive) is likely to impose a lower maximum allowable concentration for nitrate leachate concentrations, thus further constraining agricultural production (Schulte et al., 2006).

In studies by Ryan et al. (2001) and Keane (1994), lower levels of leaching losses and nitrate concentrations in the leachate were found than those predicted in this study. Ryan et al. (2001) investigated the impact of high (302 kg total N/ha) and low (187 kg total N/ha) annual nitrogen application rates and estimated that 12% and 22% of applied N was leached, respectively. For the finishing scenarios in our study, FL and FH, total applied N was within this range and 28% of the applied N was leached. In investigating the impact of beef production on nitrate leaching, Keane (1994) found concentrations of 8.8 and 2.2 mg NO₃/l for grazed pasture receiving 431 and 207 kg total N/ha, respectively. These nitrate concentrations are substantially lower than those predicted by our model. Therefore, N loss figures reported in our study are appropriate for comparison between scenarios, but further calibration of IFSM may be required to more accurately predict N loss pathways under Irish conditions.

Simulations of the impact of soil drainage capacity on nutrient losses indicate that total N losses increase considerably on well drained soils, with leaching losses in particular greater than that of poorly drained soils. On poorly drained soils, volatilization losses are greatest with relatively low leaching losses. While this is expected, it reinforces the view that nutrient management planning is more appropriate at the whole-farm or field level.

To investigate the potential to reduce N losses, the effect of further constraining inorganic N use was investigated for FH. It was found that decreasing inorganic N applied resulted in a reduction in total N losses, although farm gross margin also decreased markedly. It is therefore unlikely, in the absence of financial rewards or regulations, that farmers can be encouraged to reduce N use below the thresholds set by REPS and the Nitrates Directive.

The low margins of calf-to-stocker systems and the sizeable difference between these and the margins of calf-to-finish producers has the potential to encourage many current calf-to-stocker producers to finish some or all of their beef animals. It is apparent from the results presented that such a scenario would be undesirable from an environmental perspective. The net effect leads to an intensification of production which increases N losses and P accumulations in the soil.

Stockers from calf-to-stocker farms are typically finished on another beef finishing farm and thus, the adverse environmental impact may simply be transferred from one farm to another. Schulte et al. (2006) found that, in Ireland, the regional variability of agro meteorological factors that influence nutrient loss to water requires that farm practices be customized to reflect local risk. Many factors influence farm nutrient losses, so production systems using separate farms for calf-to-stocker and finishing operations may provide more efficient management of nutrients with less loss. A more complete analysis from a regional perspective or covering the entire life-cycle of such animals is required to investigate this more comprehensive view. Nevertheless, a fertilizer use survey conducted by Teagasc in 2000 found that from a national perspective mean N and P use on cattle farms was low at 48 and 8 kg/ha, respectively (Coulter et al., 2002). Thus cattle farming in Ireland may pose little environmental risk when codes of good practice are followed.

The REPS program has been successful in encouraging farmers to adopt more extensive forms of production based on lowering N inputs, and the payments received from the program are a significant contributory to farm gross margins. An extension of such programs is required to encourage further N application reductions.

CONCLUSIONS

The management of financially optimum beef production systems leads to intensification of production in many cases particularly where beef prices increase. Such intensification can result in greater N losses to the environment. In scenarios investigated, where beef prices (and input costs) increase, beef cow numbers and net farm gross margin increased by 25% and $1,700, respectively, compared to the low-price scenario where offspring were sold as stockers rather than finished. Where offspring were finished, land area farmed increased to facilitate increased cow numbers in the FH scenario and thus, there was little difference in nutrient losses between this and the FL scenario. Leaching of N was of most concern on well-drained soils with volatilization losses greatest on poorly drained soils. Further investigation indicated that there was little incentive for farmers to reduce N application given that such a reduction in inorganic N use resulted in markedly lower gross margins. Agri-environmental programs will continue to be important in promoting more extensive, low N input systems. Predicted phosphorus losses were negligible in all cases for these perennial grassland systems; however, accumulation in the soil was of concern for potentially increasing future losses.

REFERENCES


