Beef Production and Climate Change

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Abstract

This paper synthesizes the literature on the impact of cattle finishing methods and production phases on greenhouse gas (GHG) emissions. To achieve this objective, we focus on two beef finishing methods (feedlot finishing and grass finishing) and three beef production phases (cow-calf, stocker, and feedlot). Without accounting for soil carbon sequestration, we found that on average feedlot finishing emits 13.83 kg CO_2 equiv. per kg carcass weight while grass finishing emits 22.27 kg CO_2 equiv. per kg carcass weight. However, accounting for soil carbon sequestration substantially reduces average GHG emissions from grass finishing (11.60 kg CO_2 equiv. per kg carcass weight) compared to feedlot finishing (15.25 kg CO_2 equiv. per Kg carcass weight). Furthermore, the average GHG emissions of the cow-calf, stocker, and feedlot phases are 13.33, 2.57, and 3.65 kg CO_2 equiv. per kg carcass weight, respectively. But none of the studies used in the production phases synthesis account for soil carbon sequestration. These results suggest that climate change mitigation policies should target the cow-calf and stocker production phases and the grass finishing method to reduce GHG emissions through soil carbon sequestration.

Keywords: Beef, Cow-calf, Stocker, Feedlot, Feedlot Finishing, Grass Finishing, Soil Carbon Sequestration

1 Introduction

Cattle production is one of the major sectors of the US agricultural industry. In 2021, the cattle sector was estimated to account for 17% of the $391 billion revenue from agricultural commodities (USDA, 2021a). However, cattle production can cause environmental challenges, which have become an increasing concern for many producers, consumers, and policymakers. Producers are concerned with choosing the most efficient, profitable, and environmentally friendly production and management methods, while some consumers are substituting plant protein for animal protein for health and environmental reasons (NCBA, 2021; Li et al, 2016). Additionally, numerous policymakers wish to promote policies that could mitigate climate change without impeding consumer choice or distorting the cattle market (Shouse et al., 2021; Krupnick, 2022). Balancing these competing interests and concerns is challenging and requires a better understanding of existing cattle production methods and their impacts on greenhouse gas (GHG) emissions.

Beef production accounts for over 41% of the livestock sector's contribution to the global GHG emissions (Gerber et al, 2013). Furthermore, some researchers have reported that beef production emits 2-10 times more GHGs than other animal products and 50-100 times more GHGs than plant sources of food (Figure 1). Other researchers have noted that the environmental footprint of beef production can be substantially reduced by switching to improved grazing management practices (Teague et al, 2016). For example, Stanley et al. (2012) conclude that using adaptive multi-paddock grazing would help to reduce GHG emissions from beef production. But only a few studies have synthesized such literature and have made policy suggestions on how improved management practices can help reduce the environmental footprint of cattle production.

[Insert Figure 1 around here]

The production phases of beef cattle comprise cow-calf, stocker, and feedlot operations. Each of these operations contributes to GHG emissions (see Table 1 for the summary of similarities and differences among them). Cow-calf operation is generally characterized as an extensive production system where breeding cows and bulls are kept primarily for producing calves (Endres and Schwartzkoph-Genswein, 2018). Depending on economic and weather conditions, the calves can either be retained as stockers or sent directly to the feedlot for finishing (Ruff et al, 2016). The second production phase is the stocker operation, which is also typically an extensive production system where weaned calves graze on natural grassland or pasture and are often supplemented with grain and other forage until they reach the target weight (Endres and Schwartzkoph-Genswein, 2018). The third production phase is feedlot where cattle are kept in confinements in which they are fed mainly grains until they reach market weight. Feedlot operations are usually large with capacities for thousands of cattle.

[Insert Table 1 around here]

Due to the differences in the feedlot, stocker, and cow-calf production phases, efforts to mitigate the GHG emissions in each of the phases might differ. For example, some cattle producers have adopted grass-finishing (which consists of keeping stockers on pasture and allowing them to graze freely until they reach market size) instead of feedlot-finishing (Table 1). The potential of grass-finishing as a more environmentally friendly production system has also caught the attention of some researchers. This led Capper (2012) to compare the GHG emissions of grass-finishing and feedlot-finishing, but she found that feedlot-finishing had lower GHG emissions relative to grass-finishing. This result is primarily due to feedlot cattle consuming high-energy grains and, therefore, growing and reaching market weight more rapidly. The GHG emissions of feedlot finishing relative to grass finishing are corroborated by Heflin et al (2019). However, both Capper

(2012) and Heflin et al (2019) did not account for the soil organic carbon (SOC) effect of the finishing systems, which could have led to biased estimates of net GHG emissions. Other studies accounting for the SOC effect found that the net emissions of grass finishing are less than that of the feedlot-finishing (Lupo et al., 2013; Stanley et al., 2018).

GHG emissions of different cattle production phases have also been analyzed (Stackhouse-Lawson et al., 2012; Rotz et al., 2013, 2015; Asem-Hiablie et al., 2019). For example, Stackhouse et al. (2012) found that per animal GHG emissions of the cow-calf operations are 4.3 times greater than the stocker operations and 6.7 times greater than the feedlot-finishing operations. Similarly, Rotz et al. (2013) found GHG emissions per unit carcass weight of the cow-calf production phase to have been 3.8 times greater than stocker operations and 4.5 times greater than the feedlot operations. Rotz et al (2015) and Asem-Hiablie et al (2019) also reached similar conclusions. However, none of these studies account for the carbon sequestration potential of the grassland, which could offset the GHG emissions from cow-calf and stocker operations.

Given that different management practices/strategies are likely associated with different levels of GHG emissions, there are opportunities to determine practices with the least GHG emissions while maintaining the profitability of cattle production. In a synthesis of several studies across the globe, Cusack et al. (2021) found that management strategies such as using grass finishing instead of feedlot finishing and using improved feed/supplements reduce GHG emissions from beef production. Similarly, Lynch (2019), Clune et al (2017), and Tang et al (2019) provide additional syntheses of studies on GHG emissions from livestock and crop production. However, like Cusack et al (2021), these review studies provide a global perspective, but they do not primarily investigate the impact of beef production on GHG emissions in North America.

Our study focuses on the impact of beef production on GHG emissions in the United States (US). Specifically, our goal is to synthesize existing research results regarding the GHG emissions of different production phases (cow-calf, stocker, and feedlot) and beef cattle finishing systems (feedlot-finishing and grass-finishing), as well as the carbon sequestration potential of these different production systems. We also aim to provide useful insights regarding the following topics in the literature: 1) whether feedlot-finishing is more environmentally friendly than grass-finishing cattle, 2) which production phase should be given the most attention for reducing GHG emissions, and 3) the role of carbon sequestration in beef cattle production.

2 Methodology

2.1 Data Collection

To achieve our specific objectives, we used three criteria for selecting the published studies suitable for our study sample. These criteria included: (1) Studies that focused on beef cattle production; (2) Studies that were carried out in the US and/or Canada. (3) Studies that measure/estimate GHG emissions for at least one of the following categories in production operation phases (i.e., cow-calf, stocker, and/or feedlot) and/or finishing methods (i.e., feedlot-finishing and/or grass-finishing).

We first identified four review papers that synthesize information regarding the GHG emissions of cattle production. Specifically, Cusack et al (2021) reviewed 57 studies, Lynch (2019) reviewed 22 studies, Clune et al (2017) reviewed 369 studies, and Tang et al (2019) reviewed 63 studies. We used these studies as the base for our review. We screened the studies using the aforementioned criteria and found 8 articles that are suitable for our synthesis based on their title, abstract, and keywords as mentioned below?

In addition, we did a thorough search of the literature to identify other studies that are related to our objectives. This involved searching for papers through google scholar using keywords “beef cattle”, “cow-calf”, “stocker”, “feedlot”, “grass-fed”, “feedlot finishing”, “grass-finishing”, along with a search for “life cycle assessment” and “GHG emissions”, “United States” and “Canada”. We identified several papers and assessed them by checking their title, abstract, and keywords, which allowed us to determine whether the studies should be included in the final sample. Out of this search, we included 5 additional studies in our synthesis that are not covered by the four base review studies, making a total of 13 studies. These 13 studies included 6 studies for the synthesis of feedlot and grass finishing emissions and 7 studies for the synthesis of the cow-calf, stocker, and feedlot emissions.

2.2 Comparison Approach

Given that some of these studies used different GHG emissions units, we used a common unit (Kg CO2 equiv. per 1 Kg Carcass Weight) that allows for comparisons within and across studies. Furthermore, to compare the sizes of the GHG emission estimates, we adopted a percentage change approach that calculates a unitless measure that is comparable across studies. The percentage change is calculated as:

$$\left(\frac{GHG\ emissions\ Grass\ Finishing\ -\ GHG\ emissions\ Feedlot\ Finishing}{GHG\ emissions\ Feedlot\ Finishing}\right) \times 100\% \qquad (1)$$

and

$$\left(\frac{GHG\ emissions\ Cowcalf - GHG\ emissions\ Stocker\ and\ Feedlot}{GHG\ emissions\ Stocker\ and\ Feedlot}\right) \times 100\%. \qquad (2)$$

The feedlot finishing and stocker/feedlot operation was chosen as denominators because they represent operations that are expected to have less GHG emissions based on previous literature (Capper 2012; Heflin et al 2019; Stackhouse-Lawson et al., 2012; Rotz et al., 2013, 2015; Asem-Hiablie et al., 2019; Lupo et al., 2013; Stanley et al., 2018). In these equations, percentage changes positive (negative) in equation (1) indicate that grass finishing has greater (lower) emissions than feedlot finishing.

3. Results and Discussion

3.1 Summary of Reviewed Studies

Table 2 summarizes studies that compare the GHG emissions of feedlot finishing with those of grass finishing and the GHG emissions across the cow-calf, stocker, and feedlot phases. All cited studies used the life cycle analysis (LCA) method, which generally accounts for all sources of GHGs within the designated system boundaries of each study. LCA also accounts for the duration of each production phase and finishing system. Table 2 shows the longer duration of the grass finishing phase when compared with the duration of the feedlot finishing phase, whereas the duration of the stocker phase is the lowest among the three. The difference in duration impacts the amount of GHGs produced. Additionally, the number of animals and their starting and finishing weights also impact the amount of GHGs emitted. Thus, Table 2 provides information that forms the basis of our GHG estimates comparisons.

[Insert table 2 around here]

3.2 Feedlot Finishing vs. Grass Finishing

Table 3 compares GHG emissions from feedlot finishing and grass finishing. This comparison is based on 6 studies. Three of these studies (Capper 2012; Heflin et al. 2019; Klopatek et al, 2022) do not consider the impact of soil carbon sequestration while the 3 remaining studies (Lupo et al 2013; Pelletier et al 2010; Stanley et al, 2018) account for soil carbon sequestration.

[Insert Table 3 around here]

For example, Capper (2012) found that feedlot finishing produces 15.99KgCO_2e/KgCW while grass finishing produces 26.79KgCO_2e/KgCW of GHG emissions. Similarly, Heflin et al (2019) found that feedlot finishing produces 9.6 while grass finishing produces 27.5KgCO_2e/KgCW, and Klopatek et al (2022) found that feedlot finishing emits 4.79KgCO_2e/KgCW while grass finishing emits 7.48KgCO_2e/KgCW. Thus, these three studies reach the same conclusion—feedlot finishing emits less GHG than grass finishing. However, Capper (2012), Heflin et al. (2019), and Klopatek et al, (2022) do not account for soil carbon sequestration, and this could have biased their results.

There are at least three reasons why grass finishing generally emits more GHGs than feedlot finishing without accounting for soil carbon sequestration. The reasons are the duration of the finishing phase, the efficiency of converting grass/feed to beef, and the use of fertilizer on grassland (Stanley et al 2018). As shown in table 2, the duration of feedlot finishing is about 4-10 months whereas the duration of grass finishing is about 7 to 23 months. This entails that all the resources used in the production of the animals such as water (some of which is irrigated) are used more throughout the period (Stanley et al 2018; Capper 2012; Klopatek et al 2022). Furthermore, the rates of grass/feed conversion to beef differ significantly and this also contributes to the differences in the GHG emissions. Table 2 illustrates these differences through the starting and finishing weights of cattle for both feedlot finishing and grass finishing. The average range for feedlot finishing is 288kg to 614kg while the average range for grass finishing is 275kg to 496kg. This implies that despite the longer duration in the finishing phase, the average grass-finished cattle have less finishing weight than average feedlot-finished cattle owing to their feed/grain conversion (Capper 2012; Heflin et al. 2019; Klopatek et al, 2022; Lupo et al 2013; Pelletier et al 2010; Stanley et al, 2018). Finally, fertilizer application accounts for a significant portion of GHG emissions and maintaining grassland for grass finishing using fertilizers contributes more to GHG emissions than feedlot finishing (Stanley et al 2018; Stewart et al 2009; Capper 2012).

Pelletier et al (2010), Lupo et al (2013), and Stanley et al (2018) account for soil carbon sequestration and thus address a limitation of Klopatek (2022), Capper (2012), and Heflin et al (2019). Specifically, Lupo et al (2013) found that the GHG emissions from grass finishing reduced from 32.00KgCO_2e/KgCW to 24.00KgCO_2e/KgCW when soil carbon sequestration is considered. The reduction in GHG emissions due to soil carbon sequestration is even more substantial in Pelletier et al (2010) and Stanley et al (2018). In fact, GHG emissions reduced from 30.48KgCO_2e/KgCW to 17.46KgCO_2e/KgCW in Pelletier et al (2010) and from 9.62KgCO_2e/KgCW to -6.65KgCO_2e/KgCW in Stanley et al (2018). This finding indicates that accounting for soil carbon sequestration can in some cases entirely offset the GHG emissions from grass finishing (Stanley et al, 2018). Although the influence of soil carbon sequestration on GHG emissions appears to offset only the emissions of grass-finished cattle, croplands can also sequester carbon and reduce the GHG emissions of feedlot-finished cattle (Stanley et al 2018).

3.3 Cow-Calf vs. Stocker/Feedlot Operations

Table 4 compares GHG emissions from cow-calf, stocker, and feedlot operations. This comparison is based on 7 studies. None of these studies account for soil carbon sequestration, which could offset GHGs in the cow-calf and stocker operations. Unlike the dissension in the previous section, the conclusions are unanimous for these 7 studies—on average, the cow-calf operation emits more GHG than the stocker and feedlot operations, and the feedlot operation emits more GHGs than the stocker operation.

[Insert table 4 around here]

For example, Asem-Hiablie et al (2019) found that cow-calf emitted 9.50KgCO_2e/KgCW whereas feedlot emitted 2.47KgCO_2e/KgCW. Thus, the cow calf emitted 285% more GHGs than the feedlot. Similarly, Rotz et al (2013) found that the cow-calf emitted 7.79KgCO_2e/KgCW while the feedlot emitted 2.03KgCO_2e/KgCW, resulting in 284% more GHGs from the cow-calf. Both Asem-Hiablie et al (2019) and Rotz et al (2013) sidestep the stocker operation in their estimations but Rotz et al (2015) and Stackhouse-Lawson et al (2012) consider the stocker operation in their estimations. Rotz et al (2015) found that the GHG emissions from the cow-calf, stocker, and feedlot operations are 13.60KgCO_2e/KgCW, 3.60KgCO_2e/KgCW, and 3.00KgCO_2e/KgCW. These findings indicate that the cow-calf operation emits 278% more GHGs than the stocker operation and 353% more GHGs than the feedlot operation. Similarly, Stackhouse-Lawson et al (2012) estimated that the cow-calf, stocker, and feedlot operations emitted 12.74KgCO_2e/KgCW, 2.68KgCO_2e/KgCW, and 1.71KgCO_2e/KgCW. This also indicates that the cow-calf emitted 375% more GHGs than the stocker and 645% more GHGs than the feedlot. Furthermore, both Rotz et al (2015) and Stackhouse-Lawson et al (2012) found that the stocker operation emits more GHGs than the feedlot operation.

The main implication of these findings is that efforts to reduce the GHG emissions of beef production should primarily target the cow-calf production phase, followed by the feedlot production phase, and then the stocker production phase. This sequence emphasizes the level of emissions in each production phase but obscures the sources of GHG emissions. For example, in the cow-calf phase, potential targets for reducing GHG emissions could be increased efficiency in water usage (Stanley et al 2018; Capper 2012; Klopatek et al 2022) or a reduction in the use of fertilizer (Stanley et al 2018; Stewart et al 2009; Capper 2012). Similarly, for the feedlot production phase, feed production could be targeted as the major source of GHG emissions in the phase (Asem-Hiablie et al 2019). Thus, to achieve the overall goal of reducing GHG emissions for the entire cattle production system, it is important to note the specific sources of GHGs to be targeted in each production phase.

5 Conclusion

This study synthesized existing research on beef cattle finishing methods (feedlot vs. grass-fed) and production operations (cow-calf, stocker, feedlot) in the US and Canada. The main motivation is to provide insights that contribute to the debate on which finishing method and production operation are more environmentally friendly and which should be the target for mitigating the climate change impacts of cattle production.

Using a comparison approach, we made two findings that map to our objectives. First, without accounting for soil carbon sequestration, we found that feedlot finishing is more environmentally friendly than grass finishing (Capper 2012; Heflin et al. 2019; Klopatek et al, 2022). However, this finding reverses once soil carbon sequestration is considered. This result suggests that grass finishing could provide a potential carbon sink and should be given serious consideration for mitigating the climate change impacts on beef production (Lupo et al 2013; Pelletier et al 2010; Stanley et al, 2018). This could also be extended to the croplands that produce grains for the feedlot finishing. Second, without accounting for SOC, we found that the cow-calf production phase emits more GHG than the stocker and the feedlot production operations (Asem-

Hiablie et al 2019; Rotz et al 2013; Rotz et al 2015; Stackhouse-Lawson et al 2012). This is because the cow-calf operation maintains a large breeding stock, requires more land, and consumes a more grass-based diet. These results indicate the need to use regenerative crop and grazing management in beef production, especially for the cow-calf and stocker production operations.

These results have implications for mitigating the climate change impacts of beef production, which is of interest to several stakeholders including policymakers at all levels. First, this study highlights different avenues for mitigating GHG emissions in beef production. The avenues emphasized are the finishing phase (feedlot vs grass) and the production operations (cow-calf, stocker, feedlot). Second, each of these avenues indicates the importance of soil carbon sequestration. Accounting for soil carbon sequestration could overturn results that seem conclusive such as feedlot finishing emitting less GHG than grass finishing and the feedlot operation emitting less GHGs than the cow-calf and stocker operations.

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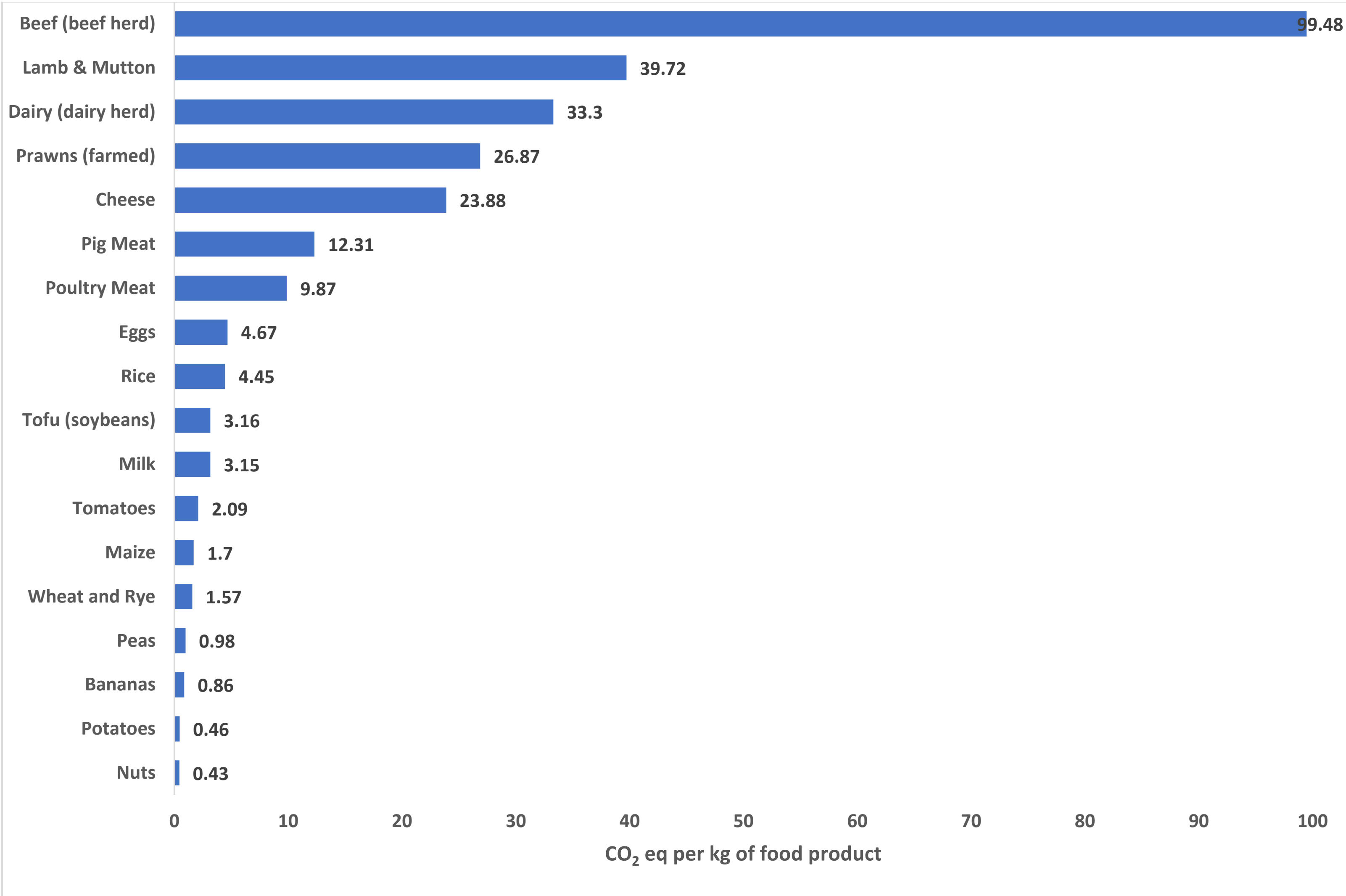
Figure 1: Greenhouse Gas Emissions per Kilogram of Food Product



Source: Ritchie and Roser (2020)

Table 1: Similarities and Differences between Beef cattle Production Operations

	Cow-Calf	**Stocker**	**Feedlot**	**Grass-fed**
Diet	Milk, Grass	Grass, Hay, Roughage, Silage, Grain	Silage/Grain	Grass/Forage/Roughage
Housing-type	Extensive	Extensive	Intensive	Extensive
Birth Weight —Sell Weight	150 lbs – 450 lbs	450 lbs – 850 lbs	850 lbs to 1300 lbs	450 lbs to 1300 lbs
Time in Cycle	~ 6 months	~ 6 months	~ 5 months	~ 2 – 3 years

Source: Endres and Schwartzkoph-Genswein (2018)

Table 2: Summary of Reviewed Studies for the GHG Emission Comparisons

Citation	System Boundaries	Methodology	Number of Animals	Duration in Finishing Phase (months)	Starting Weight (kg)	Finishing Weight (kg)
Feedlot Finishing and Grass Finishing						
Klopatek et al (2022)	Cradle-to-gate	LCA	22 steers per treatment	5 – feedlot 9 – grass	283 283	632 524
Heflin et al (2019)	Cradle-to-gate	Simulation	1 steer per treatment	8 – feedlot 23 – grass	250 250	622 500
Stanley et al (2018)	Cradle-to-gate	LCA	16 steers - Feedlot 210 steers - AMP	6 – feedlot 7 – AMP	361 362	654 530
Lupo et al (2013)	Cradle-to-gate	LCA	1 steer per treatment	7 – feedlot 12 – grass	250 250	612 429
Capper (2012)	Cradle-to-gate	EIM	N/A	4– feedlot 10 – grass	367 293	530 486
Pelletier et al (2010)	Cradle-to-gate	LCA	75 calves per treatment	10 – feedlot 15 – grass	216 216	636 505
Cow-calf, Stocker, and Feedlot						
Matlock et al (2021)	Cradle-to-gate	LCA	190 – Background 60 – Feedlot	3 – Background 6 – Feedlot	245 293	293 590
Asem-Hiablie et al (2019)	Cradle-to-gate	LCA	5783 – Cow-calf 3742 – Stocker 3724 – Feedlot	6 – Cow-calf 3 – Stocker 7 – Feedlot	- 296 367	296 367 581
Rotz et al (2015)	Cradle-to-gate	LCA	N/A	6 – Cow-calf 6 - Stocker 5 - Feedlot	- - -	- - 590
Dudley et al (2014)	Cradle-to-gate	LCA	N/A	6 (Feedlot)	334	583
Rotz et al (2013)	Cradle-to-gate	LCA	5783 – Cow-calf 3742 – Stocker 3724 – Feedlot	6 – Cow-calf 3 – Stocker 7 – Feedlot	- 296 367	296 367 581

Stackhouse-Lawson et al (2012)	Cradle-to-gate	LCA	600 – Cow-calf 1000 – Stocker 5000 – Feedlot	12 – Cow-calf 6 – Stocker 4 – Feedlot	40 283 379	280 384 571
Beauchemin et al (2010)	Cradle-to-gate	LCA	102 - Cow-calf 99 – Stocker 98 - Feedlot	7 – Cow-calf 4 – Stocker 6 – Feedlot	40 240 350	240 350 605

Table 3: GHG Emissions from Feedlot Finishing and Grass Finishing (in Kg CO_2 equiv. per 1 Kg Carcass Weight)

Citation	Region	Is Carbon Sequestration Included?	Feedlot	Grass	Percentage Difference
Klopatek et al (2022)	California	No	4.79	7.48	-0.36
Heflin et al (2019)	Southern High Plains	No	9.6	27.50	-0.65
Stanley et al (2018)	Midwest	Yes	6.12	-6.65	1.92
		No	6.09	9.62	-0.37
Lupo et al (2013)	Northern Great Plains	Yes	19	24.00	-0.21
		No	23	32.00	-0.28
Capper (2012)	All Regions	No	15.99	26.79	-0.40
Pelletier et al (2010)	Midwest	Yes	20.63	17.46	0.18
		No	23.49	30.48	-0.23
			Without Carbon Sequestration		
		Max	23.49	32.00	-0.23
		Min	4.79	7.23	-0.65
		Average	13.83	22.27	-0.38
			With Carbon Sequestration		
		Max	20.63	24.00	1.92
		Min	6.12	-6.65	-0.21
		Average	15.25	11.60	0.63

Table 4: GHG Emissions from Cow-calf, Stocker, and Feedlot Operations (in Kg CO_2 equiv. per 1 Kg Carcass Weight)

Citation	Region, Country	Cow-calf	Stocker	Feedlot	Total Emissions
Matlock et al (2021)	Kansas, Nebraska	26.45	1.43	11.12	39.00
Asem-Hiablie et al (2019)	All Regions	9.50	-	2.47	11.97
Rotz et al (2015)	Kansas, Oklahoma, Texas	13.60	3.60	3.00	20.20
Dudley et al (2014)	Central	5.60	-	2.57	8.17
Rotz et al (2013)	Nebraska	7.79	-	2.03	9.82
Stackhouse-Lawson et al (2012)	California	12.74	2.68	1.71	17.13
Beauchemin et al (2010)	Canada	17.60	1.76	2.64	22.00
	Max	26.45	3.60	11.12	39.00
	Min	5.60	1.43	1.71	8.17
	Average	13.33	2.57	3.65	17.72