A multicriteria assessment of forage or concentrate-based finishing diets for temperate pasture-based suckler beef production systems

Doyle, P.R.* †; O'Riordan, E.G.*; McGee, M.*; Crosson, P.*; Kelly, A.K.†; Moloney, A.P.*
*Teagasc, Animal & Grassland Research and Innovation Centre, Grange, Dunsany, Co. Meath, Ireland;
†University College Dublin, Belfield, Dublin 4, Ireland

Key words: grazing; pasture; profitability; greenhouse gas emissions; grain

Abstract
This study evaluated the effect of contrasting 'finishing' diets on animal performance, meat nutritional value, land use, food-feed competition, farm economics and greenhouse gas (GHG) emissions in temperate pasture-based suckler weanling-to-steer beef systems. Post-weaning, eight-month-old, spring-born, late-maturing breed steers (333 kg) were assigned to one of three systems: (1) Grass silage + 1.2 kg concentrate DM (148 days), followed by pasture (123 days) and finished on *ad libitum* concentrates (120 days) - slaughter age, 21 months (GRAIN); (2) as per (1) but pasture (196 days) and finished on grass silage *ad libitum* + 3.5 kg concentrate DM (124 days) - slaughter age, 24 months (SIL+GRAIN); and (3) grass silage-only (148 days), pasture (196 days), silage-only (140 days) and finished on pasture (97 days) - slaughter age, 28 months (FORAGE). The mean target carcass weight was 390 kg for each system. Data generated was used to parameterise a farm-level beef systems model. Measured concentrate DM intake was 1187, 606 and 0 kg/head, and average daily gain was 0.83, 0.72 and 0.62 kg for GRAIN, SIL+GRAIN and FORAGE, respectively. Direct (pasture) land use was lowest for GRAIN. FORAGE was more profitable and was the only net producer of human edible protein and energy/ha. GRAIN produced the lowest GHG emissions per animal and meat essential amino acid concentration. FORAGE was more favourable for GHG emissions per kg of net (produced vs. consumed) production of human edible protein. Muscle amino acid and saturated fatty acid concentrations did not differ between the production systems, but FORAGE had the highest muscle concentration of omega-3 poly-unsaturated fatty acids. Differences in muscle mineral concentration were small. In conclusion, there are inverse relationships between food-feed competition, land-use, economics and GHG emissions per unit of product among different systems.

Introduction
Beef produced from pasture-based systems ('forage-fed beef') is attracting increasing attention as compared to concentrate-fed beef, it is perceived by consumers as being more environmentally sustainable, better for human health and more animal welfare friendly (Stampa et al., 2020). Furthermore, forage-only systems use no human edible feed and, as a consequence, positively contribute to food security (Mosnier et al., 2021). However, there is a paucity of research information on the impact of removing concentrates from beef production systems on farm level profitability, environmental footprint, overall meat nutritional value and food-feed competition of contrasting finishing beef farms. In addition, in those studies that considered environmental footprint, few examined greenhouse gas (GHG) emissions relative to net production of human edible food.

In countries with temperate climates, such as Ireland, grass-based production system 'blueprints' focus on producting suckler bred steers at 24 months of age, with the finishing phase indoors using grass silage with moderate concentrate supplementation levels (700 kg dry matter (DM)/head) (Drennan and McGee, 2009). Concentrates are rarely offered *ad libitum* in this sytem, however, this is more common in other parts of the world (Klopatek et al., 2022). At the other extreme, complete removal of concentrates from the diet is not commonly practiced as it reduces daily energy intake, carcass gain and carcass fat deposition (Caplis et al., 2005). Forage-only systems would therefore be expected to require an older slaughter age to achieve similar carcass weights and fat scores as a 'feedlot' systems. This may (Klopatek et al., 2022) or may not (Herron et al., 2021) increase GHG emissions. The objective of this study was to evaluate the effect of forage and concentrate finishing diets in a weanling-to-steer beef system on animal performance, meat nutrient value, land-use, food-feed competition, greenhouse gas emissions and farm-level economics.

Methods
This study was conducted at Teagasc, Grange Research Centre, Ireland. Fifty-four spring-born, late-maturing, recently-weaned (October) steers (333kg; 8 months of age) were blocked on mean live-weight within sire breed (Limousin or Charolais) and assigned to one of three weanling-to-beef production systems: (1) Grass

silage + 1.2 kg concentrate DM (148 days), followed by pasture (123 days) and finished on *ad libitum* concentrates and silage (120 days) - slaughter age, 21 months (GRAIN); (2) Grass silage + 1.2 kg concentrate DM (148 days), followed by pasture (196 days) and finished on grass silage *ad libitum* + 3.5 kg concentrate DM (124 days) - slaughter age, 24 months (SIL+GRAIN); and (3) grass silage-only (148 days), pasture (196 days), silage-only (140 days) and finished on pasture (97 days) - slaughter age, 28 months (FORAGE). The target mean target carcass weight for each production system was 390 kg. The concentrate supplement (862 g rolled barley, 60 g soyabean meal, 50 g molasses and 28 g minerals and vitamins per kg fresh weight), where fed, was offered once each morning. At pasture, steers rotationally grazed perennial ryegrass swards with an average pre-grazing herbage mass (> 4 cm) of 2083 kg DM/ha and grazed to a mean post-grazing sward height of 4.3 cm. At 48 hours post-mortem, the *M. Longissimus lumborum* muscle was excised, vacuum-packed, stored at 2°C for a further 19 days, cut into individual steaks (thickness 25 mm) and frozen until further analysis.

Farm systems analysis was modelled using the Grange Beef Systems Model (Crosson et al., 2006) in a similar manner to that described by McGee et al. (2022). The model was parameterised using the biological and animal production data from the current experiment, which included live-weight, average daily live-weight gain, silage and concentrate intake, carcass weight, days at pasture or indoors, composition of the concentrate offered and muscle crude protein concentration. The production system operated was weanling-to-beef and in each scenario the production system began with the purchase of 200 weanlings on the 1 December and this was assumed to be the start of the 'first' winter, and ended when the animals were slaughtered. The model did not consider the suckler cow 'overhead cost' in the system. The farm area owned was assumed to be 37 ha (area of land required for GRAIN production system) and a land rental charge was applied as appropriate to any additional land required. Assumed prices are outlined in the footnote of Table 1. Labour and European Union farm support payments were not included. The BEEF systems GHG emissions Model (Foley et al., 2011) was used to estimate GHG emissions within a weanling-to-beef scenario, similar to that described by McGee et al. (2022). On-farm emissions included enteric fermentation, animal slurry and silage effluent storage and application, inorganic fertiliser application, deposition of excreta at pasture by grazing animals and on-farm fuel use. Emissions generated off-farm from the manufacture of purchased concentrate feed, inorganic fertiliser, diesel and electricity, in addition to nitrous oxide emissions, resulting from N leaching and ammonia volatilisation, were also included. One hundred year global warming potential CO_2 equivalents (CO_2eq) were calculated from GHG emissions. The GWP values used for methane and nitrous oxide were 28 and 265 CO_2eq, respectively (Myhre et al., 2013). To evaluate the contribution of each production system to food protein and energy security, i.e. human food fed to the animals vs. human food produced by the animals, the approach described by Mosnier et al. (2021) was used within a weanling-to-beef system context. An efficiency greater than one meant that the system produced more human edible protein or energy, than consumed, whilst an efficiency less than one indicated that the system produced less human edible protein or energy, than consumed. Analysis of variance using the MIXED procedure of Statistical Analysis Software (SAS) was used to compare animal production, carcass and meat quality data across production systems. Individual animal was considered the experimental unit. The model contained production system and block as fixed effects and differences between means were tested for significance using the PDIFF statement.

Results and Discussion

Measured DM concentrate intake was 1187, 606 and 0 kg/head and herbage DM proportion was 0.61, 0.84 and 1.0 for GRAIN, SIL+GRAIN and FORAGE, respectively. Consequently, average daily gain from the start of the first winter to slaughter was greater for GRAIN than SIL+GRAIN, which in turn was greater than FORAGE (0.83, 0.72 and 0.62 kg, respectively; $P < 0.001$). Age at slaughter was lower for GRAIN than SIL+GRAIN, which in turn was lower than FORAGE (20.9, 23.7 and 27.6 months, respectively; $P < 0.001$). Carcass weight and fat score did not differ ($P > 0.05$) between systems. Amino acid concentrations, mono- and poly-unsaturated fatty acid and saturated fatty acid concentrations did not differ ($P > 0.05$) between muscle from the different production systems, but muscle from FORAGE had a greater concentration of omega-3 poly-unsaturated fatty acids than muscle from SIL+GRAIN, which in turn was greater than GRAIN ($P < 0.01$). Cholesterol concentration tended to be lowest ($P = 0.07$) for SIL+GRAIN and did not differ between GRAIN and FORAGE. Absolute differences in muscle mineral concentration between the systems were small.

Land-use, food-feed competition, farm-level profitability and GHG emissions are outlined in Table 1. From a food 'security' perspective FORAGE was a net producer of human edible food, whereas SIL+GRAIN and GRAIN, were net consumers. Nonetheless, consistent with international literature, FORAGE produced less meat per ha of agricultural land than GRAIN system (McGee et al., 2022). However, FORAGE makes an important positive contribution to food security on land that is unsuitable for cropping, as it does not utilise any human edible food.

Despite the lower carcass output/ha, FORAGE had the greatest farm level profitability per ha and per animal compared to the other systems, largely reflecting differences in the relative cost of grazed grass compared to purchased concentrates in temperate climates (Finneran et al., 2012). Similarly, McGee et al. (2022) found that in Irish weanling-to-beef systems, suckler bulls finished on a grass-only diet were more profitable than those finished at the same age on *ad libitum* concentrates (McGee et al., 2022). In the international literature, forage-only systems are reported to increase (Berthiaume et al., 2006) or decrease (Klopatek et al., 2022) farm-level profitability compared to grain-finishing systems.

GRAIN steers, which were younger at slaughter than FORAGE steers, produced 18 % lower GHG emissions per animal, which is consistent with the literature (Klopatek et al., 2022). The ranking of results did not change when GHG emissions were expressed against ‘product unit’ as GRAIN also produced lower GHG emissions per meat weight gain, kg edible protein gain and kg essential amino acids gain compared to SIL+GRAIN and FORAGE. However, when the net production of human edible protein was taken into account (as above), FORAGE was more favourable compared to SIL + GRAIN and GRAIN systems, and was the only system with a positive value, in terms of GHG emissions per kg of human edible protein produced. A negative value is undesirable as it implies net consumption of human edible protein. Therefore, it is clear that there are trade-offs in GHG emissions between systems depending upon which metric GHG emissions are expressed against.

Conclusions and/or Implications

From this study it is clear that the concept of ‘sustainability’ in beef production systems encompasses multiple trade-offs between food-feed competition, land-use, GHG emissions and profitability. Compared to intensive grain-finishing, forage-only systems have a number of advantages including an enhanced fatty acid profile in the meat, improved profitability and improved food security, from the perspective of producing human edible food on land unsuitable for cropping, with SIL+GRAIN being intermediate with the exception of profit. The older age at slaughter and associated increased GHG emissions per animal and land-use in forage-only production systems compared to grain-finishing systems is a disadvantage. Nonetheless forage-only systems had the lowest GHG emissions per kg of net production of human edible protein. Mitigation strategies are also being investigated to reduce age at slaughter in forage-only production systems (Herron et al., 2021).

Acknowledgements

The authors acknowledge Joe Munroe, Francis Collier, Pat Whelan and Patsy Martin for their care of the animals. Also thanks to the following Teagasc staff for their assistance with laboratory analysis, Martin Danaher, Ciara Carberry, Anne Marie McAuliffe, Ann Marley and Abimbola Ikoyi.

References

Berthiaume, R., Mandell, I., Faucitano, L. and Lafreniere, C. 2006. Comparison of alternative beef production systems based on forage finishing or grain-forage diets with or without growth promotants: 1. Feedlot performance, carcass quality, and production costs. *J. of Anim. Sci.,* 84: 2168-2177.

Caplis, J., Keane, M.G., Moloney, A.P. and O'Mara, F.P. 2005. Effects of supplementary concentrate level with grass silage, and separate or total mixed ration feeding, on performance and carcass traits of finishing steers. *Ir. J. of Agri. and Food Res.,* 44: 27-43.

Crosson, P., O’Kiely, P., O’Mara, F. and Wallace, M. 2006. The development of a mathematical model to investigate Irish beef production systems. *Agri. Sys.,* 89: 349-370.

Drennan, M.J. and McGee, M., 2009. Performance of spring-calving beef suckler cows and their progeny to slaughter on intensive and extensive grassland management systems. *Lives. Sci.,* 120: 1-12.

Finneran, E., Crosson, P., O'Kiely, P., Shalloo, L., Forristal, P.D. and Wallace, M. 2012. Stochastic simulation of the cost of home-produced feeds for ruminant livestock systems. *The J. of Agri. Sci.,* 150: 123-139.

Foley, P.A., Crosson, P., Lovett, D.K., Boland, T.M., O’Mara, F.P. and Kenny, D.A. 2011. Whole-farm systems modelling of greenhouse gas emissions from pastoral suckler beef cow production systems. *Agri. Ecos. & Envi.,* 142: 222-230.

Herron, J., Curran, T.P., Moloney, A.P., McGee, M., O'Riordan, E.G. and O'Brien, D. 2021. Life cycle assessment of pasture-based suckler steer weanling-to-beef production systems: Effect of breed and slaughter age. *Animal,* 15: 100247.

Klopatek, S.C., Marvinney, E., Duarte, T., Kendall, A., Yang, X. and Oltjen, J.W. 2022. Grass-fed vs. grain-fed beef systems: performance, economic, and environmental trade-offs. *J. of Ani. Sci.,* 100: skab374.

McGee, M., Lenehan, C., Crosson, P., O'Riordan, E.G., Kelly, A.K., Moran, L. and Moloney, A.P. 2022. Performance, meat quality, profitability, and greenhouse gas emissions of suckler bulls from pasture-based compared to an indoor high-concentrate weanling-to-beef finishing system. *Agri. Sys.,* 198: 103379.

Mosnier, C., Jarousse, A., Madrange, P., Balouzat, J., Guillier, M., Pirlo, G., Mertens, A., O'Riordan, E.G., Pahmeyer, C., Hennart, S., Legein, L., Crosson, P., Kearney, M., Dimon, P., Bertozzi, C., Reding, E., Iacurto, M., Breen, J., Carè, S. and Veysset, P. 2021. Evaluation of the contribution of 16 European beef production systems to food security. *Agri. Sys.*, 190: 103088.

Myhre, G., Shindell, D., Bréon, F.M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.F., Lee, D., Mendoza, B., Nakajima, T., A., R., Stephens, G., Takemura, T. and Zhang, H. 2013. Anthropogenic and Natural Radiative Forcing. In: Intergovernmental Panel on Climate Change (eds.) *Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Stampa, E., Schipmann-Schwarze, C.and Hamm, U. 2020. Consumer perceptions, preferences, and behavior regarding pasture-raised livestock products: A review. *Food Qual. and Pref.*, 82: 103872.

Table 1 Land use, food-feed competition, farm-level profitbaility and greenhouse gas (GHG) emissions of suckler weanling-to-beef production systems (Grain, Silage + grain and Forage) as modelled using the Grange Beef Systems Model (Crosson et al., 2006) and Grange GHG emissions Model (Foley et al., 2011) parameterised using production data from this study.

	Scenario[1]		
	GRAIN	**SIL + GRAIN**	**FORAGE**
Land-use and food-feed competition			
Total pasture land use (ha)	36.7	65.4	90.1
Carcass gain output (kg/ha)	1,169	630	491
Human edible meat (kg/ha)	788	424	331
Net human edible protein output (kg/ha)[2]	-452	-85	78
Net human edible energy output (MJ/ha)[2]	-78,232	-20,373	3,075
Food-Feed; human edible protein[2,3]	0.29	0.53	-
Food-Feed; human edible energy[2,3]	0.09	0.16	-
Farm-level profitability (€/farm)			
Gross output[4]	162400	150500	163800
Variable costs[5]	126500	99200	65800
Fixed costs	37600	41000	41500
Net margin (including land charge expense)[6]	-1700	-2600	32500
Total GHG emissions (kg CO_2eq, weanling-to-beef)			
Per animal ('00)	34.7	41.6	42.9
Per kg carcass weight gain	16.0	19.8	19.0
Per kg meat weight gain	23.5	29.2	28.0
Per kg edible protein gain	99	128	118
Per kg essential amino acids gain	247	308	291
Per net production of human edible protein[7]	-41.4	-147	118
Per hectare of pasture land area ('00)	187	125	93

[1]Suckler weanling-to-beef production system (assumes 200 animals per production system)

[2]Accounts for human edible meat in the carcass only

[3]There is no numeric value for Forage as there was 0 kg DM of human edible food offered in the diet.

[4]Beef carcass price was €4.20/kg for SIL+GRAIN and FORAGE and €4.26/kg for GRAIN, due to a greater conformation score.

[5]Key input price assumptions; Finishing concentrate €400/t DM, Urea fertiliser €370/t, Calcium ammonium nitrate fertiliser €270/t, Weanling purchasing €2.67/kg live weight

[6]Land charge expense of €450/ha for each additional ha required above 37 ha (with 37 ha being the land required for the GRAIN production system).

[7]GHG emissions (kg CO_2eq) per kg of net production of human edible protein. Low positive values are desirable (i.e. a positive value close to zero). A negative value is undesirable as it implies net consumption of human edible protein.