**Supplementary material**

**Supplementary Table 1**: Emission factors/coefficients used for greenhouse gas emissions for the three suckler weanling-to-beef systems modelled.

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| **Source** | **Coefficient/ emission factor** | **Reference** |
| Methane emissions |  |  |
| Enteric fermentation at grazing (% of GEI)1 | 6.3 | IPCC (2019) |
| Enteric fermentation on high-concentrate diets (% of GEI) | 3.0 | IPCC (2019) |
| Enteric fermentation on conserved feeds (kg CH4/day)2 | [0.964 - 4.078(MEI/GEI)  + 2.23(DEI/GEI)] \* LW + 166.9FL -194.7 | Yan et al. (2009) |
| Pastorally deposited excreta (kg CH4)3 | Bo3 0.18; MCF 0.47%; 0.67 kg/m3 CH4 | IPCC (2019) |
| Stored slurry (kg CH4) | Bo3 0.18; MCF 17%; 0.67 kg/m3 CH4 | IPCC (2019) |
| Direct nitrous oxide emissions |  |  |
| Liquid manure storage (kg N2O-N/kg N) | 0.002 | IPCC (2019) |
| Solid manure storage (kg N2O-N/kg N) | 0.01 | IPCC (2019) |
| Liquid manure spreading (% N lost as N2O ) | 0.01 | IPCC (2019) |
| Dung excreted onto pasture (kg N2O-N/kg N) (Spring) | 0.0009 | Krol et al (2016) |
| Dung excreted onto pasture (kg N2O-N/kg N) (Summer) | 0.0021 | Krol et al (2016) |
| Dung excreted onto pasture (kg N2O-N/kg N) (Autumn) | 0.0052 | Krol et al (2016) |
| Urine excreted onto pasture (kg N2O-N/kg N) (Spring) | 0.0067 | Krol et al (2016) |
| Urine excreted onto pasture (kg N2O-N/kg N) (Summer) | 0.0071 | Krol et al (2016) |
| Urine excreted onto pasture (kg N2O-N/kg N) (Autumn) | 0.0156 | Krol et al (2016) |
| CAN4 fertiliser application (kg N2O-N/kg N) | 0.0149 | Harty et al (2016) |
| Urea fertiliser application (kg N2O-N/kg N) | 0.0025 | Harty et al (2016) |
| Urea+NBPT5 fertiliser application (kg N2O-N/kg N) | 0.004 | Harty et al (2016) |
| Direct carbon dioxide emissions |  |  |
| Diesel use (kg CO2eq/L) | 2.91 | EPA (2019a) |
| Electricity generation (per kW hour) | 0.465 | Irelands, National Inventory Report (2019 |
| Diesel production (kg CO2eq/L) | 0.302 | Kramer et al. (1999) |
| Concentrate for growing animals (kg CO2e/kg) | 0.669 | Ecoinvent, (2010) |
| Ammonia emissions |  |  |
| Housing liquid manure (kg NH3-N/kg TAN)6 | 0.277 | EPA (2019b) |
| Housing solid manure (>12mths)( kg NH3-N/kg TAN) | 0.168 | EPA (2019b) |
| Housing solid manure (<12mths) (kg NH3-N/kg TAN) | 0.042 | EPA (2019b) |
| Liquid manure storage (kg NH3-N/kg TAN) | 0.050 | EPA (2019b) |
| Solid manure storage (kg NH3-N/kg TAN) | 0.350 | EPA (2019b) |
| Liquid manure (kg NH3-N/kg TAN) (Spring, Autumn) | 0.260 | EPA (2019b) |
| Liquid manure spreading (kg NH3-N/kg TAN) (Summer) | 0.484 | EPA (2019b) |
| Solid manure spreading(kg NH3-N/kg TAN) | 0.680 | EPA (2019b) |
| Grazing  (kg NH3-N/kg TAN) | 0.060 | EPA (2019b) |
| CAN fertiliser application (kg NH3-N/kg N) | 0.022 | EPA (2019b) |
| Urea fertiliser application (kg NH3-N/kg N) | 0.243 | EPA (2019b) |
| Urea+NBPT fertiliser application (kg NH3-N/kg N) | 0.028 | Forrestal et al. (2016) |
| Ammonia emissions converted to N2O-N | 0.010 | IPCC (2019) |
| Nitrate leaching |  |  |
| Nitrate leaching (% N applied) Spring | 0.1 | IPCC (2019) |
| Nitrate converted to N2O-N | 0.11 | IPCC (2019) |

1 GEI= gross energy intake ega joules (MJ); 2 MEI= metabolisable energy intake (MJ), DEI= digestible energy intake (MJ), LW= live weight (kg), FL= feeding level; 3 Bo= methane producing capacity; MCF= methane conversion factor; 4 CAN= Calcium ammonium nitrate; 5 NBPT= N-(n-butyl) thiophosphoric triamide; 6 TAN= total ammoniacal nitrogen

**Supplementary Figure 1** The effect of production system ( Grain,  Silage + grain and  Forage) on ultrasonic fat depth pattern (mm) of steers.

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| **Supplementary Table 2** Estimated haem pigment percentage (%) of the *longissimus lumborum* muscle from suckler bred steers from different production systems (Grain = finished on *ad libitum* concentrates at 21 months of age; Silage + grain = finished on grass silage plus 3.5 kg concentrate dry matter at 24 months of age; and Forage = finished at pasture (forage-only) at 28 months of age). |
|   | **Grain** | **Silage + grain** | **Forage** | **S.E.M.** | ***P* value** |
| Oxymyoglobin | 77.1b | 80.1a | 75.8b | 0.60 | \*\*\* |
| Metmyoglobin | 12.2c | 13.1b | 14.1a | 0.29 | \*\*\* |
| Myoglobin | 10.7a | 6.8b | 10.1a | 0.55 | \*\*\* |
| S.E.M. standard error of the mean |
| a,b,c means within a row with different superscripts differ (*P* < 0.05) |

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| **Supplementary Table 3** Fatty acid concentration (mg/100g muscle) of the *longissimus lumborum* muscle from suckler bred steers on different production systems (Grain = finished on *ad libitum* concentrates at 21 months of age; Silage + grain = finished on grass silage plus 3.5 kg concentrate dry matter at 24 months of age; and Forage = finished at pasture (forage-only) at 28 months of age). |
|   | **Grain** | **Silage + grain** | **Forage** | **S.E.M.** | ***P* value** |
| C 4:0 | 1.05 | 1.03 | 1.19 | 0.090 | NS |
| C 10:0 | 1.08 | 1.12 | 1.03 | 0.099 | NS |
| C 12:0 | 1.39 | 1.51 | 1.52 | 0.115 | NS |
| C 13:0 | 35.8b | 38.9ab | 41.5a | 1.542 | \* |
| C 14:0 | 30.10 | 37.99 | 28.72 | 3.896 | NS |
| C 15:0 *iso* | 1.36 | 1.24 | 1.36 | 0.057 | NS |
| C 15:0 *anteiso* | 1.89b | 2.99a | 3.17a | 0.324 | \* |
| C 14:1 | 3.16b | 4.09ab | 4.52a | 0.369 | \* |
| C 15:0 | 7.52 | 8.46 | 7.15 | 1.009 | NS |
| C 15:1 | 6.44 | 7.00 | 7.82 | 0.770 | NS |
| C 16:0 *iso* | 3.82b | 4.43a | 4.55a | 0.163 | \*\* |
| C 16:0 | 335ab | 428a | 317b | 35.2 | 0.07 |
| C 17:0 *iso* + C 16:1 *t*9 | 5.19c | 6.84b | 8.58a | 0.555 | \*\*\* |
| C 16:1 *t*10-12 | 2.82a | 3.46ab | 3.89a | 0.346 | 0.1 |
| C 16:1 *c*91 | 47.18 | 57.95 | 50.05 | 5.764 | NS |
| C 16:1 *c*13 | 2.46 | 2.39 | 2.17 | 0.226 | NS |
| C 17:0 | 16.53 | 16.29 | 14.90 | 1.604 | NS |
| C 17:1 *t*11 | 19.38b | 22.43a | 23.85a | 0.934 | \*\* |
| C 18:0 | 189b | 250a | 193ab | 21.105 | 0.1 |
| C 18:1 *t*6-8 | 1.34 | 1.20 | 1.43 | 0.138 | NS |
| C 18:1 *t*9 | 2.26 | 2.86 | 2.84 | 0.249 | NS |
| C 18:1 *t*10 | 5.34a | 1.93b | 2.14b | 0.506 | \*\*\* |
| C 18:1 *t*11 | 7.51b | 14.20ab | 20.59a | 2.648 | \*\* |
| C 18:1 *t*12-13 | 1.50 | 1.83 | 2.09 | 0.230 | NS |
| C 18:1 *c*9 | 411b | 544a | 432ab | 43.7 | 0.10 |
| C 18:1 *c*11 | 24.49 | 23.76 | 21.11 | 2.009 | NS |
| C 18:1 *c*12 | 2.07 | 2.31 | 2.13 | 0.165 | NS |
| C 18:1 *c*13 | 4.43 | 4.33 | 3.89 | 0.454 | NS |
| C 18:1 *t*16 | 2.15b | 3.31a | 3.63a | 0.326 | \*\* |
| C 18:1 *c*152 | 2.63 | 3.07 | 3.08 | 0.264 | NS |
| C 18:2 10,133 | 2.58b | 3.27ab | 4.25a | 0.366 | \*\* |
| C 18:2 *t*9,*c*15 | 1.40a | 1.46a | 1.08b | 0.089 | \*\* |
| C 18:1 *c*16  | 2.16b | 2.57ab | 3.58a | 0.373 | \* |
| C 18:2 *t*10,*c*15 | 2.02b | 3.14b | 4.65a | 0.498 | \*\* |
| C 18:2 *t*12,*c*15 | 2.00 | 1.76 | 1.77 | 0.163 | NS |
| C 20:0 | 1.94a | 2.48a | 1.97a | 0.194 | 0.1 |
| C 20:1 *t*15 | 1.21 | 1.40 | 1.24 | 0.128 | NS |
| C 20:1 *c*11 | 2.24b | 2.79a | 1.94b | 0.166 | \*\* |
| C 18:2 *t*10,*c*12(CLA) | 1.12b | 1.39ab | 1.80a | 0.177 | \* |
| C 20:3 *n*-6 | 7.72a | 6.74ab | 5.91b | 0.474 | \* |
| C 20:4 *n*-6 | 16.45 | 16.18 | 15.90 | 0.957 | NS |
| C 24:0 | 1.16 | 1.33 | 1.16 | 0.064 | NS |
| C 20:5 *n*-3 (EPA) | 8.25b | 9.74b | 15.76a | 0.689 | \*\*\* |
| C 22:6 *n*-3 (DHA) | 3.00b | 3.44b | 4.88a | 0.256 | \*\*\* |
| Unidentified | 93.60b | 110.74a | 115.24a | 4.899 | \*\* |
| Atherogenicity index4  | 0.72a | 0.70a | 0.59b | 0.032 | \* |
| Thrombogenic index4  | 1.44a | 1.41a | 1.07b | 0.065 | \*\*\* |
| CLA = conjugated linoleic acid, EPA = Eicosapentaenoic acid, DHA = Docosahexaenoic acid, SFA = saturated fatty acids, MUFA= monounsaturated fatty acids, PUFA= polyunsaturated fatty acids |
| 1co-eluted with C 17:0 *anteiso* |
| 2co-eluted with C18:2 10,14 and C19:0 |
| 3co-eluted with C18:2, 11,14 |
| 4Calculated as described by Ulbricht and Southgate (1991) |
| S.E.M. standard error of the mean |
| a,b,c means within a row with different superscripts differ (*P* < 0.05) |
| NS = non-significant, \* *P* < 0.05, \*\* *P* < 0.01, \*\*\* *P* < 0.001 |

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| **Supplementary Table 4** The mineral nutritional proportion (mineral concentration in a 100 g meat serving expressed against mineral recommended daily intake) from the *longissimus lumborum* muscle of suckler bred steers on different production systems (Grain = finished on *ad libitum* concentrates at 21 months of age; Silage + grain = finished on grass silage plus 3.5 kg concentrate dry matter at 24 months of age; and Forage = finished at pasture (forage-only) at 28 months of age). |
|   | **Grain** | **Silage + grain** | **Forage** |
| Vitamins |  |  |  |
| Vitamin E (alpha-tocopherol)  | 0.01 | 0.03 | 0.03 |
| Major minerals |  |  |  |
| Calcium | 0.01 | 0.00 | 0.01 |
| Phosphorus | 0.31 | 0.29 | 0.29 |
| Potassium | 0.12 | 0.12 | 0.12 |
| Magnesium | 0.08 | 0.08 | 0.08 |
| Sodium | 0.03 | 0.03 | 0.03 |
| Trace minerals |  |  |  |
| Iron | 0.15 | 0.17 | 0.16 |
| Manganese | 0.00 | 0.00 | 0.00 |
| Copper | 0.05 | 0.04 | 0.04 |
| Zinc | 0.23 | 0.23 | 0.23 |
| Lead | . | . | . |
| Selenium | 0.41 | 0.76 | 0.99 |
| Average |  |  |  |
| *Average proportion (without selenium)* | 0.09 | 0.09 | 0.09 |
| *Average proportion (with selenium)* | 0.12 | 0.15 | 0.16 |
| Recommended daily intake source = FSAI (2020) - using European Food Safety Authority reference values |

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| **Supplementary Table 5** Nutrient index of a steak serving (100g/day) from the *longissimus lumborum* muscle of suckler bred steers on different production systems (Grain = finished on *ad libitum* concentrates at 21 months of age; Silage + grain = finished on grass silage plus 3.5 kg concentrate dry matter at 24 months of age; and Forage = finished at pasture (forage-only) at 28 months of age). |
| **Nutrient/index** | **Unit** | **RDI** | **Grain** | **Silage + grain** | **Forage** |
| Protein | g/day | 50.25b | 23.8 | 22.9 | 23.7 |
| MUFA | g/day | 37.5b | 0.55 | 0.71 | 0.59 |
| EPA+DHA | mg/day | 250c | 11.3 | 13.2 | 20.6 |
| Ca | mg/day | 950d | 5.29 | 4.46 | 5.06 |
| Fe | mg/day | 11d | 1.65 | 1.89 | 1.71 |
| Riboflavine | mg/day | 1.6d | 0.24 | 0.24 | 0.24 |
| Folatee | µg/day | 330d | 16.8 | 16.8 | 16.8 |
| Vitamin B12e | µg/day | 4d | 2.00 | 2.00 | 2.00 |
| Se | µg/day | 70d | 28.8 | 52.6 | 69.2 |
| Zn | mg/day | 11.45d | 2.62 | 2.59 | 2.61 |
| Naa | g/day | 1.5d | 0.05 | 0.05 | 0.05 |
| SFAa | g/day | 25b | 0.60 | 0.76 | 0.59 |
|  |  |  |  |  |  |
| UKNIprot7-2f | % RDI |  | 9.9 | 9.8 | 10.6 |
| UKNIprot10-2f | % RDI |  | 17.5 | 20.7 | 23.7 |
| aNutrients to be discouraged |
| RDI; Recommended daily intake/allowance is based on data from bMcCauliffe et al. (2018), cFSAI (2020) and dEFSA (2010) |
| eWas not measured in this experiment. Values are based from McCance and Widdowson (2014) |
| fUKNIprot7-2 = first seven beneficial nutrients (protein, monounsaturated fatty acids, eicosapentaenoic acid (EPA) + docosahexaenoic acid (DHA), calcium, iron, riboflavin and folate) minus the two harmful (saturated fatty acids and sodium) nutrients. UKNI10-2 is the same equation but includes a further 3 beneficial nutrients (vitamin B12, selenium and zinc) |

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| **Supplementary Table 6**. Proportion of each greenhouse gas emission (CO2eq.) (GHG) in suckler weanling-to-beef-production systems (Grain = finished on *ad libitum* concentrates at 21 months of age; Silage + grain = finished on grass silage plus 3.5 kg concentrate dry matter at 24 months of age; and Forage = finished at pasture (forage-only) at 28 months of age). |
|   | Weanling-to-beef production system1 |
| **(% total)** | **Grain** | **Silage + grain**  | **Forage**  |
| Methane | 62% | 66% | 69% |
| Nitrous oxide | 14% | 17% | 22% |
| Carbon dioxide | 25% | 17% | 10% |
| 1From the point of purchase (8 month weanling) through to slaughter, corresponding to a duration of 382, 459 and 572 days for Grain, Silage + grain and Forage, respectively (assumes 200 animals per production system) |