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Bioeconomic modelling of male Holstein-Friesian dairy calf-to-beef production systems on Irish farms

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With the abolition of milk quota in 2015 and increase in the use of Holstein-Friesian sires in recent years there is predicted to be an increase in the number of male Holstein-Friesian animals available for beef production. In broad terms, farmers have two options for finishing these animals; as bulls or steers. In either case, Irish beef cattle systems are based on maximising lifetime live-weight gain from grass-based diets. Managing the relationship between the supply and demand for grazed grass is complicated in these pasture-based systems due to the seasonal variability in grass growth. The Grange Dairy Beef Systems Model (GDBSM) was used to simulate the relationship between grazed grass supply and demand and then determine the profitability of Holstein-Friesian male animals finished as bulls at 16 (B16), 19 (B19) and 22 (B22) months of age and steers at 24 (S24) months of age. Combinations of these cattle finishing options were also evaluated. The most profitable system was S24. All systems were very sensitive to variations in beef and concentrate prices and less sensitive to calf price changes with fertiliser price changes having very little effect. Bull systems were more sensitive than the steer system to variation in beef, calf and concentrate prices. There was no advantage of combination systems in terms of utilisation of grass grown or net margin.

Keywords: bulls; dairy beef; grass-based; simulation; steers

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Introduction

The abolition of the European Union milk quota system in 2015 (European Commission 2009) is expected to lead to an expansion of the dairy cow herd in Ireland which will increase the number of dairy origin calves available for beef production. When this is combined with the increase in the use of Holstein-Friesian sires (increased by 14% from 2008 to 2011; DAFM 2009, 2012) the number of Holstein-Friesian male animals available for beef production in Ireland is set to rise considerably. In Ireland, the number of bulls slaughtered as a percentage of total slaughtering (excluding cull cattle) increased from 3 to 20% from 2000 to 2012 (Bord Bia 2013a). The increase in bull beef production is due to a number of reasons. Bull beef have a number of performance advantages when compared to steer beef systems. Bulls have greater live-weight gain and carcass gain than steers (Steen 1995; Steen and Kilpatrick 1995; Keane 2003; Kirkland *et al*. 2006) and also have a higher feed conversion ratio (Steen 1995). Keane (2003) found that bulls had 0.5 units better conformation than steers when slaughtered at similar carcass weights. Bulls were also found to have a greater kill out proportion than steers when slaughtered at similar weights (Steen 1995; Steen and Kilpatrick 1995; Keane 2003). Furthermore, the decoupling of direct payments in 2005 (Swinbank and Daugbjerg 2006) resulted in steers no longer receiving a higher premia than bulls which could have also influenced farmers to finish male animals as bulls rather than steers. The increased number of bulls slaughtered could also be influenced by the export market for Irish beef with the percentage of Irish beef exported to European countries (excluding Britain) increasing from 36% in 2004 to 47% in 2011 (Bord Bia 2004, 2012).

Ireland has a cool temperate climate and thus, has the potential to produce high yields (12 to 16 t/ha DM; O'Donovan, Lewis and O'Kiely 2011) of high digestibility grass, a key competitive advantage relative to many other beef producing countries. This has led to a predominantly grass-based agricultural sector with over 90% of agricultural land under grassland (O'Riordan and O'Kiely 1996) with grazed grass being the predominant feed in the diet of beef animals. However, grass growth in Ireland is seasonal with growth starting around the beginning of March peaking in May followed by a lower peak in August with growth declining rapidly to almost zero in November (Drennan, Carson and Crosse 2005). Furthermore, different beef production systems have different demands for grass throughout the season (O'Riordan and O'Kiely 1996). For example, Keane, O'Riordan and O'Kiely (2009) found that animals finished at 17 and 30 months of age had a grazed grass requirement of 640 and 3,950 kg DM per animal, respectively. As grazed grass is the cheapest feed available to Irish farmers (Finneran *et al*. 2012) one of the key objectives of beef farms in Ireland is to utilise pasture efficiently and ensure quality herbage is continuously available to the animals throughout a long grazing season. The aim is to maximise the proportion of the animals' live-weight gain achieved whilst grazing, while at the same time also making provision for adequate winter feed. This same principle applies for dairy production with the objective in this case to maximise the production of milk from grazed grass resulting in the majority of dairy cows calving in the spring (February–April; DAFM 2012).

There have been few models that have studied beef production systems using calves from the dairy herd (e.g., Kilpatrick and Steen 1999; Bonesmo and Randby

2010; Ashfield, Crosson and Wallace 2013; Ashfield *et al*. 2014). Feeding strategies were modelled by Bonesmo and Randby (2010) who found that feeding bulls high energy grass silage during the finishing period increased profitability. Kilpatrick and Steen (1999) developed a model that predicted the growth and carcass composition of a range of cattle breeds over a range of different feeds. However, these studies were only concerned with the finishing stage of the system. Ashfield *et al*. (2013, 2014) studied dairy calf-to-beef systems at a whole farm level, however, balancing of the seasonal supply and demand of grazed grass was not analysed. Thus, it is apparent that the majority of beef system models have focussed mainly on finishing systems and there is a paucity of whole farm models of dairy calf-to-beef production systems looking specifically at balancing the seasonal supply and demand of grazed grass with the nutritional demands of Holstein-Friesian bulls and steers.

Hence the objectives of this study were to; 1) modify the Grange Dairy Beef Systems Model (GDBSM; Ashfield *et al*. 2013) to facilitate the simulation of seasonal supply and demand of grazed grass. 2) use the GDBSM to determine the most profitable system for finishing Holstein-Friesian male animals by comparing finishing bulls at 16, 19 and 22 months of age and steers at 24 months of age, and 3) to determine if some combination of these systems could better utilise grazed grass, thus improving farm profitability.

Materials and Methods

Model description

The GDBSM is a whole farm model and thus, it integrates the various components of beef farming systems into a single framework. The model is described in detail by Ashfield *et al*. (2013) and so is only summarised here. The model adopts a single year static approach and assumes that the system has reached a steady state condition. This facilitates the technical and economic evaluation of dairy calf-to-beef production systems. It is an empirical model that uses data from production research experiments, conducted primarily at the Animal and Grassland Research and Innovation Centre, Teagasc, Grange, to specify coefficients and production functions (e.g., grazed grass dry matter digestibility and energy content, live-weight gain (LWG) and the monthly proportion of grazed grass and grass silage in the diet). In setting up each model run, the farm land area owned and the cattle production system choices (e.g., animal breed, gender and age at slaughter) must be specified. Production systems modelled are based on three breed groups which represent the progeny of Holstein-Friesian dairy cows which are bred to late-maturing (LM; Charolais and Belgian Blue cattle breeds), early-maturing (EM; Aberdeen Angus and Hereford cattle breeds) and Holstein-Friesian (FR) sires. Within these three breed groups, male cattle can be produced as bulls or steers. Heifer finishing options are also included for EM and LM progeny but not for FR since it is assumed that these are retained as replacements for the dairy production system from which they were bred. The model incorporates a range of finishing ages for each breed/gender combination. For steers the finishing age ranges from 20 to 30 months of age for EM and from 22 to 30 months of age for FR and LM animals. The finishing age for bulls ranges from 15 to 22 months of age for all breeds. Heifers can be finished from 18 to 20 months of age for EM and 20 to 22 months of age for LM animals. Animals within each group, according to breed, gender and finishing age, are assumed to be homogenous and consequently the model excludes variability among animals within groups.

The forage system in terms of inorganic nitrogen (N) applied to the grazing area and number of grass silage harvests (one or two) must also be specified. Inorganic N application rates for grass silage production are set according to Teagasc recommendations (Coulter and Lalor 2008). The model consists of four sub-models comprising farm systems, animal nutrition, feed supply and financial components. A schematic diagram of how the different components of the model interact is shown in Figure 1.

The farm systems sub-model defines the dairy calf-to-beef production system (breed, gender and finishing age) and calculates, on a monthly basis, animal inventories, mean live weight of animals in each group, slurry production and accommodation for animals during the indoor period (accommodation on the farm is not set and fluctuates, with a corresponding change in accommodation cost, so there is enough housing space for the number of animals on the farm). Animal numbers are calculated at the start of the month based on animal mortality, sales, purchases and movements into different groups from the previous month. Animal live weights are calculated at the start of each month

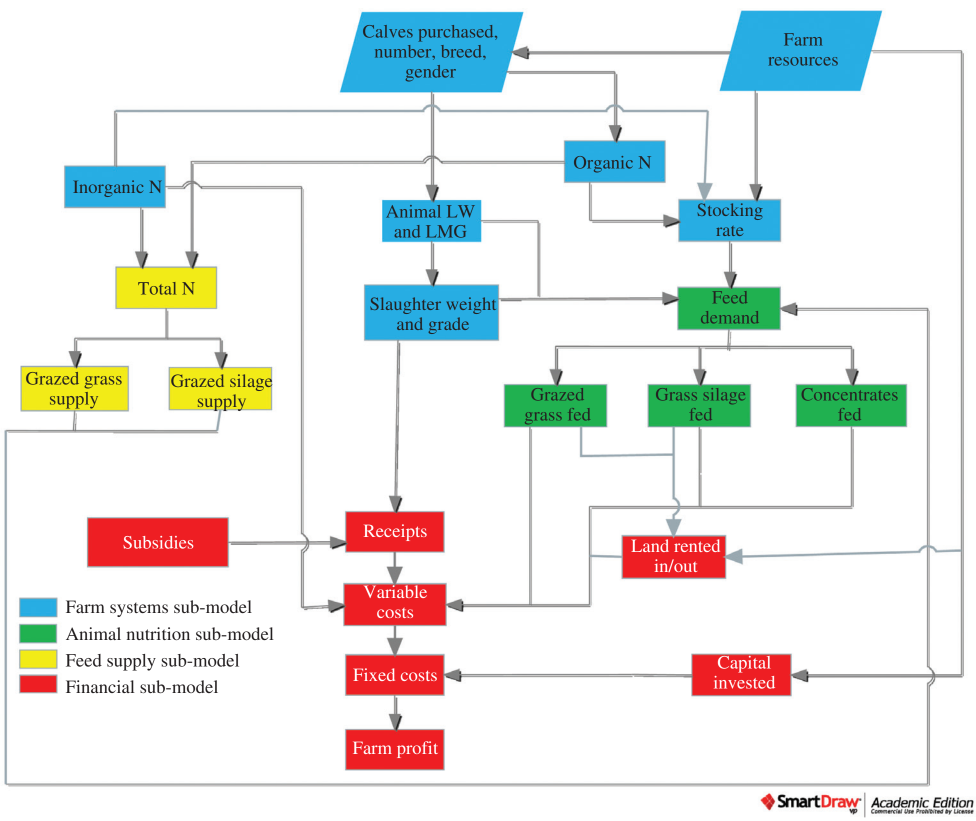

Figure 1. Schematic diagram of the Grange Dairy Beef Systems Model.

based on the starting live weight and LWG from the previous month. The amount of slurry produced during the indoor period is based on the volume of slurry produced per animal per day (DAF 2000) and the number of days spent indoors.

The animal nutrition sub-model determines energy demand and, consequently, animal feed requirements (grazed grass, grass silage and concentrate) on a per animal basis which is aggregated to a herd level for each month. Energy demand, estimated using the INRAtion program (INRAtion 3.22; INRA 2003) adapted for Irish conditions (O'Mara, Caffrey and Drennan 1997; Crowley 2001; Crowley *et al*. 2002), is a function of live weight and LWG of the animal taken from the farm systems sub-model. Energy demand is used to calculate the feed dry matter (DM) requirements which are also subject to the maximum intake capacity (IC) of the animal. The IC is calculated according to equations derived by Crowley (2001) and is specified in terms of CFUs (Fill Unit for cattle; Jarrige 1989). Available feeds (grazed grass, grass silage and concentrate) are also specified in terms of these parameters (UFL or UFV/kg DM and CFU/kg DM) and hence, required intake is calculated. Where the quantity of forage required to satisfy energy demand exceeds the animals' IC then, 1) forage quantity is fed at t he maximum level possible as determined by the animals' IC and, 2) supplementary concentrate is fed to meet the energy deficit. Substitution rate of forage is estimated using the 'apparent fill' method outlined by Jarrige (1989).

The feed supply sub-model determines the forage production systems used to satisfy the grazed grass and grass silage feed demand on the farm. The production of grass silage to meet winter feed requirements is calculated firstly and thus, the grass grazing area is calculated as the total farm area minus the total area required for grass silage in any given month. Grass silage yield data is based on cutting date for first harvest silage and regrowth period for subsequent harvests (O'Kiely 2004). Total annual grass production (t/ha DM) on the grazing area is determined according to the quadratic grass growth function of Butler (2006) whereby herbage production is a function of the specified N (organic and inorganic) application rate (kg/ha). Nitrogen, phosphorous (P) and potassium (K) inputs for grass silage and P and K inputs for grazing are set according to the specifications of Coulter and Lalor (2008) assuming a soil index 3 for P and K.

The financial sub-model quantifies costs and receipts generated from the system being modelled. It is linked to the farm systems, animal nutrition and feed supply sub-models to obtain quantities of inputs used and physical output (beef carcass) produced. Variable and fixed costs are calculated on a monthly basis. To account for seasonal fluctuations in the Irish beef price the monthly deviations from the annual average for the years 1996 to 2009 was calculated (Bord Bia 2011). This was then used to calculate the beef price for each month by adjusting the user specified annual average price. The model does not include imputed charges for the opportunity cost of owned land and unpaid family labour (including the farmer's own labour). Key outputs from the financial sub-model are the monthly and annual cash flow and, annual profit and loss account. All costs and margins are presented per farm, hectare, livestock unit (LU), animal unit (AU) and kilogram of beef sold.

Modelling grass growth monthly

In the GDBSM (Ashfield *et al*. 2013) grazed grass grown and grazed grass demand were balanced on a yearly basis so that the annual demand for grazed grass could not exceed annual yield. However, in this current study one of the key objectives was to simulate the monthly balance between grass supply, which is highly seasonal, and animal feed demand, which is a function of the cattle production system modelled (i.e., individual animal intake and total animal numbers) and also shows considerable monthly variation. Thus, it was required to model grass available for grazing and animal feed demand on a monthly basis. Total grass growth for the period February to October was calculated using the equation of Butler (2006; see model description section) with the monthly distribution based on historical data from Teagasc, Animal & Grassland Research and Innovation Centre, Grange. The grass available for grazing was calculated to include surplus grass from the previous month. Grass growth was further extended over the winter period with an average growth of 3.8 kg/d DM for the months of November, December, January and February (Neilan 1997). The surplus grazed grass available at the end of December was transferred to the start of January. The grazed grass demand per animal per month was divided into the total grazed grass available per month to give the animal carrying capacity for that month during the grazing season. The default setting for the grazing season and indoor winter feeding period is March to October and November to February, respectively, but can be modified to reflect the modelled production system e.g., cattle systems with an indoor finishing period between March and October. The animal carrying capacity of the farm was, therefore, set by the month with the lowest animal carrying capacity. For the remaining months when grazed grass supply was greater than demand, surplus grass that was grown was harvested as round bale grass silage and sold off farm. The cost of making round bale silage (set by the user to cover mowing, baling, wrapping and stacking) is subtracted from the sale value of the silage [set by the user as €/t (DM)] to give a net income.

Scenarios

To investigate the profitability of Holstein-Friesian animals, scenarios based on finishing bulls at 16, 19 and 22 months of age and steers at 24 months of age were investigated. All scenarios were based on spring-born calves arriving on farm at 1 week of age on the 1st of February. All calves were subjected to the same rearing regime and similar management during the first grazing season (Ashfield *et al.* 2013). Housing for the first winter occurred on 1st November following which cattle were fed a diet of grass silage and concentrates. Bulls finished at 16 months of age (B16) remained indoors on a diet of *ad libitum* concentrates and grass silage until they were finished at the end of May. Bulls finished at 19 (B19) and 22 (B22) months of age and steers finished at 24 (S24) months of age were turned out for a second grazing season on the 1st March and returned indoors for a final finishing period on the 1st June, 1st September and 1st November, respectively. Animals in B19 and B22 were finished on a diet of *ad libitum* concentrates and grass silage at the end of August and November, respectively. Animals in S24 were finished on a diet of grass silage and concentrates at the end of January. Live-weight gains for the different periods for all scenarios are presented in Table 1. Stocking intensity was defined in terms of organic N per hectare and set at 210 kg organic N/ha. This is the quantity of organic N excreted by animals on an annual basis with excretion rates of 65 kg for suckler cows and cattle >24 months of age, 57 kg for cattle aged 13

Table 1. Live-weight gains (kg/d), live weight (kg), kill out proportion (g/kg) and carcass weight (kg) at slaughter for Holstein-Friesian males finished at 16 (B16), 19 (B19), 22 (B22) and 24 (S24) months of age

Scenario	B16[1]	B19[1]	B22[1]	S24
Calf rearing (kg/d)	0.70	0.70	0.70	0.70[1]
1st season at grass (kg/d)	0.72	0.72	0.72	0.72[1]
1st indoor period (kg/d)	N/A	0.84	0.84	0.55[2]
2nd season at grass (kg/d)	N/A	0.60	1.02	0.90[2]
Finishing period (kg/d)	1.36	2.23	1.44	0.90[2]
Live weight at slaughter (kg)	523	596	654	610[2]
Kill out proportion (g/kg)	528	528	531	516[2]
Carcass weight at slaughter (kg)	276	315	347	315[2]

[1](Robert Prendiville, Teagasc, personal communication), [2]Keane *et al.* (2009).

to 24 months of age and 24 kg for cattle aged 0 to 12 months of age (DAF 2008). Price and cost assumptions for all scenarios are shown in Table 2. All scenarios were subjected to sensitivity analysis of beef, calf, concentrate and fertiliser prices. Combinations of these systems (B16/B19, B16/B22, B16/S24, B19/B22, B19/S24, B22/S24, with relative weightings ranging from 10:90 to 90:10) were evaluated to determine if these combinations could provide a better match between monthly grass availability and demand on the farm and, therefore, increase profitability.

Table 2. Prices used in the scenarios to determine the profitability of different dairy calf-to-beef systems

Holstein-Friesian calf price (€/head)	125
Average annual beef price (R3 steer) (€/kg)[1]	4.21
Average annual beef price (R3 bull) (€/kg)[1]	4.17
Calf concentrate (€/t)	350
Yearling concentrate (€/t)	300
Finisher concentrate (€/t)	300
Milk replacer (€/t)	2,100
Calcium ammonium nitrate (€/t)	330
Urea (€/t)	440
P & K compound fertiliser 0-10-20 (€/t)	425
P & K compound fertiliser 0-7-30 (€/t)	450

[1]The model accounts for differences in conformation and fat class of the animal and seasonal fluctuations in beef price. The average annual beef price is the base price from which all other prices are calculated based on conformation and fat class and month of the year sold.

Results

Table 3 presents the main physical results for the individual scenarios investigated. Grazing area was largest for B16. The amount of grazed grass and grass silage consumed per animal was highest for S24. The proportion of grazed grass in the diet for B16, B19, B22 and S24 was 23, 35, 51 and 62%, respectively. Scenario B16 and B19 resulted in 146 and 72 t DM of grazed grass being removed for baled silage, respectively. The amount of concentrate consumed per animal was greatest for B16. The scenario with the highest inorganic N application rate was S24. The scenario with the largest number of animals purchased and finished was B16. Scenario B22 had the highest live-weight output/head (Table 1) but B16 had the greatest live-weight output/ha. Carcass output per head (Table 1) and per hectare reflects the live-weight output per hectare.

The main financial results for the individual scenarios investigated are presented in Table 4. Scenario B16 had the highest livestock sales, silage sales and livestock purchases resulting in B16 having the highest gross output. Concentrate,

Table 3. Physical results for dairy calf-to-beef males finished as bulls at 16 (B16), 19 (B19) and 22 (B22) months of age and steers finished at 24 (S24) months of age investigated using Grange Dairy Beef Systems Model

Scenario	B16	B19	B22	S24
Area farmed (ha)	50.0	50.0	50.0	50.0
Grazing area (ha)	43.3	36.1	38.8	36.6
1st silage harvest (ha)[1]	6.7	13.9	11.2	13.4
2nd silage harvest (ha)[1]	4.5	9.3	7.5	8.9
Grazed grass consumed per animal (kg DM)	586	1,151	2,403	2,719
Grass silage consumed per animal (kg DM)	210	581	585	793
Concentrate consumed per animal (kg DM)	1,742	1,550	1,682	868
Whole farm inorganic N (kg/ha)	72	102	145	155
Number purchased (head)	255	192	154	137
Number finished (head)	241	181	145	127
Live-weight output (kg/ha)	2,524	2,157	1,887	1,539
Carcass output (kg/ha)	1,333	1,139	1,002	794

[1]Includes aftermath grazing.

veterinary and medicine and other variable costs were also largest for B16. Grazing grassland costs were greatest for B22 and S24 with silage costs highest for B19. This resulted in total variable costs being largest for B16 and lowest for S24. Gross margin was greatest for S24. Fixed costs were similar for all scenarios with

Table 4. Financial results for dairy calf-to-beef males finished as bulls at 16 (B16), 19 (B19) and 22 (B22) months of age and steers finished at 24 (S24) months of age investigated using the Grange Dairy Beef Systems Model (all results in €000s per farm)

Scenario	B16	B19	B22	S24
Livestock sales	273	224	192	160
Silage sales	6	3	0	0
Livestock purchases	32	24	19	17
Gross output	248	203	173	143
Variable costs				
Concentrate	156	104	90	43
Grazing grassland	4	4	7	7
Silage	3	7	6	7
Vet and Med	9	8	7	7
Other[1]	39	30	25	21
Total	211	154	136	85
Gross margin	37	49	37	58
Fixed costs	27	29	30	29
Net margin	9	20	7	29
Net cash flow[2]	15	24	15	27
Sensitivity (impact on net margin per farm)				
Beef price (± 10 c/kg)	6.9	5.6	4.8	4
Calf price (± €10/animal)	2.8	2.1	1.7	1.5
Concentrate price (± €10/t)	5.4	3.6	3.1	1.4
Fertiliser price (± €10/t)	0.1	0.1	0.2	0.2

[1]Slurry, straw, milk replacer, reseeding etc. [2]Net cash flow = net margin – depreciation.

the result that net margins were highest for S24 and lowest for B22. Scenario S24 was found to have the greatest net cash flow with B16 and B22 the lowest. Table 4 further shows the effect of variations in beef, calf, concentrate and fertiliser prices on net margin. Changing beef, calf and concentrate price had the largest effect on B16 and lowest effect on S24. Variations in fertiliser price had the highest effect on B22 and S24 and lowest on B16 and B19. Changing beef price had the highest effect on net margin followed by concentrate, calf and fertiliser price, respectively, for B16, B19 and B22. However, for S24 variations in calf price had a greater effect then concentrate price.

The ranking of the individual scenarios (B16, B19, B22 and S24) when variations in beef and concentrate price were investigated and the results are presented in Figures 2 and 3. Variations in beef price were found to have the largest effect on the comparable profitability of the systems. Results indicated that a beef price rise of more than 80 c/kg was required for Scenario B16 to become most profitable. However, B16 was least profitable when beef price decreased by 10 c/kg or more. Scenario S24 was the most profitable system until beef price increased by more than 55 c/kg. Scenario B19 was the most profitable system when beef price increased by between 55 and 80 c/kg. All scenarios showed some level of concentrate price volatility which is evident in their relative profitability to each other. Scenario B16 was the most profitable when concentrate price decreased by more than €60/t but the least profitable when concentrate price increased by more than €10/t. Scenario S24 was the most profitable until concentrate price decreased by more than €40/t. Variations in calf and fertiliser prices had a very small effect and no effect, respectively, on the ranking of the systems with S24 always remaining the most profitable.

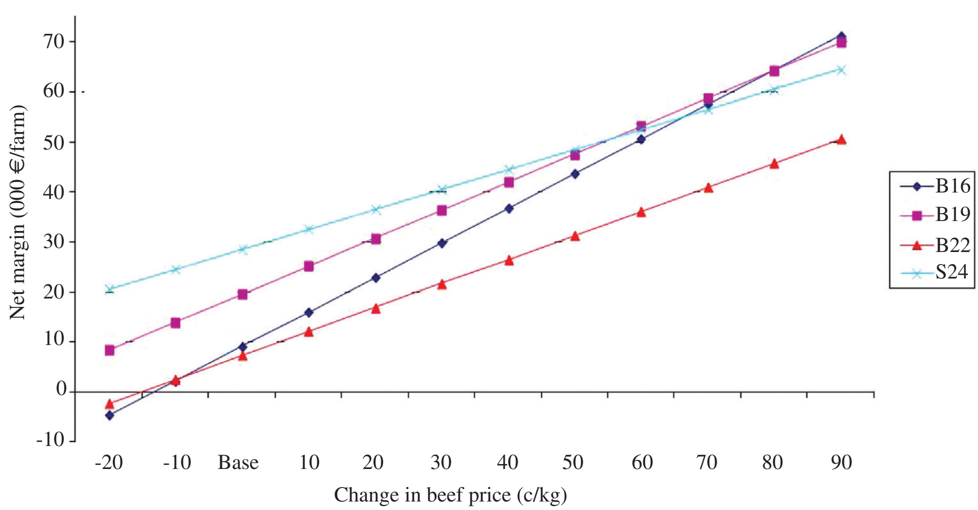

Figure 2. Effect of changing beef price on net margin of dairy calf-to-beef males finished as bulls at 16 (B16), 19 (B19) and 22 (B22) months of age and steers finished at 24 (S24) months of age investigated using the Grange Dairy Beef Systems Model (all results in €000s per farm).

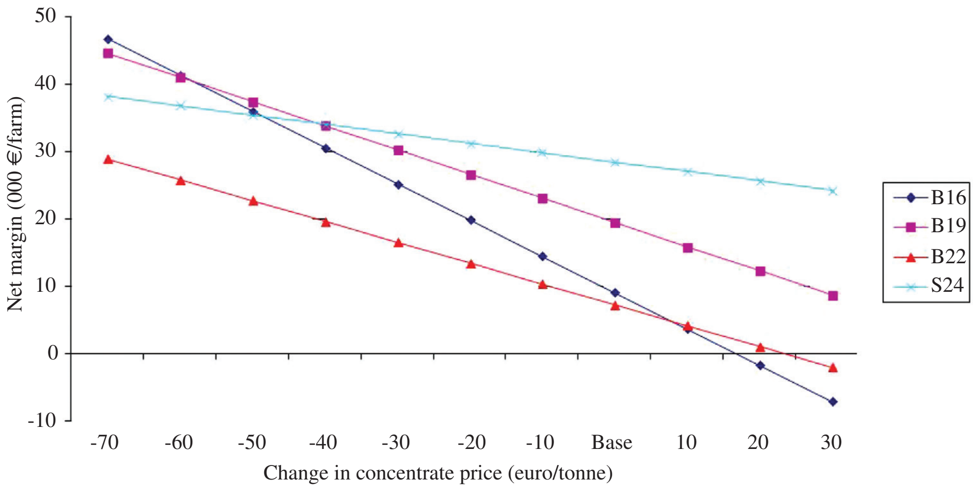

Figure 3. Effect of changing concentrate price on net margin of dairy calf-to-beef males finished as bulls at 16 (B16), 19 (B19) and 22 (B22) months of age and steers finished at 24 (S24) months of age investigated using the Grange Dairy Beef Systems Model (all results in €000s per farm).

Figure 4 illustrates the grazed grass supply and demand for B16, B19, B22 and S24. These graphs show that there is considerable excess grazed grass available in B16 throughout the season and B19 from June to October. These surpluses are harvested and sold as baled silage as indicated in Table 4. In contrast, B22 and S24 provide a better match between the monthly supply of grass and animal feed demand. However, results indicated that none of the combination systems resulted in a higher proportion of the total grass grown on the farm harvested as grazed grass rather than grass silage. Correspondingly, these combination systems did not lead to an increase in profitability.

Discussion

This paper compared Holstein-Friesian males finished as bulls at 16, 19 and 22 months of age or as steers at 24 months of age. The effect of combining systems was also investigated. The most profitable system in the individual scenarios was S24; this system also had the highest proportion of grazed grass in the diet (62%). Crosson, Rotz and Sanderson (2007) and Ashfield *et al*. (2013) also found that the most profitable system had the highest proportion of grazed grass in the diet and is due to grazed grass being the cheapest feed available to Irish farmers (Finneran *et al*. 2012), therefore, reducing the overall costs of production. The second most profitable system was B19 which had a gross and net margin greater than B22 despite having a lower proportion of grazed grass in the diet (35% *vs.* 51%). The profitability of B19 is driven by the high carcass output per hectare which was found by Crosson, McGee and Drennan (2009) to be one of the main drivers of profitability. McRae (2003) found that it may be necessary to reduce carcass output per hectare to increase profitability per hectare by increasing the utilisation of

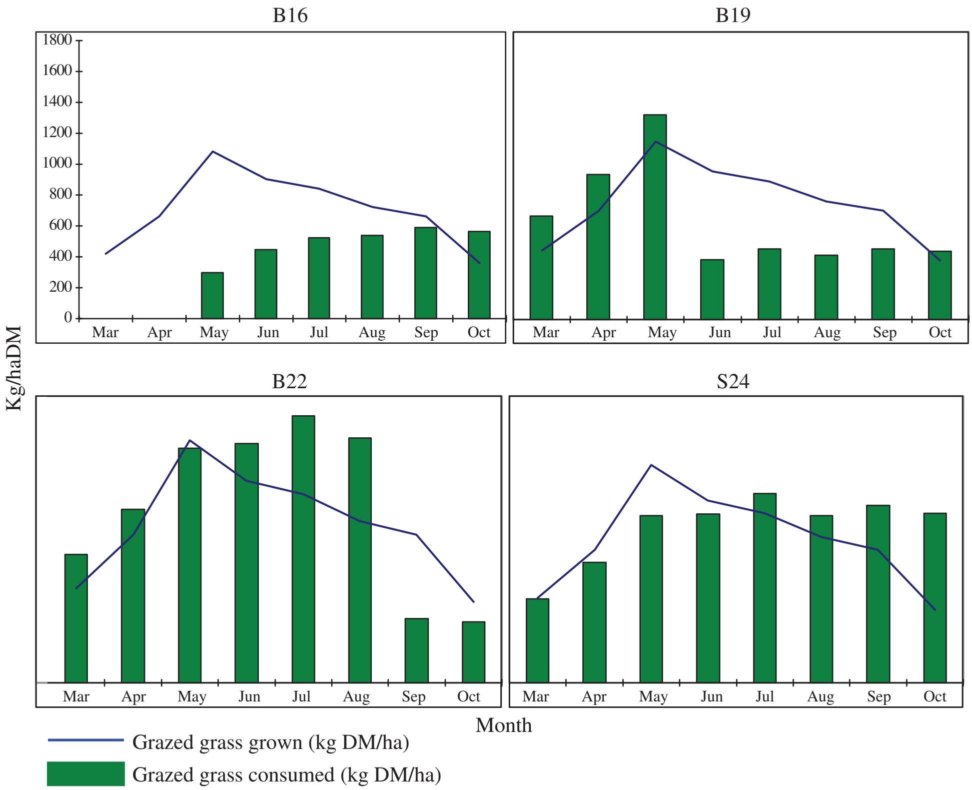

Figure 4. Grazed grass growth and demand per hectare per month for dairy calf-to-beef animals finished as bulls at 16 (B16), 19 (B19) and 22 (B22) months of age and steers at 24 (S24) months of age.

grass grown on the farm. Ashfield *et al*. (2013) also found that two of the main drivers of profitability in dairy beef systems are carcass output per hectare and the proportion of grazed grass in the diet. Therefore, both of these factors must be considered when developing blueprints for dairy calf to beef systems with the economically optimum balance depending on relative price levels. Scenarios B16 and B22 had the highest levels of concentrate consumed per animal which contributed to these scenarios having the lowest net margins. This is supported by Koknaroglu *et al*. (2005) who found that the most profitable systems were those with lower levels of concentrate fed.

Market volatility is a reality on Irish beef cattle farms with significant fluctuations in beef, concentrate, calf and fertiliser prices in recent years. Beef price increased from €2.87/kg in 2009 to €3.86/kg in 2012 (Bord Bia 2013b). Concentrate price increased from €250/t in 2007 to €308/t in 2012 (CSO 2013). Calf price decreased from €147 in 2005 to €92 in 2010 and then increased to €200 in 2012 (Noirin McHugh, Teagasc, personal communication). Changes in beef, concentrate and calf price had the largest effect on B16 because this system had the largest carcass output, concentrate requirement and number of calves purchased. Conversely, changes in beef, concentrate and calf price had the smallest effect on S24 because this system had the lowest carcass output, concentrate requirement and number of calves purchased. Fertiliser price changes had a relatively small effect on all systems because of the small proportion of total costs attributed to fertiliser purchases. This shows the wide change in prices and, in conjunction with Table 4 and Figures 2 and 3, illustrates how the profitability of the different systems and the ranking of systems can change between years. It is, therefore, necessary for farmers to undertake detailed enterprise budgets using the prevailing conditions on their farm and sensitivity to price changes to ascertain the resilience of alternative dairy calf-to-beef enterprise.

The combination of systems was evaluated to quantify the impact on grazed grass consumed on the farm and consequences for gross and net margin. Results indicated that there was very little effect of combining systems leading to no advantage of this practice. There was no improvement in the proportion of grazed grass that was consumed since grass growth matched demand in the month of October (Figure 4) for all systems. Thus, for each of the systems October was the month that had the lowest animal carrying capacity which dictated the animal carrying capacity of the farm (see model grass growth monthly section).

The net margin presented in this study does not account for labour, and given the large variation in animal numbers in the individual systems (ranging from 255 in B16 to 137 in S24) this is an issue that warrants consideration. The calf rearing period is the most labour intensive part of the systems. Gleeson, O'Brien and O'Donovan (2008) found that labour requirement per calf was 36 s/d this equates to an additional 66 hours work between B16 and S24 for an 8 week calf rearing period. If labour costs of €9.10/h (minimum agricultural wage in Ireland) during the calf rearing period are taken into account the ranking of the systems does not change but there is an additional €603 involved in rearing calves in the B16 compared to S24 system. Therefore, the economic advantage of S24 relative to B16 is increased. The large variation in the number of animals that can be kept in each system also means that the housing requirements vary greatly. This leads to a large variation in capital requirements between systems; in particular, the housing capacity of the bull systems is greater than the steer system due to differences in animal numbers (i.e., 255 and 137 calf spaces required for the B16 and S24 system, respectively).

Farmers face uncertainty about the economic consequences of their actions due to their limited ability to predict factors such as weather, prices and biological responses to different farming practices (Pannell, Malcolm and Kingwell 2000). Meuwissen, Huirne and Hardaker (2001) found that price was perceived as one of the most important sources of risk. Therefore, this study has tried to encompass some of the risk involved around changing prices and it was found that there is considerably higher risk in the bull systems than the steer system. The bull systems were found to be more sensitive to beef, calf and concentrate price changes and have greater levels of money invested in livestock and variable costs for lower net margins than the steer system which leads to higher levels of financial risk. However, to further determine the effect of price risk on the systems a more thorough examination of the empirical covariance of risk in beef, calf, fertiliser and concentrate prices would be required and an analysis of the robustness of the dominance of the S24 scenario assessed. Cash flow is an important part of any business and in the current analysis S24 was found to have the most positive net cash flow followed by B19, B22 and B16, respectively. This again makes the steer system more financially attractive than the bull systems. There are conflicting reports on the quality of meat from bull beef systems compared to steer systems. Sinclair *et al*. (1998) found that bulls were more tender and acceptable than steers, Keane and Allen (1998) found no differences in shear force between bulls and steers with Arthaud *et al*. (1977) finding that bulls had less tender meat than steers. Despite this equivocal information the market for bulls slaughtered over the age of 16 months seems to be very limited with specific export markets requiring that bulls be <16 months of age when slaughtered (Dawn Meats 2011). This further adds to the risk of the bull beef systems.

Hutchinson, Shalloo and Butler (2013) found that fresh sexed semen can lead to faster more profitable expansion of Irish dairy herds. Therefore, this could result in a reduced number of Holstein-Friesian males becoming available for beef production because less dairy cows have to be breed to Holstein-Frisian sires to generate sufficient replacements. However, the use of sexed semen has been found to reduce conception rates when compared to conventional semen (Norman, Hutchison and Miller 2010) and it is not certain what the uptake of sexed semen at farm level will be. Furthermore, the use of sexed semen could lead to an increase in the number of dairy cows bred to beef sires (LM and EM) because there will be a reduction in the amount of Holstein-Friesian sires used due to an increase in proportion of heifer calves born from sexed semen. This could result in a larger number of beef breed animals and lower number of Holstein-Friesian animals being available for beef production from the dairy herd.

Conclusions

The GDBSM was further developed to more accurately simulate the relationship between grazed grass supply and demand. The most profitable system in the current study was found to be S24, however, as the sensitivity analysis shows these systems are very sensitive to changes in beef, calf and concentrate prices and the ranking of the systems can change with changes in prices. Despite the inherent ability of bulls to grow faster than steers, the steer system is more profitable as a result having a greater proportion of live weight at slaughter gained from grazed grass. The combining of systems did not show any advantage over individual systems in terms of net margin or increased quantity of grass grown on the farm which is grazed.

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