Final Technical Report

FCEB Project #44

Florida Cattle Enhancement Board

Environmental Impact Analysis of Cow-Calf Operations in Florida: A Life Cycle Assessment

Final Report

Submitted By:

Principal Investigator: Diwakar Vyas, PhD

Project Title: Environmental Impact Analysis of Cow-Calf Operations in Florida: A Life Cycle Assessment

The objectives of this study align with the Research and Education priority of Florida Cattlemen Enhancement Board in area of “Ecosystem services of grazing lands” and specifically its impact on “Greenhouse gas mitigation”. Following are the specific goals of this study:

a. To utilize life cycle assessment (LCA) for estimating environmental impact of different management practices in commercial cow-calf operations in Florida

b. To identify opportunities for enhancing environmental sustainability by lowering greenhouse gas (GHG) emissions and increasing productivity in livestock production.

c. To determine Net Protein Contribution (NPC) of cow-calf operations raised on extensive systems simulating common feeding practices in Florida

It has been well established that cattle consuming feed with low digestibility tend to generate more methane (CH_4) emissions as compared to cattle eating more digestible feed (e.g., feedlot diets with high-grain diets). This project also emphasizes that there is sustainability trade-off between GHG emissions in the cow-calf operations and ability to convert feeds unsuitable for human consumption like grass into human usable products. Beef products offer a more comprehensive and biologically valuable source of dietary protein compared to plant-based sources, which often lack sufficient levels of indispensable amino acids. Developing methods of accurately accounting for beef’s contribution to human nutrient supplies and for the costs associated with beef production is essential for addressing societal concerns and optimizing sustainability. Life cycle assessment is a comprehensive methodology used to evaluate the environmental impacts of a product or system throughout its entire life cycle. In the context of cow-calf operations, LCA can be applied to identify management practices that have the potential to lower GHG emissions once the hotspots for GHG emissions are identified in operations. Specific aims (a) and (b) are focused on evaluating environmental impact of the cow-calf operations and identifying practices to lower GHG emissions and improve livestock productivity. Specific objective (c) is aimed at estimating net protein contribution for the cow-calf operation in Florida. Net protein contribution is a food competitiveness index that conveys the capability to produce human-edible protein (heP) in terms of protein quality and requirements to meet human protein demand by considering heP consumed in the feed. It is essential to emphasize the importance of NPC in the beef production systems because it has the advantage of converting low-quality proteins and human-inedible fibres from plant biomass, such as grasses or by-products from the food industry, into beef, a high-quality protein source for humans.

APPROACH: The project employed a comprehensive LCA approach to assess the environmental impacts across the entire life cycle of cow-calf operations. This involved:

- Collecting data on various aspects of cow-calf operations, including feed consumption, livestock management, and output production.
- Analyzing these data to identify the main sources of GHG emissions.
- Evaluating the efficiency of feed conversion into human-edible protein through the NPC metric.
- Identifying and recommending management practices that can reduce environmental impact and improve productivity.

METHODS:

The system boundaries and functional unit

Cradle-to-farm-gate systems were used as boundary systems, by considering all farm operations of beef cow-calf production, using real field data with a timeline of 365 days.

Therefore, the study considered the direct and indirect impacts due to on-farm and off-farm activities. Greenhouse gas emissions were calculated as CH_4 production from enteric fermentation, cattle dung and burning; nitrous oxide (N_2O) emission from burning and dung and urine deposited in the pasture; N_2O emission from fertilizer applications in the field; and fossil CO_2 emission from the production, manufacture, and transport of animal feeds and fertilizers, from the use of diesel for on-farm operations, and from the production of electricity. Emissions associated with buildings and machinery or with veterinary product and pesticide products, and emissions generated beyond the farm gate (transport for feedlots, slaughter, and carcass processing, among others), were omitted from the analysis. Soil organic carbon was assumed to be at equilibrium across all production systems.

The modeling data were integrated with the reviewed literature and an electronic spreadsheet based on the International Panel on Climate Change (IPCC) models, which facilitated the calculation of GHG intensities.

All gases were expressed as CO2 eq to account for the global warming potential of the respective gases: CH_4, kg * 27.2 + N2O kg *273 + CO_2, kg (IPCC, 2021). To report GHG intensity, emissions were allocated as a function of kg CO_2e kg^{-1} body weight produced per weaned calf.

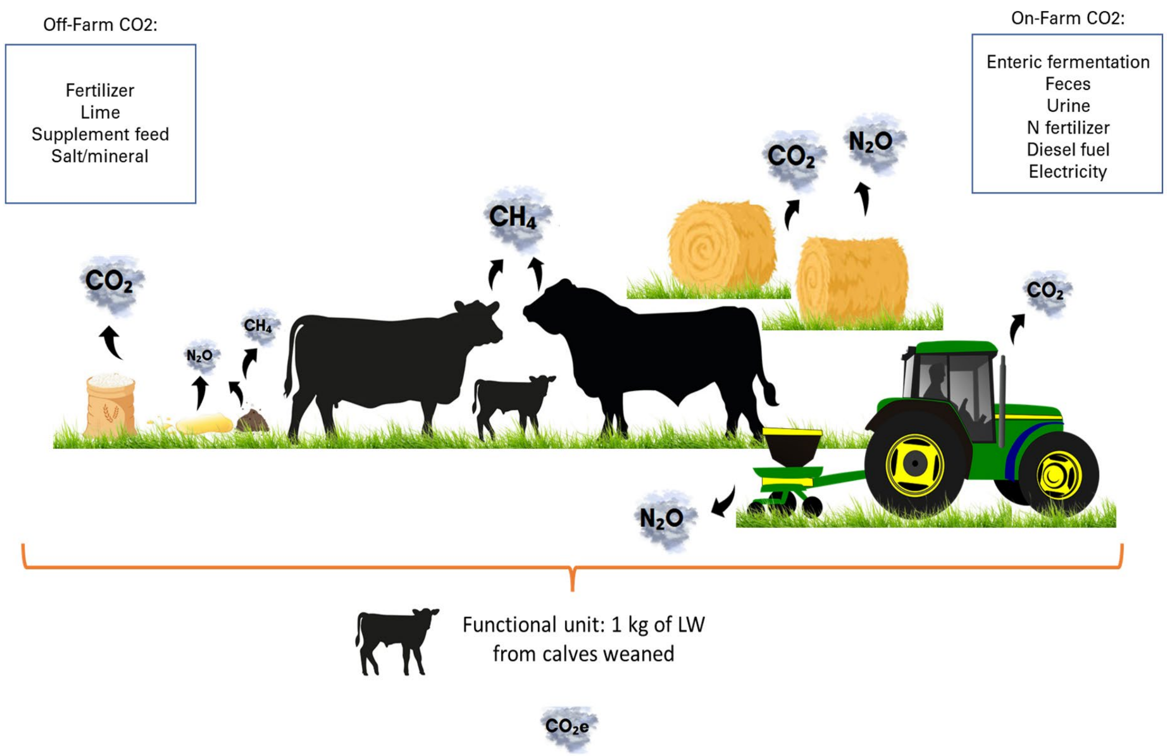

Figure 1. Inputs, source of emissions, and components of the life cycle assessment of cow-calf systems in Florida

Life cycle inventory

Emissions Inventory data for the productive indices and GHG emissions were collected from 16 Floridian beef cow-calf production systems for 2023 (Figure 1), during which production was ongoing. The study selected farms situated in southern, central, and northern Florida to capture the diverse array of management practices implemented across the entire state. Only farms that had herds in steady-state conditions were considered. Herein, the farms were selected to obtain primary data according to the following criteria: (1) representativeness of Floridian beef cow-calf production systems in terms of herd size, feeding strategy, and farm operations; and (2) existence of an organized accounting and management system that provides comprehensive and good-quality data for inventory analysis. The information was gathered through direct interviews conducted with farmers. These surveys encompassed inquiries into various facets of farm infrastructure, geographical location livestock management practices, herd composition, feeding regimes, external resource utilization, and productivity metrics (Table 1).

Table 1. Description of area and herd of selected farms.

Farms	Region	City	Area (ha)	Cows	Bulls	Heifers	Calves
Farm-1	Northern	Fort White	81	36	2	14	43
Farm-2	Northern	High Springs	46	35	1	5	30
Farm-3	Northern	Alachua	263	400	12	6	360
Farm-4	Northern	High Springs	15	12	1	5	17
Farm-5	Central	Lorida	364	200	10	50	212
Farm-6	Southern	Palm City	86	105	7	30	115
Farm-7	Southern	Okeechobee	203	215	9	24	194
Farm-8	Central	Arcadia	243	200	9	20	187
Farm-9	Central	Arcadia	97	85	6	15	85
Farm-10	Southern	Sidell	3561	1337	65	138	1283
Farm-11	Central	Arcadia	850	3500	160	100	2880
Farm-12	Southern	Okeechobee	3642	2000	110	150	1828
Farm-13	Northern	Cottondale	55	35	3	5	36
Farm-14	Northern	Westville	16	28	1	5	33
Farm-15	Northern	Marianna	170	160	8	23	174
Farm-16	Northern	Mayo	647	400	27	98	423

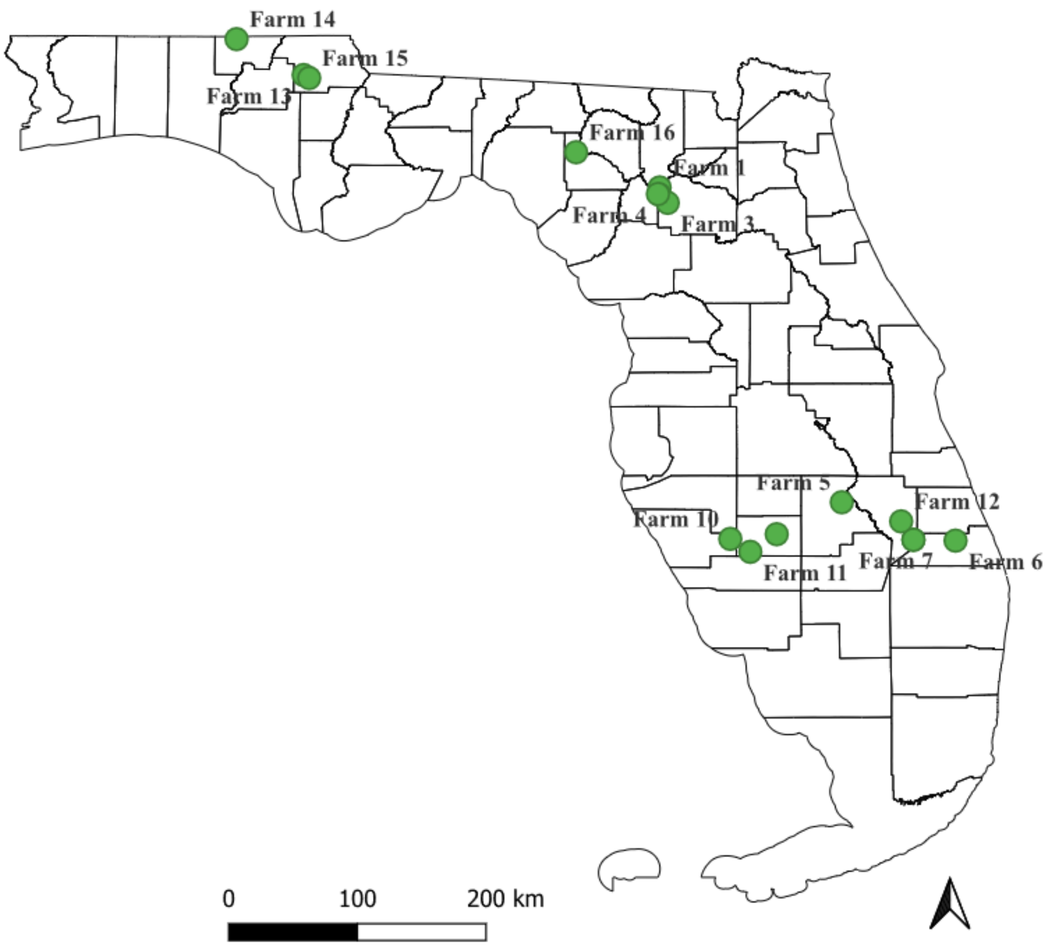

Figure 1. Location of selected farms.

Life-cycle impact Assessment

Greenhouse gas emissions were estimated using Tier 2 refinement methods of IPCC (IPCC, 2019), applying local emission factors (EF) whenever available. Enteric CH_4 emission was modeled using the EF of 23.3 g CH_4 kg^{-1} dry matter intake (DMI) (IPCC, 2019) for non-dairy cattle fed a diet with more than 75% forage and less than 62% of digestible energy (DE). The dry matter intake for each animal category was computed using the metabolic weight of the animal ($LW^{0.75}$) and the digestibility of the consumed feed.

Methane (CH_4) emissions originating from manure were assessed based on the total fecal production derived from estimated DMI and digestibility. We applied Equation 10.23 from the methodology (IPCC, 2006) to calculate the CH_4 emissions factor from dung. Additionally, Equation 10.24 was utilized to determine volatile solids (VS) production for Equation 10.24. To estimate N_2O emissions from dung and urine, we initially calculated the total nitrogen (N) intake by multiplying the protein content (6.25 × N concentration) of the forage/ration by the dry matter intake, following the same approach used for estimating CH_4 emissions from dung. The total N excreted was determined as the N intake minus the N accumulated in the animal carcass (estimated at 2.5% of the live weight gain) and N exported in milk for lactating cows. We estimated direct N_2O emissions from feces and urine excreted on pasture separately, employing N_2O–N EFs (EF_{3PRP}) for grazing beef cattle (0.2% and 2.14%, respectively) derived from a study conducted in Florida (Kohman et al., 2013). We utilized Equation 2.27 as prescribed in the IPCC's 2006 methodology to quantify non-CO_2 emissions arising from the burning of grasslands. Our examination, delineated in the Cropland and Grassland sections of the IPCC report, exclusively addressed non-CO_2 emissions, under the premise that any CO_2 emissions would be offset by subsequent vegetation regrowth within a one-year timeframe.

The quantification of GHG emissions attributed to fuel, energy, fertilizers, and feed inputs within beef production systems were based on established IPCC factors for materials wherever applicable, supplemented by relevant sources identified and referenced within the scientific literature. Notably, N_2O stemming from nitrogen (N) fertilizers and residual N deposits in crop production were duly accounted for. Moreover, emissions of CO_2eq associated with electrical energy and diesel fuel were determined following the methodologies stipulated by the Energy Information Administration (EIA) in 2020 and 2022, respectively. Detailed elucidation of the assumptions and EFs utilized for each input and source can be found in Table 2.

Table 2. Emissions factors used for GHG inventory calculations.

Gas/ source	**Emission factor**	**Reference**
Methane sources		
Enteric Fermentation	23.3 g CH_4 kg^{-1} DMI	IPCC (2019)
Manure emission	0.01 kg CH_4^{-1}	IPCC (2006)
Burning	2.3 kg CH_4 ha^{-1}	IPCC (2006)
Carbon Dioxide sources		
Electricity	180.8 kg CO_2e· MW h^{-1}	EIA (2020)
Fuel use	2.69 kg CO_2e L^{-1}	EIA (2022)
N fertilizer production	3.88 kg CO_2e kg^{-1}	(Ledgard et al., 2011)
P fertilizer production	2.7 kg CO_2e kg^{-1}	(Ledgard et al., 2011)
K fertilizer production	1.11 kg CO_2e kg^{-1}	(Ledgard et al., 2011)

Lime	0.48 kg CO_2e kg^{-1}	IPCC (2006)
Manufacture of feed	from 0.29 to 1.29 kg CO_2e kg^{-1} DMI (depending on the type of feed)	Feedpint (Vellinga et al., 2013)
Nitrous Oxide Sources		
Direct Emissions		
Manure	Urine	
	0.0214 kg N_2O N^{-1}	Kohmann (2013)
	Feces	
	0.0002 kg N_2O N^{-1}	Kohmann (2013)
Soil N inputs	0.01 kg N_2O N^{-1}	IPCC (2019)
Burning	0.21 kg N_2O ha^{-1}	IPCC (2006)
Indirect Nitrous Oxide		
Manure and Soil N inputs	Leaching	
	EF = 0.011 kg N_2O N^{-1}	IPCC (2019)
	$Frac_{leach}$ = 0.24	IPCC (2019)
	Volatilization	
	EF = 0.01 kg N_2O kg N^{-1}	IPCC (2006)
	$Frac_{volatilization}$ = 0.21 kg N^{-1}	IPCC (2006)
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	$Frac_{volatilization}$ = 0.21 kg N^{-1}	IPCC (2019)

DMI = dry matter intake, MW = megawatts, EF = Emission factor, $Frac_{leach}$ = fraction leaching, $Frac_{volatilization}$ = fraction volatilization.

The CO_2 from livestock respiration is not considered as a net source of global warming according to the Kyoto Protocol; therefore, it was not included in the calculations.

Therefore, the system boundaries comprised the annual GHG emissions and beef cattle production.

Net protein Contribution

In this study, we employed a systems approach to estimate the Net Protein Contribution (NPC) of beef production, focusing specifically on the cow-calf phase within a timeline of 365 days. To estimate NPC, we utilized the methodology outlined by Wilkinson (2011), Ertl et al. (2015, 2016), and Baber et al. (2018). The calculation of Human-Edible Protein Produced (HePp) by the systems, involved estimating body protein (BP) from empty body weight (EBW) of the animals using a quadratic function, as suggested by Baber et al., (2018; Equation 1).

$$BP, kg = (0.235EBW - 0.00013EBW^2 - 2.418)$$

Empty BW includes inedible byproducts (IBP) such as hide, skull, blood, and others. These constituents represent approximately 25.0%, 24.2%, and 22.1% of EBW in steers, heifers, and cull cows, respectively, as reported by Terry et al. (1990) and Apple et al. (1999). Human-Edible Protein Produced was then calculated after removing the inedible fraction of EBW. In the cow-calf phase, HePp was estimated considering weaned calves, cull cows, and cull bulls (Equation 2).

$$HePp, kg = BP\ x\ (1 - IBP)$$

To quantify the amount of HeP removed from the human food supply by the beef value chain, total Human-Edible Protein Consumed as Feed (HePf) was estimated. Feed ingredients were classified as edible, partially edible, or inedible based on criteria suggested earlier (Wilkinson (2011), Ertl et al. (2015, 2016)). The conversion of HePf into meat, termed as Human-Edible Protein Conversion Efficiency (HePCE), was determined by calculating the ratio of HePp to the HePf (Equation 3).

$$HePCE = \frac{HePp}{HePf}$$

To evaluate the protein quality of human-edible feedstuffs used in beef cattle diets, we assessed the Digestible Indispensable Amino Acid Score (DIAAS). This score compares the amount of digestible indispensable amino acids in 1 gram of dietary protein to that in 1 gram of reference protein, as outlined by the Food and Agriculture Organization of the United Nations (2011; Equation 4).

$$DIAAS = \frac{mg\ of\ indispensable\ amino\ acid\ in\ 1\ g\ of\ dietary\ protein}{mg\ of\ same\ digestible\ indispensable\ amino\ acid\ in\ 1\ g\ of\ dietary\ protein}\ x\ 100$$

The reference protein, based on the nutritional requirements for children aged 0.5 to 3 years, served as the benchmark.

Calculation of the DIAAS for each feedstuff or diet involved obtaining data on crude protein (CP) content, amino acid composition, and true ileal amino acid digestibility from the CVB Feed Table (Blok and Spek, 2016). Only feedstuffs containing proteins potentially edible by humans were considered for analysis (Ertl et al., 2016). The lowest DIAAS value among the essential amino acids determined the overall DIAAS of the diet, representing the premise of the first limiting amino acid. This value was then used to compute the Protein Quality Ratio (PQR), which compares the DIAAS of the output product (beef) to that of the diet. With a DIAAS of 112, indicating that its amino acid profile surpasses the requirements of a child, beef serves as the reference for assessing protein quality.

The Net Protein Contribution (NPC) was computed by multiplying the Protein Quality Ratio (PQR) by the Human-Edible Protein Conversion Efficiency (HePCE; Equation).

$$PQR = \frac{DIAAS\ of\ beef}{DIAAS\ of\ diet}$$

An NPC exceeding 1 signifies a positive contribution towards fulfilling human protein needs, while an NPC below 1 suggests that the beef value chain is in competition with humans for protein.

Statistical Analyses

Principal component analysis (PCA) was obtained from a correlation matrix using the R package "FactoMineR" (http://factominer.free.fr/), to identify similarities among farms and main variables related to performance and carbon emission intensity. The variables included were: herd size (total number of heads), pregnant rate (% of breeding cows), farm area (ha), total stocking (Animal unit, AU, 1 AU = 450 kg), number of breeding cows in herd, proportion of breeding cows in herd, total weaned weight per year (kg), weaned weight per area (kg/ha), total weight gain per year (kg), weight gain per area (kg/ha), calf average daily gain (kg/d), average cow body weight (kg), carbon equivalent intensity emission related to methane (CO_{2e_CH4}/kg weaned calves) and carbon equivalent intensity emission (CO_{2e}/kg weaned calves).

RESULTS AND DISCUSSION

Annual CH_4, N_2O, and CO_2 emissions

Emissions from enteric fermentation constituted the predominant source of CH_4 emissions, accounting for 97.7% of the total, with minimal contributions from manure deposition on pastures and burning, as illustrated in Table 3. This pattern aligns with the characteristic features of extensive cattle systems prevalent in tropical and subtropical regions, where excreta management practices are infrequently adopted (Lima et al., 2022; Gaitán et al., 2016; Mazzetto et al., 2020). Additionally, burning practices were infrequent among farms, predominantly concentrated in the central and southern regions where weed incidences are higher. Nonetheless, even on those farms, emissions from burning were remarkably low.

Table 3. Annual methane emissions from farm production

Total kg of CH_4 farm^{-1} year^{-1}	**Mean**
Enteric emission	56461.6 (97.7%)
Manure	999.3 (1.7%)
Burning	358.5 (0.6%)
Total	57819.5

Our observations revealed that direct N_2O emissions from excreta deposited on grazed pastures accounted for the majority (52.9%) of N_2O emissions, with indirect N_2O emissions from manure comprising 21.2% of the total emissions (Table 4). The contribution of fertilizers to both direct and indirect emissions remained notably low (16.8% and 6.9% respectively). Our findings are consistent with those reported by González-Quintero et al. (2021), conducted in Colombia, where most farms exhibited limited adoption of technology inputs and fertilization practices.

In contrast, CO_2 emissions stemming from off-farm activities as the manufacture and transport of lime and fertilizer emerged as the primary contributors to total CO_2 emissions (66.1%), followed by the manufacturing of feeds and minerals (16%) and on-farm fuel consumption (15.1%). Emissions related to electricity usage were relatively minor (Table 5).

Table 4. Annual nitrous oxide emissions from farm production

Total kg of N_2O farm^{-1} year^{-1}	**Mean**
Fertilizer Direct emission	250.4 (16.8%)
Fertilizer Indirect emission	103.7 (6.9%)
Manure Direct emission	789.1 (52.9%)
Manure Indirect emission	316.8 (21.2%)
Burning	32.7 (2.2%)
Total	1492.8

Table 5. Annual carbon dioxide emissions from farm production

Total kg of CO_2 $farm^{-1}$ $year^{-1}$	Mean
Feed and mineral	43536.9 (18%)
Fuel	36490.5 (15.1%)
Electricity	2078.3 (0.9%)
Manufacture and transport of lime and fertilizer	160247.8 (66.1%)
Total	242353.5 (66.1%)

Contribution of individual GHG emission to the carbon emission intensity

Enteric CH_4 accounted for 70% of the total GHG emissions of the cow-calf operations. Nitrous oxide from soil and manure accounted together for 18% of the total emissions, while CH_4 emissions from manure and CO_2 emissions were minor contributors (Figure 2). This breakdown is consistent with other analyses that report enteric fermentation accounting for 40–70% of total GHG emissions in North American beef production systems (Johnson et al., 2003; Vergé et al., 2008). Enteric CH_4 is the primary gas produced by grazing animals, such as cattle. The amount of enteric CH_4 produced is influenced by several factors, including diet, animal genetics, age, and environmental conditions. In Floridian cow-calf systems, the animals primarily consume low-quality forage with minimal grain supplementation, leading to a high-fiber diet. As fiber-rich feed undergoes microbial fermentation in the rumen, volatile fatty acids (VFAs) are produced. High fiber diets are associated with higher levels of acetate and lower levels of propionate compared to high-grain diets. Acetate has a greater potential to produce methane than propionate due to the production of hydrogen during its synthesis (van Lingen et al., 2019).

As a result, diets that promote the production of acetate, such as high fiber diets, tend to increase CH_4 production. This means that ruminants in Floridian cow-calf systems are more likely to produce higher levels of methane compared to those fed low fiber diets. While methane production is a natural process in ruminant digestion, reducing its production is crucial for minimizing the environmental impact of livestock farming.

Overall, fertilization and excreta management were consistently limited across all farms, resulting in a significantly lower contribution of N_2O to total GHG emission compared to CH_4 emissions from enteric fermentation. Carbon dioxide emissions were divided into categories such as electricity and fuel usage, as well as the manufacturing and transportation of feed, minerals, and fertilizers. These emissions remained minimal, primarily due to the extensive management practices inherent in the cow-calf production system prevalent throughout the region.

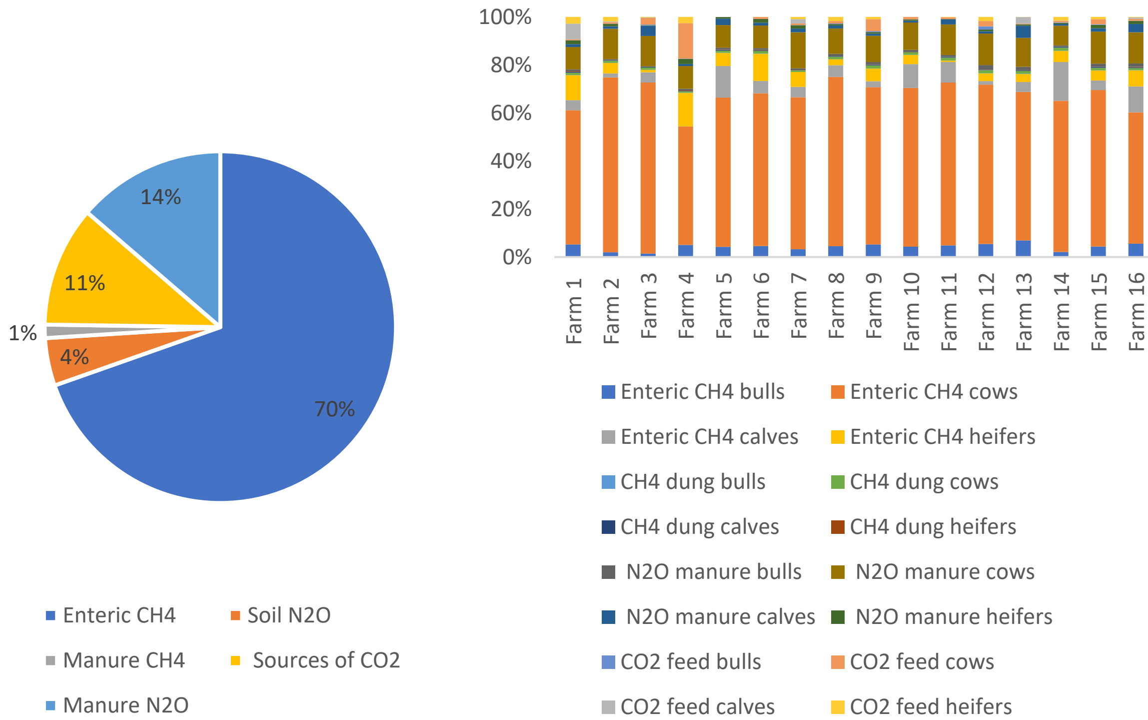

Figure 2. Contribution of each gas (CO_2e) to the carbon intensity for the studied farms

Breakdown of total GHG emissions by component of cow-calf operation in Florida

Table 6. Results from the life cycle analysis of cow-calf operations in Florida.

Farms	Variables				
	Herd size	**AU**	**SR**	**Emissions (kg) for each AU per day**	**CO_2 equivalent intensity in kg per weaned calf**
Farm-1	94.5	63.3	0.8	9.6	20.9
Farm-2	71	63.7	1.4	9.2	28.4
Farm-3	778	529.4	2	8.9	19.1
Farm-4	35	23.7	1.6	6.9	22.1
Farm-5	472.5	318.3	0.9	12.2	26.6

Farm-6	256.8	143.3	1.7	8	23
Farm-7	443.6	375.6	1.8	8.3	25.7
Farm-8	416	320.9	1.3	7.4	18.6
Farm-9	191	134.8	1.4	7.8	22
Farm-10	2822.3	2272	0.6	6.8	17.7
Farm-11	6640	4708.7	5.5	6.9	18.1
Farm-12	4087.5	2894.5	0.8	6.9	25.2
Farm-13	79	63.8	1.2	8.4	20
Farm-14	67	43.8	2.7	11.3	25.3
Farm-15	364.9	302.3	1.8	7.6	17.5
Farm-16	948.3	746.6	1.2	11.3	26.7

AU= animal unit (450kg LW)

The farms visited exhibited a wide range of herd sizes, spanning from 24 to 4,709 animal units (AU=450 kg LW). On average, emissions per AU per day were quantified at 8.6 kg of CO_2e, with an emission intensity (kg CO_2e kg weaned calf^{-1}) varying from 17.5 to 28.4 kg CO_2e (Table 6). Our emissions intensity is higher than previous findings from Canadian studies that assessed the entire beef value chain, spanning from birth to slaughter. Beauchemin et al. (2010) utilizing the HOLOs whole farm model to simulate beef and cropping production over eight years, revealed a carbon footprint of 13.04 kg of CO2e kg^{-1} live weight at the time of slaughter, while Basarab et al. (2012) reported a slightly lower figure of 12.43 kg of CO2e kg^{-1} live weight. However, Brazilian studies present higher emission values. Cardoso et al. (2016) analyzed six scenarios with varying intensification levels and found emission intensities ranging from 14.7 to 29.15 kg CO2e kg^{-1} live weight. Similarly, Dick et al. (2015) recorded elevated emissions, with values reaching 22 kg CO2e kg^{-1} live weight for extensive beef production systems.

A Chilean study investigating the impact of feed strategies and varying stocking rates on the carbon footprint of cow-calf systems discovered an average emission rate of 13.0 ± 0.4 kg of CO_2eq kg^{-1} LW (Toro-Mujica, 2021). This calculation accounted for emissions from culled cows and weaned calves sold at the point of weaning, using kg^{-1} LW at the farm gate as the functional unit. To facilitate a direct comparison with this study, we also factored in the weight of the culled cows in our analysis. Consequently, our findings exhibited a range of values from 11.5 to 20 kg CO_2eq kg^{-1} LW. However, it is worth nothing to mention that the Chilean study relied on simulated scenarios rather than real field data.

While existing research consistently highlights the cow-calf phase as the principal contributor to GHG emissions in the beef cattle production chain (Beauchemin et al., 2010), a notable void exists in the literature concerning the precise emission intensity of this phase for producing one kilogram of weaned calf. Consequently, direct comparisons with previous studies present a challenge. This phase typically has a higher emission intensity per unit of product because it includes emissions from cows, bulls, heifers, and calves, with only the calf contributing to the final product. However, when considering the entire beef cattle cycle, the emissions from the cow-calf phase are diluted over the entire lifecycle, including the stages of backgrounding, feedlot finishing, and processing, where more product is produced.

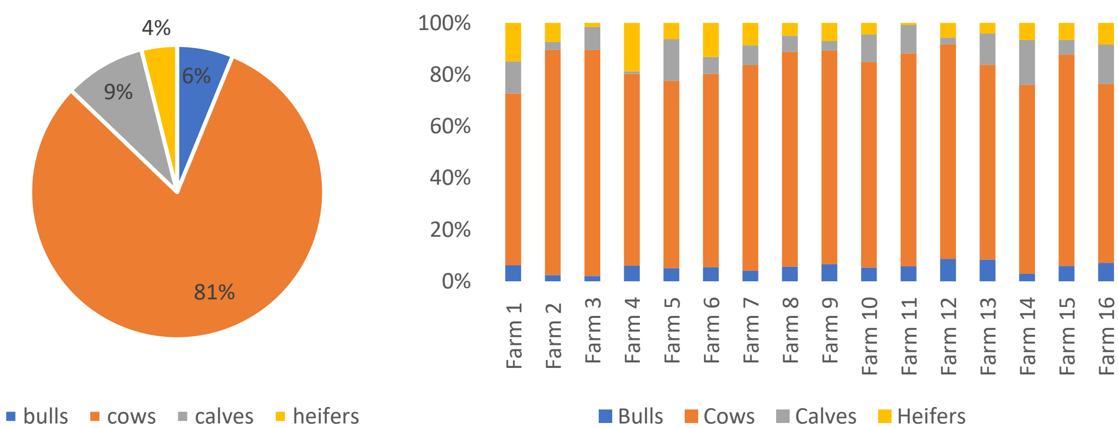

Figure 3. Breakdown of total GHG emissions (CO_2 equivalents) by component of cow-calf operation in Florida

Within the cow-calf cycle, mature cows were found to be responsible for about 80% of the total GHG emissions (Figure 3). This can be attributed to their longevity and significance within the system. Additionally, lactating, and pregnant cows have higher daily energy and nutrient requirements compared to non-lactating mature cows, and they mainly consume forages that are lower in quality, resulting in greater enteric CH_4 production.

Greenhouse gas emissions expressed as kg CO2e $hd^{-1}yr^{-1}$ from animals vary significantly across categories. Breeding bulls emitted between 3,374 to 4,879, while mature cows emitted between 2,401 to 3,622. Replacement heifers contribute between 907 to 2,495, whereas calves emit between 34 to 646 (Tabel 6.)

These findings align with previous research by Basarab et al. (2012), which documented similar variability in total animal GHG emissions. They reported annual variations, with ranges of 4,101 to 4,912 kg CO2e $hd^{-1}yr^{-1}$ for breeding bulls, 3,394 to 3,877 kg CO2e $hd^{-1}yr^{-1}$

for beef cows and 980 to 1,124 kg CO2e $hd^{-1}yr^{-1}$ for replacement heifers. Notably, they did not evaluate emissions from calves until weaning. It's important to note that some differences are expected due to variations in animal weight and diet composition.

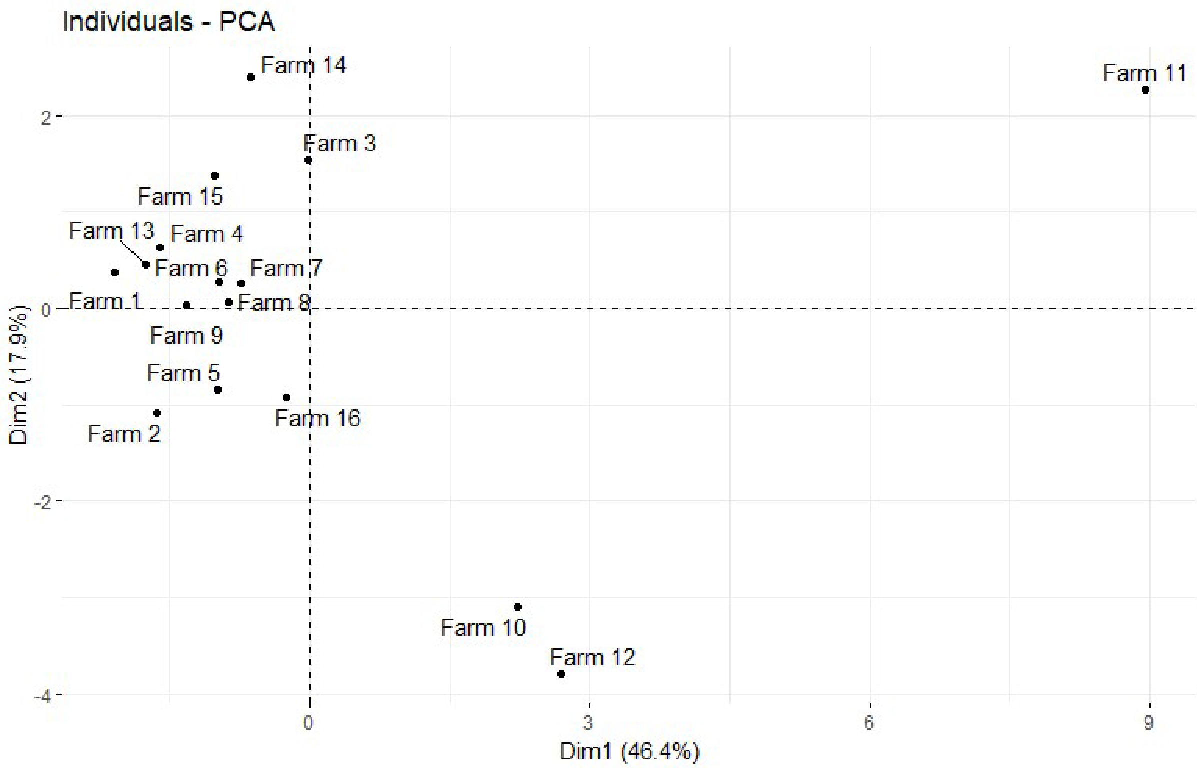

Figure 4. Principal Component Analysis of grouped farms. Dim 1 = principal component 1; Dim2 = principal component 2.

Figure 4 depicts PCA score plot of the first two principal components of grouped farms and provides a map of how the farms relate to each other. The first component (Dim1) explains 46.4% of the variation, and the second component (Dim2) explains 17.9%. Farms 1, 4, 6, 7, 13 and 15 are located together in the upper left-hand corner, representing farms with similarities in farm features, characterized as having high values of pregnancy rate and individual calf ADG, and small areas. Farms 2, 5 and 16 are characterized as having heavier cows and higher CO_2 emission intensity. Farms 10 and 12 are characterized as having the largest areas and herd, while Farm 11 stands alone, characterized as having the best performance per area.

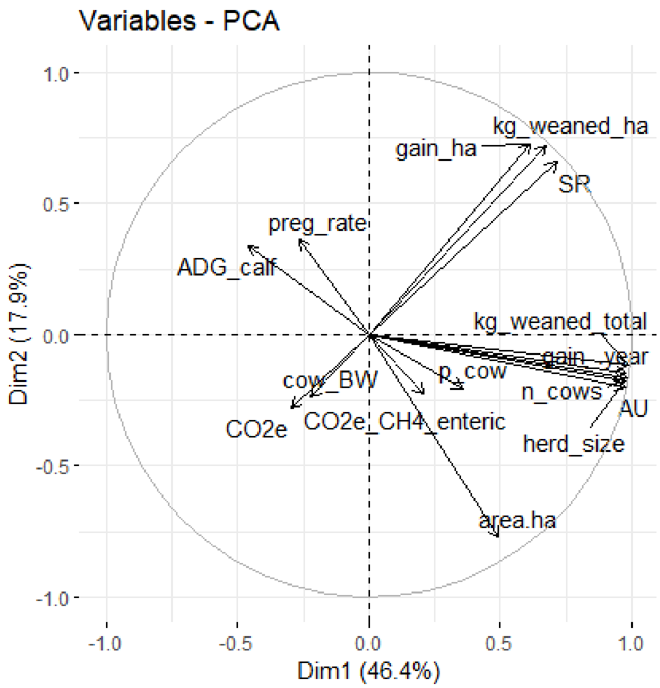

Figure 5. Principal Correlation Analysis between carbon equivalent intensity emission and farm performance variables. Dim 1 = principal component 1; Dim2 = principal component 2.

Figure 5 illustrates the relationships between the variables, grouping together those providing similar information and correlating them to provide insights into environmental performance and farming practices. This aids in identifying strategies to enhance productivity and mitigate GHG emissions. Notably, cow body weight showed a positive correlation with CO_2e emission intensity, as evidenced by their clustering in the graph. This suggests that, generally, farms with heavier cows tended to exhibit higher CO_2 emission intensity. In contrast, farms that were more productive per area (gain ha^{-1} and kg weaned calf ha^{-1}) were negatively correlated to CO_2e emission intensity. The influence of cow weight on emission intensity can be attributed to the emissions intensity metric utilized in this LCA, which is based on emissions related to one unit of output (i.e., one kg of weaned calf). Thus, any alterations in input parameters affecting output levels or the emissions associated with output production impact emissions intensity. Larger cows require more feed to maintain their weight and support reproductive processes, potentially resulting in higher GHG emissions from enteric fermentation (Beauchemin et al., 2010). Since the emissions intensity metric is founded on emissions associated with producing one kg of weaned calf, larger cows will exhibit a higher emissions intensity than smaller cows, even if they yield the same output (i.e., one calf per year). Conversely, farms achieving higher gains per hectare and weaned calves per hectare demonstrate more efficient resource utilization and management practices, leading to higher gains per animal while utilizing less area. Consequently, this results in lower emissions intensity per unit of output.

Net protein Contribution

Table 7. Human-edible protein contribution and Land use efficiency of cow calf operation in Forida

Farms	Variables						
	hePF (kg total herd-1)	hePP (kg total herd-1)	DIAAS	hePCE	NPC	Pasture area (ha)	Land use eff. (ha ton $hePP^{-1}$)
Farm-1	500.2	1712.2	54.8	3.4	7.0	80.9	47.3
Farm-2	490.4	1276.0	52.8	2.6	5.5	45.7	35.8
Farm-3	6244.6	12264.5	30.0	2.0	7.3	263.0	21.4
Farm-4	43.7	561.7	55.4	12.8	25.9	14.6	25.9
Farm-5	82.7	8112.2	56.6	98.2	194.1	364.2	44.9
Farm-6	141.1	3494.6	6.4	24.8	434.3	86.2	24.7
Farm-7	3291.6	6812.3	52.5	2.1	4.4	203.3	29.8
Farm-8	951.3	6798.0	31.7	7.1	25.3	242.8	35.7
Farm-9	734.6	2871.6	39.9	3.9	11.0	97.1	33.8
Farm-10	2776.0	46704.8	6.4	16.8	295.1	3561.2	76.2
Farm-11	4737.6	93062.2	6.2	19.6	355.6	849.8	9.1
Farm-12	14980.0	48395.2	17.0	3.2	21.2	3642.2	75.3
Farm-13	308.3	1418.0	22.5	4.6	22.9	54.6	38.5
Farm-14	456.2	1102.5	54.8	2.4	4.9	55.6	50.5
Farm-15	618.1	6875.5	32.3	11.1	38.6	170.0	24.7
Farm-16	992.3	17329.3	5.0	17.5	388.6	647.5	37.4

[1]hePF= human-edible protein consumed in feed; hePP = human-edible protein produced; hePCE = human-edible protein conversion efficiency; NPC = net protein contribution.

The calculation of Digestible Indispensable Amino Acid Score (DIAAS) for both the diets fed to the animals and the human-edible portion of a beef carcass provides valuable insights into the nutritional quality of protein sources utilized in livestock production. DIAAS, expressed as a percentage, serves as a critical indicator of a human-edible feedstuff's ability to meet the protein requirements of young children aged 0.5 to 3 years. In our study, we observed a wide range of DIAAS values, varying from 5 to 56.6 (Table 7), reflecting the diversity in protein quality among the feedstuffs examined. In contrast, beef exhibits a notably higher DIAAS value, recorded at 112, underscoring the superior protein quality of beef compared to the protein sources consumed by the animals. This discrepancy can be attributed to the fact that many ingredients in the animals' diets are byproducts, which often have lower or no nutritional value for humans. These byproducts include crop residues, agricultural wastes, and other feed ingredients not suitable for direct human consumption, but that can be efficiently converted by the ruminants into high quality edible food for human (Mottet et al., 2017).

Our NPC values appear comparatively lower than those documented in prior research, such as Fernandes et al. (2022) and Baber et al., 2018, where cow-calf grazing systems exhibited values surpassing 1000. It's worth noting that these studies relied on simulated models with minimal or absent supplementation, assuming that pasture constituted over 99% of the cattle's diet. Conversely, our study directly observed real farm data, revealing that all producers supplemented their herds during various life stages (creep feeding, supplementation of heifers and bulls) and especially during winter, when pasture availability dwindles due to cold and drought conditions.

Regarding land use efficiency, as measured by the hectares needed to produce 1 ton of hePP-1 (hectares per ton of protein), we observed variability ranging from 9.1 to 76.2 hectares. Interestingly, our findings align with those reported by Fernandes et al., (2022), a Brazilian study comparing five distinct cow-calf systems with varying intensification levels. Despite encountering significantly higher NPC values in their study, their assessment of land use efficiency ranged from 38.8 to 99.8 hectares per ton of heP.

This suggests that while the farms visited in our study exhibited lower NPC values, the implementation of higher levels of feed supplementation resulted in enhanced land use efficiency. This implies that despite lower nutritional output per unit of feed, our farms required less land to produce equivalent amounts of high-quality protein compared to the average Brazilian grazing systems.

Conclusion: Based on the results observed in this study, it is clear that enteric methane (CH4) emissions dominate the greenhouse gas (GHG) profile of cow-calf operations in Florida, contributing significantly to the overall carbon footprint. This outcome is consistent with the high-fiber, low-grain diets typical of these systems, which promote acetate production and subsequently higher methane output. While efforts to reduce CH4 emissions should remain a priority, the study also highlighted that nitrous oxide (N2O) emissions, primarily from manure and soil, and carbon dioxide (CO2) emissions from off-farm activities like fertilizer production, also contribute to the environmental impact. The analysis of Net Protein Contribution (NPC) and land use efficiency revealed that while

Florida cow-calf operations may have lower NPC values compared to other regions, the efficiency of land use remains relatively high due to strategic feed supplementation practices. These findings emphasize the need for balanced interventions that address both methane reduction and overall resource efficiency, ultimately contributing to more sustainable livestock production systems in Florida.

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UF Award #	AWD15792
Primary Project #	P0324583
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Current Invoice Amount:	$21,959.20

Description	Current	Cumulative
Personnel - Salary	$16,947.23	$19,662.67
Personnel - Fringe Benefits	$1,199.90	$1,520.31
Tuition	$1,459.29	$4,711.67
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