SYSTEMS MODELING

Evaluation of the Grange Beef Model using the Integrated Farm Systems 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 x (Limousin x Friesian) cows. Included are beef cow, replacement heifer, calf, weanling 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.

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 INRAtion. 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. 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.

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, weanlings, finishing cattle, replacement heifers, and beef cows. 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 rumenally degradable protein and a minimum requirement of rumenally undegradable protein. The energy and protein requirements of each animal group are determined using level 1 of the Cornell Net Carbohydrate and Protein System. 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 (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. 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.

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. 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. Nitrogen movement and transformation within and among soil layers is modeled with functions from the Nitrate Leaching and Economic Analysis Package (NLEAP) model. 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 and adapted to Irish conditions. Leaching and denitrification coefficients in IFSM of 0.85 and 0.125, respectively, allowed IFSM to accurately replicate NCYCLE in predicting N losses.

A component-based comparison was undertaken to evaluate the capacity of the Grange Beef Model to accurately simulate suckler beef production systems. 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 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 was then compared.

The Grange Beef Model specifies forage yield for the grazing area based on seven annual application rates of N; 0 kg N/ha 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 kg N/ha/year and 150 kg N/ha/year, are shown in Figure 1. Relative to the growth curves assumed in GBM, IFSM underestimated production in spring and overestimated production in autumn. However, the annual production across all fertilization strategies indicated a yield differential of only 2% between the two models.

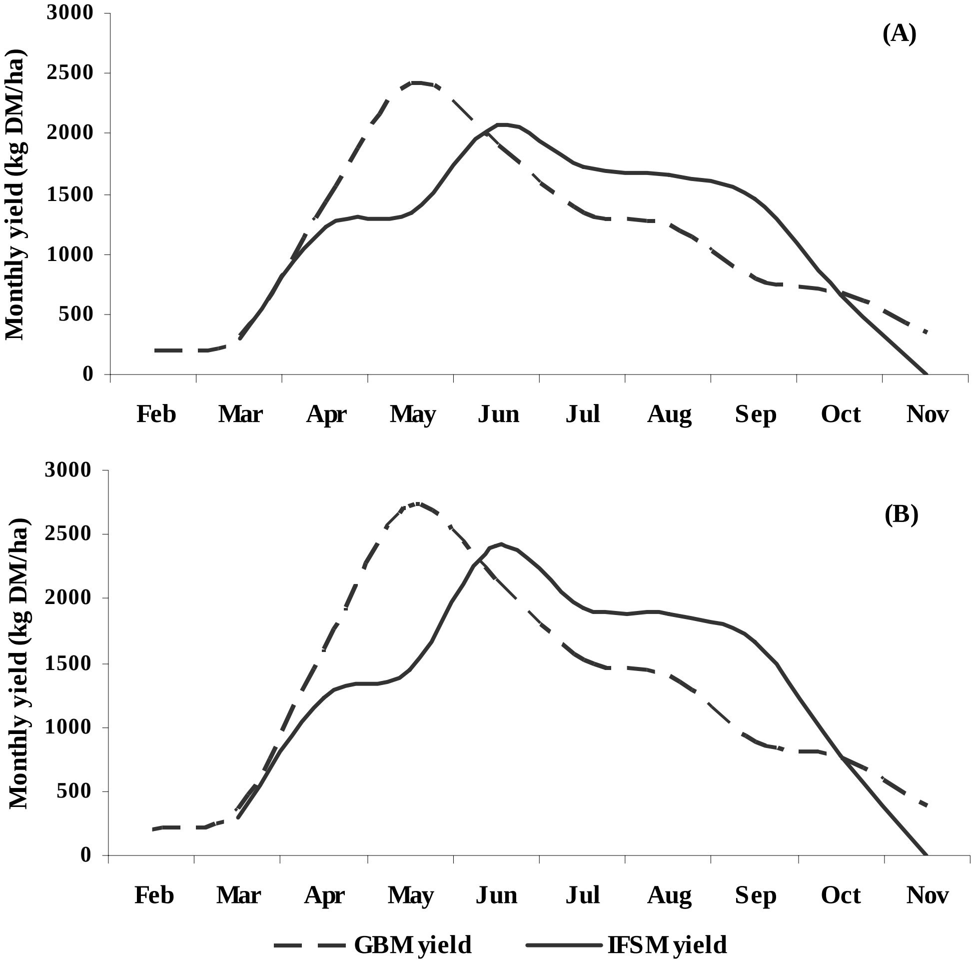

Figure 1. Comparison of grass yields predicted for two annual fertilization rates, 100 kg N/ha (A) and 150 kg N/ha (B) by the Grange Beef Model (GBM) and the Integrated Farm System Model (IFSM).

To evaluate intake predictions, the two main categories of cattle were compared, cows and weanling through finishing cattle (Figure 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 (Figure 2). For weanling through finishing cattle, intake predictions were closer throughout the year with IFSM predictions being a little greater than GBM during the finishing period (Figure 2).

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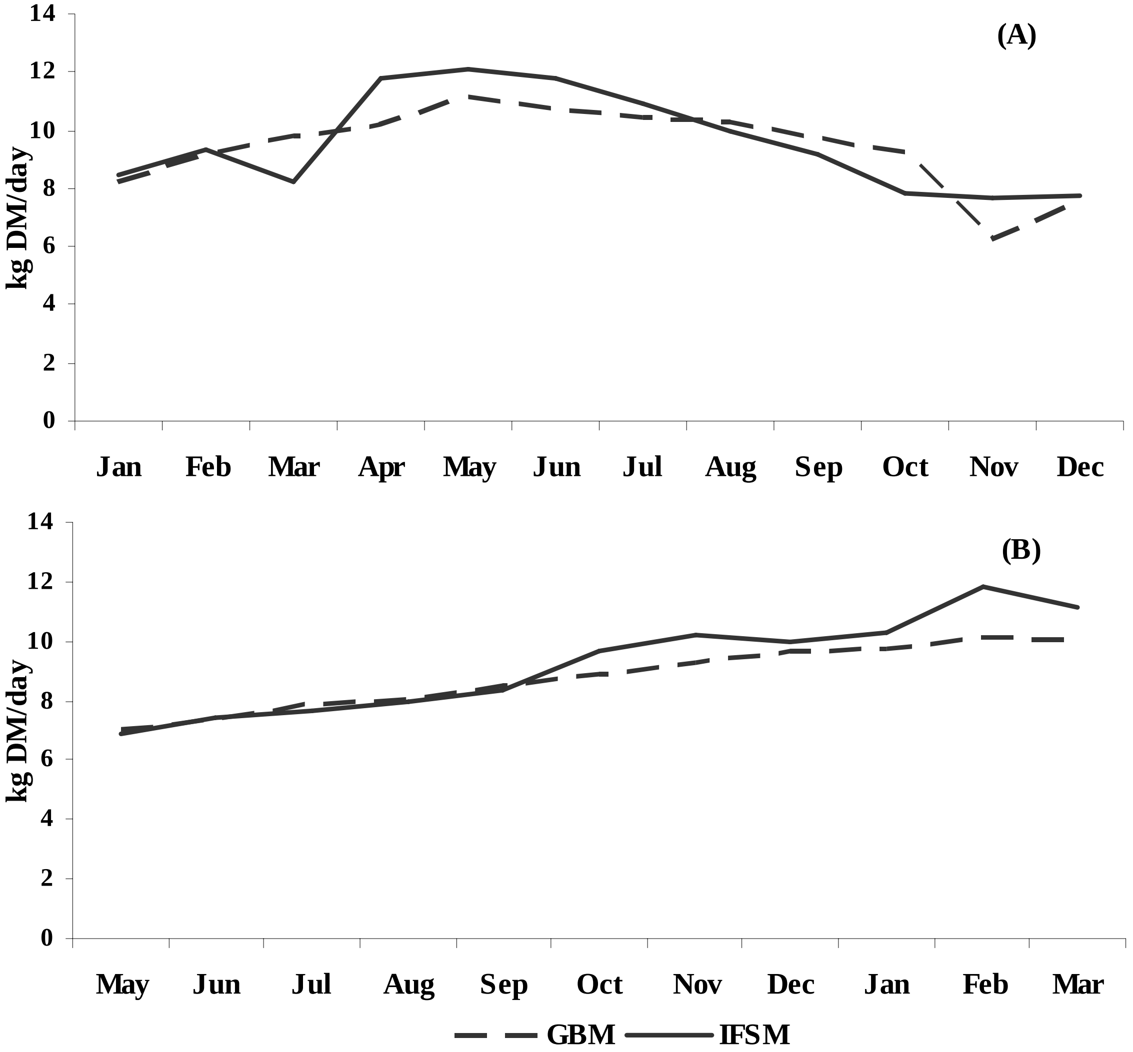

Figure 2. Comparison of total feed intake by beef cows (A) and weanling through finishing cattle (B) predicted by the Grange Beef Model (GBM) and the Integrated Farm System Model (IFSM).

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.

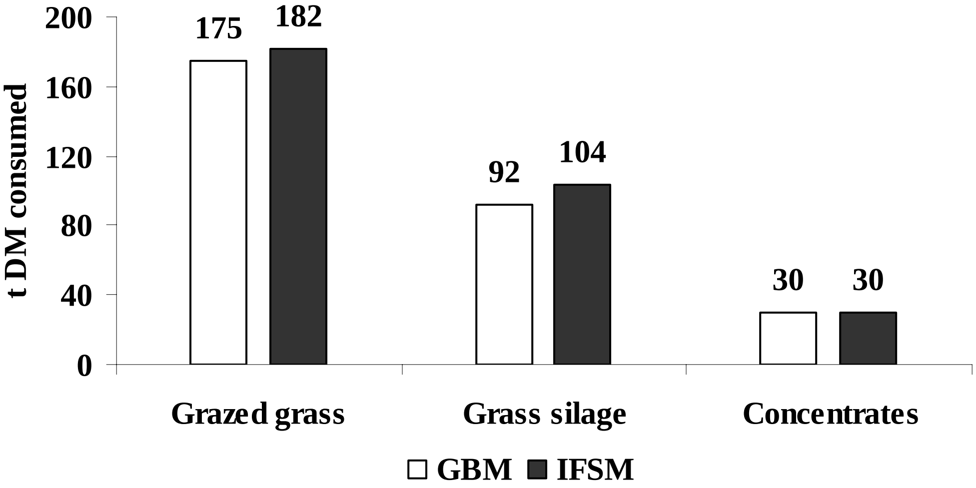

Figure 3. Comparison of total quantities of feeds fed annually on a typical beef farm as predicted using the Grange Beef Model (GBM) and the Integrated Farm System Model (IFSM).

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.

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Crosson, P., Rotz, C.A.[1], O'Kiely,P., O'Mara, F.P.[2],Wallace, M.[2] and Schulte, R.P.O.[3]
[1]USDA/ERS, Pennsylvania State University, University Park, PA 16802
[2]UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin
[3]Teagasc, Johnstown Castle Research Centre, Johnstown Castle, Wexford

Modeling the nitrogen and phosphorus inputs and outputs of financially optimal Irish beef production systems

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 minimise N losses between application to the soil and uptake by the plants. 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. A suitable P application strategy is essential to minimize surpluses and the long term accumulation of soil P on 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.

Two beef production strategies from within beef cow herd systems, calf-to-weanling and calf-to-finish, were specified with cows calving in March. In the calf-to-weanling scenarios, weanling heifers and steers were sold at 290 kg 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 kg 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 €360/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 €435/ha.

Some authors have suggested 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 weanling 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. Therefore, two price scenarios, high and low, representing 2005 and 2010 price scenarios were investigated (Table 27). In the low price scenario, cattle and beef prices were set to 2005 levels. In the high price scenario, weanling steer prices were assumed to rise by 10% while weanling 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 fertiliser, were adjusted to account for inflation for the high price scenario. An inflation rate of 2.8% per annum was assumed.

Table 27: Cattle and beef prices for the high price and low price scenarios solved using the Grange Beef Model

	Low price	High price
Weanling steer price (€ per head)	510	560
Weanling heifer price (€ per head)	435	525
Autumn beef price (€/kg carcass)	3.37	4.04
Spring beef price (€/kg carcass)	3.49	4.22
Cull cow price (€/kg carcass)	2.75	3.35

Thus four scenarios were investigated; calf-to-weanling low price (SL), calf-to-weanling 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. Thus for the scenarios investigated, two soil drainage capacities were considered; well drained soils and poorly drained soils as defined by Schulte et al.

The importance of farming within the constraints of environmental regulation has been outlined. Therefore, within the 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. Under conditions of high rainfall, nitrates are prone to be leached from the soil whereas, with poor soil aeration and high oxygen demand, denitrification can occur resulting in N_2O and N_2 being released to the atmosphere. Warm, sunny weather promotes the volatilisation of ammonia gas, particularly during the application of slurry. Therefore, these forms of N loss were investigated for each of the optimal systems identified.

A key component of a sustainable P strategy 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 8-10%. The slurry was assumed to be stored up to six months in a concrete tank with top surface loading. Slurry was applied using a splash-plate applicator without incorporation into the soil.

Key production and financial results of the optimal beef cow production systems as predicted by GBM are presented in Tables 28 and 29. Both calf-to-weanling scenarios, SL and SH, were characterised by low N fertiliser rates receiving 14 kg/ha and 23 kg/ha of inorganic N and 72 kg/ha 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 weanling animals prior to the wintering period. Since all weanlings were sold at 9 months of age, concentrates fed in the weanling 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.

Table 28: Optimal production systems for four scenarios investigated using the Grange Beef Model

	Calf-to-weanling		Calf-to-finish	
	Low price	High price	Low price	High price
Land area farmed (ha)	40.0	40.0	40.0	68.2
Land used for grazing only (ha)	35.1	32.1	19.5	32.2
Land used for silage harvests (ha)	4.9	7.9	20.5	36.0
Grazed grass consumed (t DM/year)	87.6	102.2	174.6	295.1
Grass silage consumed (t DM/year)	22.2	35.4	92.3	161.7
Total concentrates fed (t DM/year)	0.23	0.28	30.20	48.48
Inorganic N applied (kg N/ha/year)	14.2	22.6	117.7	118.3
Total N applied (kg N/ha/year)	72.3	95.4	260.0	260.0
Inorganic P applied (kg/ha/year)	16.4	17.3	20.9	21.1
Number of beef cows	24.3	30.4	36.9	62.6
Weanling heifers sold (9 months)	10.9	13.7	0.0	0.0
Weanling steers sold (9 months)	10.9	13.7	0.0	0.0
Heifers finished (24 months)	0.0	0.0	16.6	28.2
Steers finished (24 months)	0.0	0.0	16.6	28.2

The calf-to-finish scenarios were considerably more intensive than the calf-to-weanling 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-weanling 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.

Table 29: Annual financial performance of four optimal production systems as predicted using the Grange Beef Model

	Calf-to-weanling		Calf-to-finish	
Scenario	Low price	High price	Low price	High price
Revenue , €				
Animal sales	9,816	14,267	41,714	85,182
REPS[a]	7,300	7,300	7,300	7,300
SFP[b]	12,000	12,000	12,000	12,000
Interest[c]	81	86	1,081	1,884
Total	**29,196**	**33,654**	**62,095**	**106,366**
Direct costs, €				
Forage production	7,700	9,239	18,133	32,513
Concentrate purchases	42	59	5,512	10,085
Animal expenses[d]	3,295	4,125	6,734	11,435
Replacement heifers	1,213	1,732	1,844	3,570
Other[e]	4,127	4,298	3,600	11,735
Total	**16,377**	**19,454**	**35,823**	**69,338**
Gross margin	15,445	17,108	31,653	44,611

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

Table 30 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.

Table 30: Environmental indicators of four production scenarios as investigated using the Integrated Farm System Model

	Calf-to-weanling		Calf-to-finish	
Scenario	Low price	High price	Low price	High price
N imported to farm (kg/ha/year)[a]	29.8	42.2	161.0	159.6
N exported (kg/ha/year)[b]	5.8	7.9	17.7	20.3
N lost by volatilization (kg/ha/year)	9.8	13.1	48.2	45.2
N lost by leaching (kg/ha/year)	9.8	14.7	72.1	71.6
N lost by denitrification (kg/ha/year)	4.4	6.5	23	22.5
Nitrate conc in leachate (mg NO_3/l)	5.3	8.4	46.5	45.1
Crop removal over that available (%)	88	86	71	72
P imported to farm (kg/ha/year)[c]	7.7	8.3	11.9	11.4
P exported from farm (kg/ha/year)[d]	1.5	2	4.4	5.2
Total P loss in runoff (kg/ha/year)	0	0	0	0
Soil P accumulation (kg/ha/year)	6.2	6.3	7.5	6.2
Crop removal over that available (%)	70	79	89	91

[a] N imported annually in rainfall, feed purchases, inorganic fertilizer purchases, replacement heifer purchases and N fixed in the soil by micro-organisms.

[b] N exported annually in animal sales.

[c] P imported annually in rainfall, feed purchases, inorganic fertilizer purchases, and replacement heifer purchases.

[d] P exported annually in animal sales.

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 volatilisation 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_3/l. These values, although within the Nitrates Directive maximum allowable concentration in potable waters, approached this limit of 50 mg NO_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 leaving 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.

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.

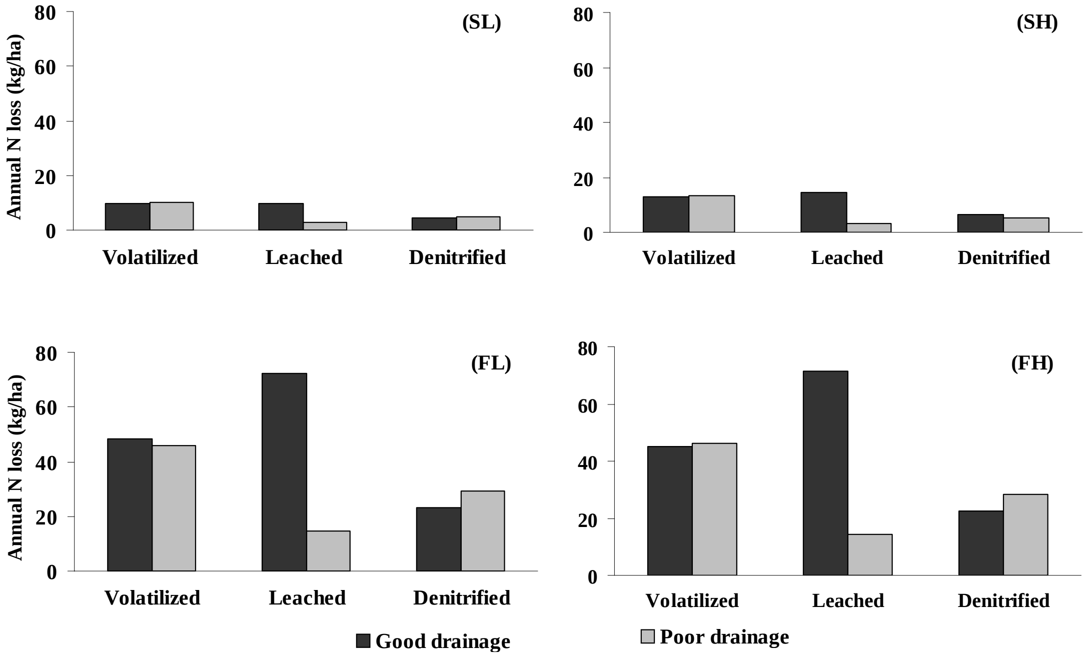

Figure 4. Impacts of soil drainage capacity on annual nitrogen losses by volatilization, leaching, and denitrification) for the four scenarios investigated using the Integrated Farm System Model (IFSM). The four scenarios are calf-to-weanling low price (SL), calf-to-weanling high price (SH), calf-to-finish low price (FL) and calf-to-finish high price (FH).

Two drainage capacities were considered representing well drained (as per results presented above) and poorly drained soils. There were considerable differences in N losses and N pathways for the two drainage classes. There was substantially less total N loss on poorly drained soils, ranging from 25% less for SL to 38% for FL. More specifically, leaching losses decreased considerably on poorly drained soils. In contrast to well drained soils, N lost by leaching was the lowest of the three N loss pathways on poorly drained soils with volatilisation and denitrification losses being greater.
From the results presented in Table 30, 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 volatilisation 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 €1,200/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 €7,800.

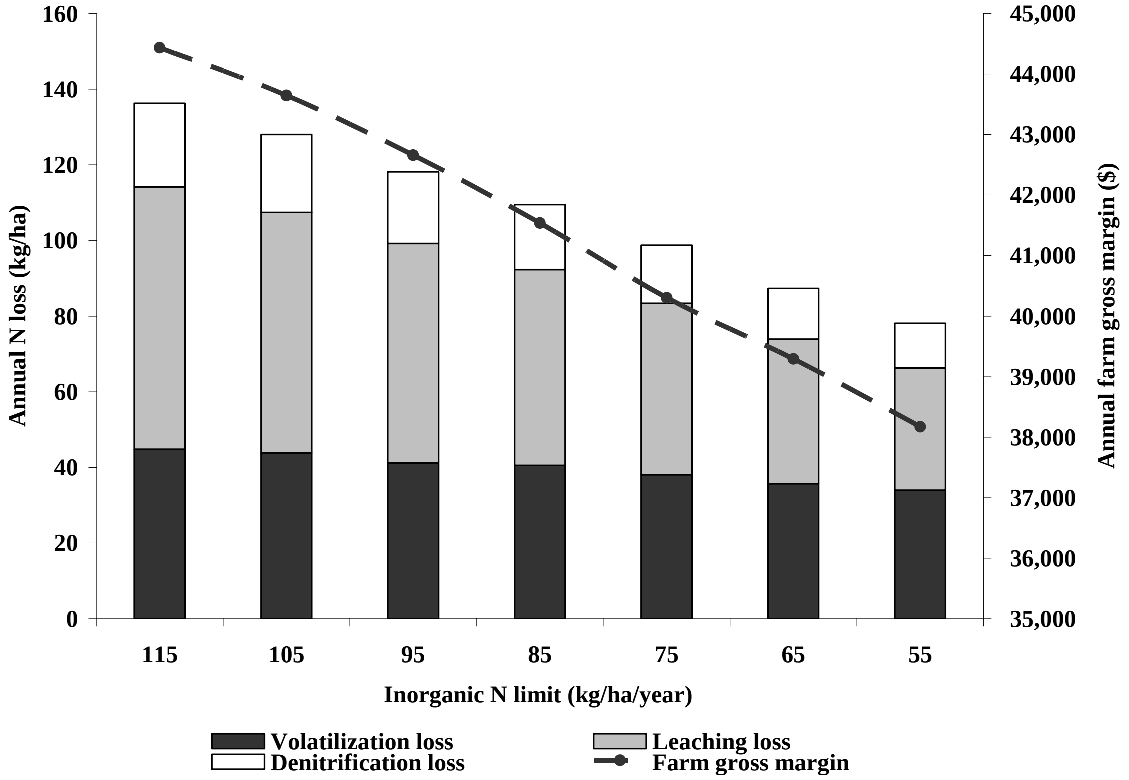

Figure 5. Impact on annual N losses and farm gross margin of imposing an inorganic N limit on production as investigated using the Grange Beef Model and the Integrated Farm System Model for the calf-to-finish beef system under a high price scenario on well drained soil.

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 €2,050, respectively, compared to the low price scenario where offspring were sold as weanlings 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 volatilisation 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.

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[1]USDA/ERS, Pennsylvania State University, University Park, PA 16802
[2]UCD School of Agriculture, Food Science and Veterinary Medicine, Belfield, Dublin
[3]Teagasc, Johnstown Castle Research Centre, Johnstown Castle, Wexford