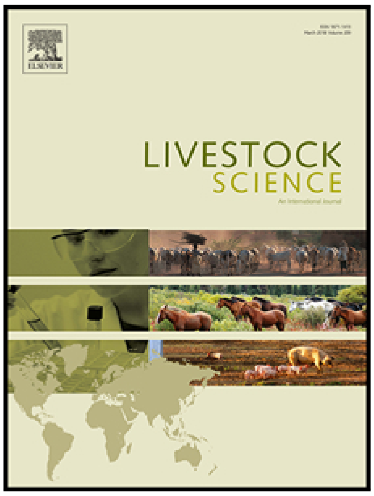

Variability in greenhouse gas emission intensity of semi-intensive suckler cow beef production systems

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Research highlights

- The whole-farm GHG model HolosNorBeef was used to estimate the variability of GHG emission intensity of Norwegian suckler cow beef production
- Enteric CH_4 was the largest source of total GHG emissions
- Soil C was the largest source of variation between individual farms
- When excluding soil C, the farms within region East and North re-ranked in terms of GHG emission intensity

Variability in greenhouse gas emission intensity of semi-intensive suckler cow beef production systems

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Abstract

Emission intensities from beef production vary both among production systems (countries) and farms within a country depending upon use of natural resources and management practices. A whole-farm model developed for Norwegian suckler cow herds, HolosNorBeef, was used to estimate GHG emissions from 27 commercial beef farms in Norway with Angus, Hereford, and Charolais cattle. HolosNorBeef considers direct emissions of methane (CH_4), nitrous oxide

(N_2O) and carbon dioxide (CO_2) from on-farm livestock production and indirect N_2O and CO_2 emissions associated with inputs used on the farm. The corresponding soil carbon (C) emissions are estimated using the Introductory Carbon Balance Model (ICBM). The farms were distributed across Norway with varying climate and natural resource bases. The estimated emission intensities ranged from 22.5 to 45.2 kg CO_2 equivalents (eq) (kg carcass)$^{-1}$. Enteric CH_4 was the largest source, accounting for 44% of the total GHG emissions on average, dependent on dry matter intake (DMI). Soil C was the largest source of variation between individual farms and accounted for 6% of the emissions on average. Variation in GHG intensity among farms was reduced and farms within region East, Mid and North re-ranked in terms of emission intensities when soil C was excluded. Ignoring soil C, estimated emission intensities ranged from 21.5 to 34.1 kg CO_2 eq (kg carcass)$^{-1}$. High C loss from farms with high initial soil organic carbon (SOC) content warrants further examination of the C balance of permanent grasslands as a potential mitigation option for beef production systems.

Keywords

Beef cattle; greenhouse gas emissions; farm scale model; regional differences; soil carbon; suckler cow production

1. Introduction

Globally, the agricultural sector accounts for 10-12% of greenhouse gas (GHG) emissions (Tubiello et al., 2014) with livestock production contributing a significant portion. It is estimated that food production will need to increase by 50% compared with 2012 levels to feed the global population in 2050 (FAO, 2017). As a consequence, beef consumption is expected to increase in both developed and developing countries (OECD/FAO, 2018) and, thus greenhouse gas (GHG) emissions from beef production are also likely to increase.

Beef products have been shown to have a relatively high GHG emission per kg food (Mogensen et al., 2012). However, there is substantial variation in emission intensities among countries (Gerber et al., 2013), and among farms within a country (Bonesmo et al., 2013). This variation in GHG intensity is partly due to methodological differences among studies, but fundamental differences in natural resource availability and farm management practices also contribute significantly (Alemu et al., 2017a; White et al., 2010). Exploring differences between farm systems in GHG intensity may help identify beef production systems and practices that are more efficient, which could lead to the development of mitigation options at farm level. Hristov et al., (2013) reviewed different management practices such as diet formulation, feed supplements, manure management, improved reproductive performance, and enhanced animal productivity to reduce GHG emissions from ruminant production and showed potential long term mitigating effects.

Globally, approximately 44% of livestock GHG emissions are in the form of CH_4 (Gerber et al., 2013). In Norway, enteric CH_4 accounts for 44-48% of total farm emissions from beef cattle production systems (Samsonstuen et al., 2019). The diet influences CH_4 emissions through the digestibility and fibre content of the feed. A high proportion of fiber in the diet yields a higher acetic:propionic acid ratio in rumen fluid, which leads to higher CH_4 emissions (Sveinbjörnsson, 2006). Enteric CH_4 emissions can be lowered through improved feed quality, use of inhibitors and by breeding animals for lower emissions (Difford et al., 2018).

Legesse et al. (2011) investigated the effect of management strategies for summer and winter feeding and found a 3 to 5% difference in CH_4 emissions across production systems. Concentrate-based beef production systems show lower GHG intensity compared with roughage based systems (de Vries et al., 2015). However, to ensure future food supply, grasslands less suitable for crop production might be preferred over highly productive cropland for production of feed for beef cattle. Beef production in Norway relies on use of pasture and forages because the total land in Norway is 90% “outfields” (i.e. rough grazing in forest, mountain and coast areas), with half the outfield area suitable as pastures or for forage production (Rekdal, 2014). According to Norwegian laws and regulations, all cattle must be kept on pasture for at least 8 weeks during the summer (Landbruks- og Matdepartementet., 2004). Grasslands have a large potential of storing C in plant biomass and soil organic matter through C sequestration (Wang et al., 2014). Grazing management influences the GHG emission intensity from beef production through diet quality (McCaughey et al., 2010), animal performance (Thornton and Herrero, 2010), nitrogen (N) fertilizer use (Merino et al., 2011), and soil C change (Alemu et al., 2017b). The effect of grazing management and stocking rate on C balance have been investigated by a number of studies (Reeder and Schuman, 2002; Soussana et al., 2007; Wang et al., 2014). Reeder and Schuman (2002) found significantly greater soil C content with light to moderate stocking rates compared with no grazing due to a more diverse plant community with fibrous rooting systems. Soussana et al. (2007) reported that managed grasslands in Europe are likely to act like atmospheric C sinks. However, when the study included C exports through grazing and harvesting and related emissions of CH_4 and N_2O, total GHG emissions from grazed European grasslands were not significantly different from zero. Alemu et al. (2017b) concluded that a whole-farm approach is important to evaluate the impacts of changes in farm management aimed at decreasing the environmental impact of beef production systems. Yet, soil C is not included in most whole-farm GHG studies (Crosson et al., 2011).

Samsonstuen et al. (2019) developed a whole farm model, HolosNorBeef, adapted to Norwegian conditions and estimated GHG emission intensities for average Norwegian beef cattle farms in two distinct geographical locations (low altitude flatlands suitable for grain production and high altitude mountains not suitable for grain production). The emission intensities in flatlands and mountains were 29.5 and 32.0 kg CO_2 eq kg^{-1} carcass for British breeds, and 27.5 and 29.6 CO_2 eq kg^{-1} for Continental breeds, respectively. However, the use of average farm scenarios did not account for variation in production systems, differences in resource base, breed differences, management practices, selection strategies, feed composition and feed quality that typically prevail among farms.

Thus, the aim of this study was to use the HolosNorBeef model to evaluate commercial herds of Aberdeen Angus, Hereford, and Charolais cattle in geographically different regions of Norway with different management practices, resources, and quality of feed available to establish the variability in emission intensities and corresponding soil carbon (C) balance from suckler cow beef production under Norwegian conditions.

2. Materials and methods

This analysis was based on a study of suckler cow efficiency and genotype × environment interactions. The project (Optibeef - Increased meat production from beef cattle herds) gathered comprehensive information from 2010 to 2014 on farm structure, herd management, animal production and economics for suckler cow herds with the breeds Aberdeen Angus (AA), Hereford (H) and Charolais (CH). To be included in the study the farms had to record a minimum of 60% of weaning weights (WW) and have a minimum of 10 purebred cows per herd. The requirements were met by 188 herds, and 27 farms (nine of each of the three breeds) were finally selected based on variety in geographical locations. The farms provided sufficient information to quantify whole-farm GHG emissions. Through market regulation and subsidies, farmers are encouraged to buy concentrates and sell grains produced on farm, rather than using it as feed in livestock production (LMD, 2018). Hence, other production enterprises on the farms not related to the cow-calf operation, such as production of natural resources, use of farm inputs (i.e. area, fertilizer, and pesticides) for grain production, ley area for horses, and finishing of calves not born on the farm, was excluded from the analysis.

The farms were distributed across Norway from Rogaland in the South to Troms in the North within climatic zones varying from 3 (good) to 8 (harsh) on the scale developed by the Norwegian Meterological Insitute and Det norske hageselskap (2006). The farms had a wide range of farm characteristics such as herd size, management practices, resource base and areas available for forage production. Thus, the farms were considered representatives of the broad spectrum of suckler cow farms in Norway.

2.1 Farm characteristics

The input data were farm specific production data, farm operational data and soil and weather data for the specific locations. The farm specific animal production data from the period 2010-2014 were obtained from the Norwegian Beef Cattle Recording System (Animalia, 2017; Table 1). Calving typically occurred in the period January-July, with an average calving date April 1st. However, three farms had a small proportion of the cows (0.18-0.41) calving during the autumn, with an average calving date October 1st.

The feeding of each group of cattle throughout the year including type and proportion of concentrates, forage type and quality and time spent on pasture, were available through interviews with the respective farmers. The nutritive values of all forages, concentrates, and pastures (Table 2) were estimated using laboratory analysis information for the specific municipalities (Eurofins, Moss, Norway), information from the two largest feed manufacturers in

Norway (Felleskjøpet SA, Oslo Norway; Norgesfor AS, Oslo Norway) and from the chemical composition of forage, grains and pasture (NMBU and Norwegian Food Safety Authority, 2008).

The manure was assumed to be deposited on pasture during the grazing period and during housing the manure handling system was deep bedding, solid storage or a combination set according to the management practices on the specific farm. All manure collected through the housing period was used for fertilizing ley areas. The areas (ha) and yields (kg ha^{-1}) of forage and use of fertilizers (kg N ha^{-1}; Table 3), were obtained through interviews with the farmers and the farm accounts. However, two farms had no grass silage production on the farm and buy grass silage from farms within the same area. Thus, the forage yield of the individual farms was assessed as the calculated forage requirement plus an additional 10% (DM basis) to account for losses due to ensilaging (DOW, 2012). The areas required for forage production on these specific farms were estimated based on yield statistics for the specific area (Statistics Norway, 2017) and the use of fertilizers was based on the Norwegian recommendations for N application levels for forage production (NIBIO, 2016).

The use of energy, fuel, and pesticides was calculated based on information from the respective farm accounts (Table 3). For each of the individual farms a cultivation factor (   ) was calculated based on annual mean indices of soil temperature (r_T) and soil moisture (r_w) according to Skjelvåg et al. (2012; Table 4). The cultivation factor was used together with initial soil C content in the Introductory Carbon Balance Model (ICBM; Andrén et al., 2004) to account for external effects such as soil moisture and temperature, and variation in resource base. Water filled pore space (WFPS) and soil temperature at 30 cm depth (ts30) for each individual farm were used for estimation of N_2O emissions. WFPS to saturation was calculated according to Skjelvåg et al. (2012) using detailed soil-type recordings available through NIBIO, whereas ts30 was calculated based on air temperature according to Kätterer and Andrén (2009). Due to expansion of the herd and/or sales of breeding stock, the herd size was not stable in most of the farms. Thus, carcass production assuming a constant herd size was calculated based on the corresponding replacement rate, farm specific slaughter weights, and dressing percentages from culled cows, surplus heifers and finishing bulls. Bulls not born on the farm were excluded as they were purchased and sold for breeding purposes, and did not contribute to carcass output.

2.2. Modelling GHG emissions

2.2.1 The HolosNorBeef model

The GHG emissions were estimated using HolosNorBeef developed by Samsonstuen et al. (2019). HolosNorBeef is an empirical model based on the HolosNor model (Bonesmo et al., 2013), BEEFGEM (Foley et al., 2011), HOLOS (Little et al., 2008), and the Tier 2 methodology of the Intergovernmental Panel on Climate Change (IPCC, 2006) modified for suckler beef production systems under Norwegian conditions. The model estimates the GHG emissions on an annual time step for the land use and management changes and on a monthly time step for animal production, accounting for differences in diet, housing, and climate. HolosNorBeef estimates the whole-farm GHG emissions by considering direct emissions of methane (CH_4) from enteric fermentation and manure, nitrous oxide (N_2O) and carbon dioxide (CO_2) from on-farm livestock production including soil carbon (C) changes, and indirect N_2O and CO_2 emissions associated with run-off, nitrate leaching, ammonia volatilization and from inputs used on the farm (Figure 1; adopted by Samsonstuen et al., 2019). All emissions are expressed as CO_2 eq to account for the global warming potential (GWP) of the respective gases for a time horizon of 100 years: CH_4 (kg) × 25 + N_2O × 298 + CO_2 (kg) (IPCC, 2007). Emission intensities from suckler cow beef production are related to the on farm beef production and expressed as kg CO_2 eq (kg beef carcass)$^{-1}$.

Methane emissions

Enteric CH_4 emissions are estimated for each age and sex class of cattle using an IPCC (2006) Tier 2 approach. Estimation of gross energy (GE) intake is based on energy requirements for maintenance, growth, pregnancy, and lactation according to Refsgaard Andersen (1990). The DM intake (DMI; Table 5) depends on both the energy requirements of the animal and the animals' intake capacity. The intake capacity is dependent on the fill value of the forage, as well as the substitution rate of the concentrates (Refsgaard Andersen, 1990). The GE intake to meet the energy requirements was estimated from the energy density of the diet (18.45 MJ kg^{-1} DMI; IPCC, 2006; Table 6). Enteric CH_4 was estimated from monthly GE intake using a diet specific CH_4 conversion factor for each cattle group (Ym = 0.065; IPCC, 2006; Table 6). The Ym factor is adjusted for the digestibility of the diet $(0.1058 - 0.006 \times DE)$ as suggested by Beauchemin et al. (2010; Table 6).

Manure CH_4 emissions are estimated from the organic matter (volatile solid; VS) content of the manure. The VS production is calculated according to IPCC (2006), taking the GE content and digestibility of the diet into account. The VS are multiplied by a maximum CH_4 producing capacity of the manure (B_o=0.18 m^3 CH_4 kg^{-1}), a CH_4 conversion factor (MCF=0.01, 0.02, 0.17 kg CH_4 VS^{-1} for manure on pasture, solid storage manure and deep-bedding, respectively) and a conversion factor from volume to mass (0.67 kg m^{-3}; IPCC, 2006; Table 6).

Nitrous oxide emissions

Direct manure N_2O emissions are calculated based on the N content of manure and an emission factor for the manure handling system (0.01, 0.02, 0.05 kg N_2O-N (kg N)$^{-1}$ for deep-bedding, pasture manure, and solid storage, respectively; IPCC, 2006; Table 6). The N content of the manure is estimated according to IPCC (2006), based on the DMI, crude protein (CP; CP = 6.25 × N) content of the diet and N retention by the animals (Table 6).

Direct soil N_2O emissions are estimated by multiplying the total N inputs with an emission factor of 0.01 kg N_2O-N kg^{-1} N according to IPCC (2006). The total N inputs include above- and below ground crop residue N, using crop yields of Janzen et al. (2003), and mineralized N in addition to application of N fertilizer and manure. The derived C:N ratio of organic soil matter (0.1; Little et al., 2008) is used to calculate mineralization of N inputs (Table 6). The effect of location and seasonal variation was taken into account by including four seasons based on the local weather conditions and growing season; spring (April-May), summer (June-August), autumn (September-November) and winter (December-March), and the relative effects of percentage WFPS ($0.0473 + 0.01102 \times \mathrm{WFPS}$; Sozanska et al., 2002) of top soil and soil temperature at 30 cm depth (ts30; $0.5762 + 0.03130 \times \mathrm{ts30}$; Sozanska et al., 2002; Table 6).

Indirect N_2O emissions from soil are estimated from the assumed losses of N from manure, crop residues, and fertilizer according to IPCC (2006). The emissions from run-off, leaching and volatilization are estimated based on the fraction of the loss for the manure handling system adjusted using emission factors (0.0075 and 0.01 kg N_2O-N kg^{-1}) for leaching and volatilized ammonia-N, respectively (IPCC, 2006; Table 6). The emissions were based on the assumed fraction of N lost adjusted for emission factors for leaching (0.0, 0.0, 0.3, 0.3 kg N (kg N)$^{-1}$ for deep bedding, solid storage, pasture manure and soil N inputs including land applied

Table 7 Mean, minimum (Min), maximum (Max) and standard deviation (SD) estimates for greenhouse gas emission intensity (kg CO_2 eq kg^{-1}carcass) (n=9 for each breed).

	A.Angus				Hereford				Charolais				Sig[a]
	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD	
Enteric CH_4	12.95	9.98	16.09	1.86	13.16	11.90	14.66	0.83	12.26	11.44	13.57	0.67	ns
Manure CH_4	1.33	0.36	3.18	1.00	1.54	0.41	2.91	1.06	1.42	0.42	3.60	0.96	ns
Manure N_2O	2.96	1.88	3.63	0.60	3.76	2.69	4.99	0.69	2.67	1.66	3.16	0.45	**
Soil N_2O	3.53	2.64	4.11	0.45	3.70	3.10	4.22	0.32	3.80	3.05	6.16	0.95	ns
Soil C	3.14	-2.73	14.11	5.13	1.97	-2.08	7.84	3.75	-0.19	-2.37	3.58	2.19	ns
Off-farm barley	0.62	0.00	0.90	0.29	0.92	0.41	2.06	0.51	1.14	0.73	1.55	0.27	ns
Off-farm soya	0.71	0.00	1.10	0.35	0.75	0.52	1.34	0.27	1.19	0.75	1.51	0.26	*
Indirect energy	1.76	0.24	4.33	1.49	2.08	0.01	3.66	1.05	2.87	1.27	4.80	1.17	ns
Direct energy	3.00	1.13	5.29	1.64	1.93	0.03	3.38	1.09	2.56	1.26	4.73	1.13	ns
Total emissions	30.00	24.32	45.20	6.31	29.80	22.67	38.07	4.61	27.71	22.49	33.52	3.72	ns
Total emissions excluding soil C	26.86	21.45	31.09	3.27	27.83	24.39	32.28	2.97	27.90	24.38	34.07	2.76	ns

[a] Sig = significance: ns = non significant, * = P≤0.05, ** = P≤0.01.

Table 8 Mean greenhouse gas (GHG) emission intensities and proportion of total emissions (in parenthesis) from average herds of beef cattle in four regions of Norway (kg CO_2 eq kg^{-1}carcass).

	East (n=16)	Southwest (n=2)	Mid (n=4)	North (n=5)	Sig[a]
Enteric CH_4	12.76 (0.46)	13.95 (0.43)	13.41 (0.47)	11.93 (0.36)	ns
Manure CH_4	1.76 (0.06)	0.96 (0.03)	1.07 (0.04)	0.86 (0.03)	ns
Manure N_2O	3.19 (0.12)	4.51 (0.14)	3.06 (0.11)	2.44 (0.07)	**
Soil N_2O	3.65 (0.13)	3.87 (0.12)	3.56 (0.13)	3.77 (0.11)	ns
Soil C	0.06 (0.00)	3.36 (0.10)	1.40 (0.05)	6.18 (0.18)	*
Off-farm barley	0.95 (0.03)	0.58 (0.02)	0.87 (0.03)	0.86 (0.03)	ns
Off-farm soya	0.88 (0.03)	0.63 (0.02)	1.07 (0.04)	0.84 (0.03)	ns
Indirect energy	2.13 (0.08)	2.13 (0.07)	1.55 (0.05)	3.18 (0.09)	ns
Direct energy	2.30 (0.08)	2.08 (0.06)	2.26 (0.08)	3.48 (0.19)	ns
Total emission	27.67	32.06	28.26	33.55	ns
Total emission excluding soil C	27.61	28.70	26.85	27.36	ns

n = number of farms.

[a] Sig = significance: ns = non significant, * = P≤0.05, ** = P≤0.01.

Table 9 Ranking of farms with Aberdeen Angus (AA), Hereford (H) and Charolais (CH) in different regions in terms of GHG emission intensities including and excluding soil C balance.

East (n=16)		Southwest (n=2)		Mid (n=4)		North (n=5)	
Incl. soil C	Ex. soil C	Incl. soil C	Ex. soil C	Incl. soil C	Ex. soil C	Incl. soil C	Ex. soil C
H1	AA3	H17	H17	CH19	AA22	CH23	AA25
CH2	H11	H18	H18	AA20	CH21	H24	H26
AA3	H1			CH21	AA20	AA25	CH23
AA4	A10			AA22	CH19	H26	H24
CH5	CH2					AA27	AA27
H6	H6						

AA7	AA4
CH8	CH5
CH9	CH8
AA10	CH14
H11	AA7
H12	CH9
A13	AA13
CH14	H12
H15	H15
CH16	CH16

n = number of farms in each region.

Table 10 Least square means (LSM) of greenhouse gas (GHG) emission intensities and proportion of total emissions (in parenthesis) from average herds of Aberdeen Angus (AA), Hereford (H), and Charolais (CH) in four regions of Norway (kg CO_2 eq kg^{-1}carcass).

	East (n=16)			Southwest (n=2)	Mid (n=4)		North (n=5)			Location	Breed
	AA	H	CH	H	AA	CH	AA	H	CH	Sig[a]	Sig[a]
Enteric CH_4	13.07	13.13	12.19	13.95	14.23	12.58	11.35	12.45	12.05	ns	ns
Manure CH_4	1.85	1.77	1.67	0.96	0.99	1.15	0.40	1.53	0.45	ns	ns
Manure N_2O	3.12	3.71	2.80	4.51	3.36	2.77	2.15	3.14	1.66	**	**
Soil N_2O	3.39	3.61	3.90	3.87	3.70	3.42	3.71	3.74	3.94	ns	ns
Soil C	0.46	0.39	-0.53	3.36	2.31	0.50	10.68	4.55	3.36	*	ns
Off-farm barley	0.62	1.02	1.16	0.58	0.66	1.08	0.61	0.99	1.09	ns	ns
Off-farm soya	0.60	0.71	1.26	0.63	1.09	1.05	0.62	0.96	1.06	ns	ns
Indirect energy	1.79	1.90	2.60	2.13	0.36	2.73	3.07	2.49	4.80	ns	ns
Direct energy	2.06	1.89	2.84	2.08	3.10	1.43	5.25	3.14	1.88	ns	*
Total emission	26.94	28.13	27.89	32.06	29.80	26.72	37.84	31.71	28.63	ns	ns
Total emission excluding soil C	26.48	27.75	28.42	28.70	27.49	26.22	27.16	27.16	28.17	ns	ns

[a] Sig = significance: ns = non significant, * = P≤0.05, ** = P≤0.01.

Table 11 Sensitivity elasticities for the effect of 1% change in soil C change external factor ($r_w \times r_T$) and initial soil organic carbon (SOC) on the greenhouse gas (GHG) emission intensities CO_2 eq (kg carcass)$^{-1}$.

		East (n=16)		Southwest (n=2)		Mid (n=4)		North (n=5)		Sig[a]
	Response	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Initial soil organic carbon	Linear	0.17	0.09	0.20	0.14	0.10	0.24	0.23	0.15	ns
Soil C change external factor[b]	Non-linear	0.17	0.04	0.12	0.02	0.19	0.03	0.19	0.03	ns

[a] Sig = significance: ns = non significant

[b] Mean sensitivity elasticity (%) for the the change ±1% of $r_w \times r_T$

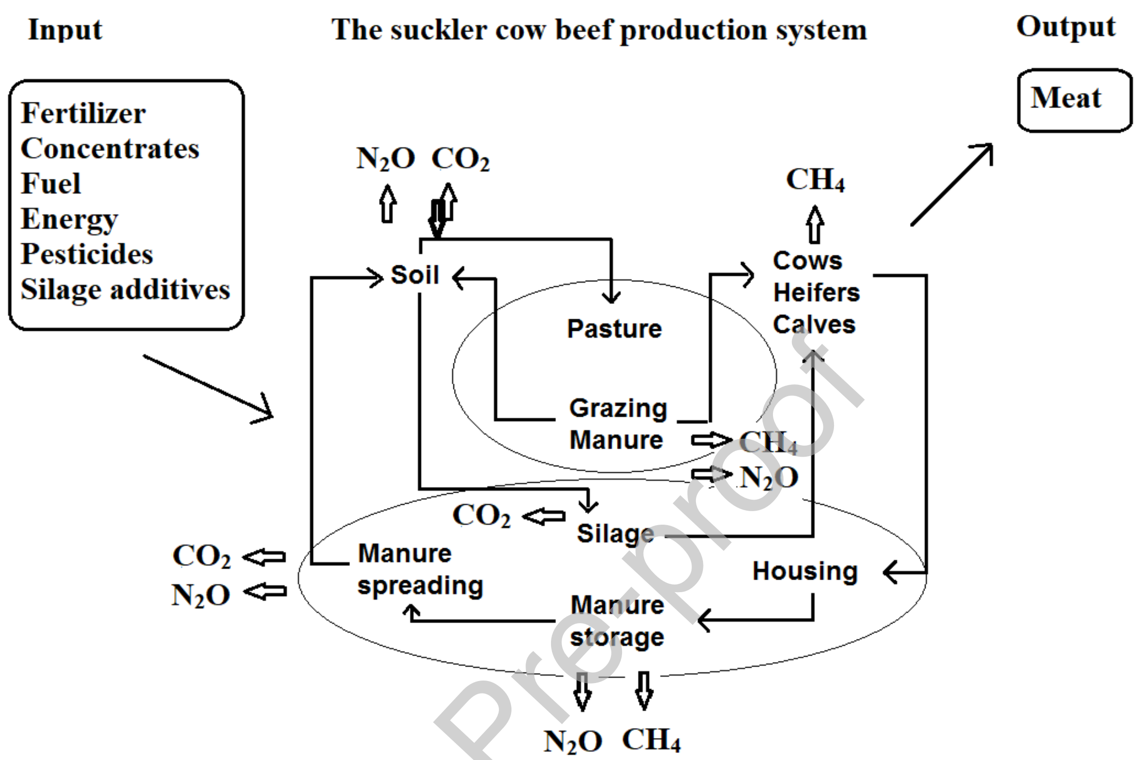

Figure 1 System boundaries of the suckler cow beef production system (Samsonstuen et al., 2019).

Author Statement

This manuscript has not been published and is not under consideration for publication elsewhere. All authors have approved the manuscript and agree with its submission to Livestock Science. We have no conflict of interest to disclose.

Conflict of interest

The authors have no conflict of interest to disclose.