Greenhouse Gas Emissions from Two Beef Systems from Birth to Slaughter in Eastern Nebraska

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Summary with Implications

Methane emissions from growing and finishing calves born into a spring calving, conventional cow system or a summer calving, partially-confined cow system were compared. Cows fed a restricted diet of corn-byproduct and grain residues in confinement produced less methane and carbon dioxide per day compared to cows grazing pasture or cover crop. Calves weaned from the confinement-based production system were smaller at weaning and compensated with greater gain during the growing phase. More days on feed in the finishing phase were needed for the calves from the confinement system to reach same backfat thickness. Over the entire growing and finishing phases, calves from the confinement-based system produced more total methane and methane per lb of carcass weight. Carbon sequestered into brome pasture and oat forage biomass was measured. Total measured emissions from all stages of beef production were combined with modeled emissions from soil and manure. Conventional cow-calf production grazing perennial cool season grasses sequestered enough carbon to offset 138% of all carbon emissions from gestation, lactation, growing and finishing stages. Annual forages grazed in the partial confinement system offset 70% of total emissions from the system. Minimizing emissions and maximizing sequestration can make beef production climate neutral or better, depending on management practices used.

Introduction

It is a common perception that agriculture, and especially the beef livestock sector, is an emitter of greenhouse gases (GHG) and contributor to climate change. Both carbon sequestration in grazing lands and global warming potential (GWP) of methane (CH_4) need to be accounted for when assessing the impact of beef cattle. Methane has traditionally been assigned a GWP of 23 to 82 times more potent than CO_2 depending on the degradation rate of CH_4 used. New GHG accounting methods simultaneously account for both production of CH_4 and natural atmospheric breakdown of CH_4 (9 to 12 years compared to 1000 years for CO_2). These accounting methods regard CH_4 as having only 4 times the potency of CO_2. Multiplying CH_4 by GWP is used to express CH_4 in CO_2 equivalents (CO_2e).

Open-air micrometeorological techniques have been implemented to measure carbon sequestration in ecosystems worldwide. Eddy covariance simultaneously measures the C flux into and out of a given area. This technique can be used to better understand C flux from beef production, taking into account emissions from enteric fermentation and respiration as well as sequestration.

The objective of this experiment was to measure GHG production within two beef production systems from conception to slaughter and express those emissions per unit of beef produced. In addition, sequestration of carbon and offsets of GHG within each system were measured. This included assessing CO_2e from CH_4 using 2 different GWP values.

Procedure

The GHG emissions from cattle in two cow-calf systems were evaluated. At the onset of the experiment, 160 cows were assigned randomly to one of 2 production systems, conventional (CONV) and alternative (ALT). Cow age was equally represented in both systems. In each system, 4 groups of cows (n=20) were raised under set conditions for 2 consecutive years, and post-weaning practices remained the same for all calves (steers and heifers). The CONV system was a pasture-based system. Cow-calf pairs grazed bromegrass pastures from May 1 to October 26, calved between April 15 and June 15 and weaned October 15 when calves were approximately 168 days of age. After weaning, cows grazed corn residue from October 27 to March 15, then returned to grass pastures and were fed grass hay until forage growth was adequate for grazing. The ALT system was an intensive, feedlot-based system during the summer and grazing during the fall and winter. Cows entered the feedlot on March 15 and were limit-fed from March 15 until calving which occurred July 15 to September 15. Cow feed intakes were adjusted to meet gestation and lactation needs. After calving, cow-calf pairs grazed secondary annual forage (oats) from October 15 to January 15, when calves were weaned. Following grazing cows grazed corn residue from January 16 to March 15.

A pen chamber was used to measure GHG emissions (*2021 Nebraska Beef Cattle Report*, pp. 79–82) from cows and calves (nursing, growing and finishing). Cattle were in the chambers for 5 days. Diets fed in the pen chamber are shown in Tables 1 and 2. During year 3 of the study, nursing calves from the ALT system remained in the pen chamber for 6 hours after the cows were sent back to the home pen. Calf CO_2 and CH_4 measured during this period in combination with some data in the literature were used to develop a regression of CO_2 and CH_4 production relative to calf body weight. The calf contribution was then subtracted from the total flux to determine the flux from only cows in grazing scenarios.

Table 1. Composition of diets (DM basis) fed to cattle during growing and finishing phases.

	Growing	Finishing	
Ingredient, % DM	Years 1 and 2	Year 1	Year 2
Dry rolled corn	30	34	
High moisture corn		34	41
Sweet Bran			40
Modified distillers grains	30	20	
Corn silage			15
Grass hay	35	7	
Supplement	5	5	4
Fine ground corn	2.52	2.29	1.878
Limestone	1.98	1.69	1.63
Tallow	0.13	0.13	0.10
Urea	0	0.5	0
Salt	0.30	0.30	0.30
Beef trace mineral	0.05	0.05	0.05
Vitamin ADE premix	0.015	0.015	0.015
Rumensin 90 premix	0.012	0.017	0.017
Tylan 40 premix	0	0.011	0.010

Table 2. Ingredient composition of confinement diet fed to alternative cow-calf system by year during pen-scale GHG measurement[1]

	Gestation			Lactation		
Ingredient, %	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
MDGS[2]	55.00	55.00	35.00	55.00	55.00	35.00
Corn silage			40.00			
Forage Silage						21.31
Wheat straw	40.00	40.00	20.00	41.34		40.00
Oat straw					41.34	
Supplement	5.00	5.00	5.00	3.66	3.66	3.69
Fine ground corn	2.47	2.49	2.49	1.79	1.80	1.83
Trace mineral salt	—	1.79	1.79	—	1.31	1.31
Limestone	1.98	0.57	0.57	1.45	0.42	0.42
Salt	0.30	—		0.22	—	
Tallow	0.13	0.13	0.13	0.09	0.09	0.09
Beef trace mineral	0.10	—		0.07	—	
Insect growth regulator	—	—		0.02	0.02	0.02
Vitamin A-D-E premix	0.02	0.02	0.02	0.01	0.01	0.01
Rumensin 90 premix	0.01	0.02	0.02	0.01	0.01	0.01
Nutrient Composition						
DM, %	66.88	66.88	55.05	66.75	67.29	63.78
TDN, % of DM	63.66	64.78	69.62	63.66	64.78	66.82
Fat, % of OM	6.29	6.24	5.26	6.29	6.24	4.27
Protein % of OM	18.3	18.1	14.7	18.3	18.1	14.4

[1] All values represented on a DM basis unless noted

[2] Modified distillers grains plus solubles

For measurements of GHG in grazed scenarios (bromegrass pasture, forage oats, and corn residue) eddy covariance techniques were used. To measure CO_2 production, an open path laser was used (LI-7500DS Open-Path CO_2 /H_2O Analyzer; LI-COR Biosciences, Lincoln, NE). For N_2O and CH_4, a closed-path analyzer was also installed (N_2O/CO Analyzer Los Gatos Research San Jose, CA). Eddy covariance uses the variation in upwind turbulence generated by wind dynamics with surface of the earth. Concentrations of CO_2 and CH_4 are measured 10 times per second. The covariance of that data over time is used to calculate the flux toward or away from the surface. Fluxes will change depending on the biomass growth and other sources and sinks in the ecosystem measured. Cattle are moving point sources and their locations must be tracked to determine if they are in the upwind area known as the fetch.

To track individual animal movements, GPS loggers (igotU GT-600; Tenergy) were given to each cow, bull and calf in the cow group being measured. The GPS collars were removed every 4 to 6 weeks to download the data and recharge the batteries. The spatial distribution of the livestock was averaged over a 30-minute duration and a gap-filling procedure was used to calculate the location of the animal based on the previous and subsequent GPS coordinates in the event of missing data. The flux per animal was determined from the regression of animals in the footprint relative to size of the flux.

Manure emissions (CH_4, CO_2 and nitrous oxide, N_2O) and fossil fuel use were not directly measured. Work from other life-cycle assessments of beef production estimated 5.84 lb CO_2e per lb of hot carcass weight (HCW) from manure and soil GHG and CO_2 from combustion of fossil fuels used in beef production. Modeled emissions were combined with measured CH_4 and CO_2 from CONV and ALT to determine total GHG to be sequestered from the production system. Cattle in CONV and ALT were slaughtered at equal backfat thickness, but groups had different numbers of days on feed and feed intake.

Production of CO_2 and CH_4 (grams/lb DMI) from pen-chamber data were

Table 3. Observed CH4 and CO2 production per animal in pasture-based (CONV) or partial-confinement (ALT) beef productions systems.

		CH_4			CO_2		
	DMI, lb	Per lb. DMI, g	Per animal daily, g	Total per animal, lb	Per lb. DMI, g	Per animal daily, g	Total per animal, lb
Cow only							
Corn Residue	19.7	9.7	191.9	12.2	375.6	7399.7	469.9
Brome Pasture	31.0	9.6	297.8	24.0	532.8	16500.0	1332.2
Cover crop	51.2	6.0	309.2	11.6	305.4	15625.0	588.3
Gestating Cow (Drylot)	15.3	9.0	137.0	7.6	389.7	5945.0	331.7
Lactating Cow (Drylot)	20.2	7.4	149.4	6.9	254.7	5131.9	237.4
Growing Calf							
CONV	19.6	6.2	121.8	36.8	252.4	4948.0	1498.0
ALT	19.1	6.4	122.9	35.0	246.8	4713.0	1330.0
Finishing Calf							
CONV	23.3	5.4	125.0	40.6	323.9	7551.0	2485.0
ALT	23.8	6.1	145.2	59.5	298.4	7111.0	2852.0
Calf contribution on cow							
Pen chamber			25.6			1892.2	
Pasture			51.6			2740.7	
Cover Crop			54.6			2856.0	

analyzed using PROC MIXED, with day in barn as the repeated measure. Because intake was not measured in grazing scenarios, emissions were expressed per animal daily instead of unit of DMI. The 95% confidence interval around the mean was calculated for eddy covariance data with minimum and maximum values reported. The difference in min and max for each system was used as an indication of numerical vs statistical difference.

Results

Emissions—CH4

Results of pen chamber and open-air measurements are presented in Table 3. For cows grazing corn residue CH_4 production was 204 ± 25.8 g per cow daily compared to 155 ± 14.6 g from gestating cows in ALT system. During lactation ALT cow-calf pairs produced 175 g ± 16.8 g compared to CONV pairs grazing brome pasture which produced 322.76 ± 50.7, 404.81 ± 113.7 and 322.0 ± 56.9 g during early, mid, and late grazing periods respectively. ALT cows grazing cover crops produced 357.23 g ± 43.1 per pair per day.

Comparison of systems GHG production during gestation and lactation phases are presented in Table 4. Overall, less CH_4 was observed during gestation since CONV cows were producing 204 g per animal per day grazing residue and ALT cows were only producing 155 g per animal per day when being fed in the drylot. Considering the number of days in each environment, CONV and ALT cows produced 84.4 ± 13.9 and 62.4 ± 7.4 lb CH_4 over the gestation period. During lactation cows produced 136 for conv ± 20.6 and 105 ± 11.7 lb CH_4 for CONV and ALT, respectively.

During the growing phase (Table 5) no differences in DMI were observed, but compensatory gain in ALT calves resulted in greater ADG and improved F:G ($P < 0.01$; *2021 Nebraska Beef Cattle Report*, pp. 79–82). No differences in CH_4 per day or lb DMI were observed, but CONV calves produced more ($P < 0.01$) CH_4 per lb ADG (53.7 vs 44.8 g per lb ADG, respectively). There were no differences in total CH_4 per hd during growing. In the finishing phase many of the opposite trends observed in the growing phase were observed. During finishing CONV calves had greater ADG and no differences in DMI, resulting in improved F:G. No differences in CH_4 per lb DMI but greater ($P = 0.02$) CH_4 per lb ADG in ALT (43.2 vs 31.7 g per lb ADG, respectively). During the finishing phase ALT calves were fed 35 days longer than CONV calves to achieve similar backfat. The advantage in emissions from the gestation phase was lost during the finishing phase since ALT calves had greater total CO_2e (3090 ± 556 vs 2647 ± 291).

Emissions—CO2

During gestation carbon dioxide production was greater during CONV system because CO_2 production per animal per day was 7,400 g on corn residue and only 5,945 g when ALT cows were limit-fed in a drylot. Production of CO_2 was high in both pasture grazing (16,500 g CO_2 per cow per day) and cover crop (15625 g CO_2 per cow per day) grazing likely due to high intakes by lactating cows.

Daily production of CO_2 during growing (4948 and 4713 g per animal per day for CONV and ALT, respectively) and finishing (7551 and 7111 g per animal per day for CONV and ALT, respectively) was not statistically different between CONV

Table 4. Production of CH4 and CO2 in pasture-based (CONV) or partial-confinement (ALT) production systems during gestation, and lactation.

	CONV			ALT		
	Mean	Lower	Upper	Mean	Lower	Upper
Gestation						
DMI, lb	21.0	14.1	28.8	16.7	13.7	20.1
Days	188.0	188.0	188.0	183.0	183.0	183.0
CH_4						
CH_4 per lb DMI, g	9.7	12.1	8.8	9.3	10.0	8.6
CH_4 per hd per day, g	203.5	170.1	253.2	154.7	136.4	172.6
Total CH_4, lb	84.4	70.5	104.9	62.4	55.0	69.6
CO_2						
CO_2 per lb DMI, g	353.6	380.2	250.2	384.3	389.2	327.5
CO_2 per hd per day, g	7436.5	5349.2	7204.7	6414.0	5322.9	6566.5
Total CO_2, lb	3082.2	2217.1	2986.1	2587.7	2147.5	2649.2
Global warming potential						
CO_2e from CH_4, lb 4x	337.4	282.1	419.7	249.6	220.2	278.5
CO_2e from CH_4, lb 23x	1940.2	1621.9	2413.3	1435.3	1266.1	1601.4
CO2e per hd per d, lb	3.4	2.5	3.4	2.8	2.4	2.9
Lactation						
DMI, lb	31.0	15.7	50.0	34.5	23.6	54.2
Days	177.0	177.0	177.0	182.0	182.0	182.0
CH_4						
CH_4 per lb DMI, g	11.3	17.7	8.4	7.6	9.9	5.4
CH_4 per hd per day, g	349.5	278.8	420.1	262.2	233.2	291.5
Total CH_4, lb	136.4	108.8	163.9	105.2	93.6	117.0
CO_2						
CO_2 per lb DMI, g	350.8	173.4	647.7	333.0	220.9	536.3
CO_2 per hd per day, g	19240.7	14919.7	26470.7	12311.8	10618.5	14005.6
Total CO_2, lb	7508.1	5821.9	10329.4	4940.0	4260.6	5619.6
Global warming potential						
CO_2e from CH_4, lb 4x	545.6	435.2	655.6	420.8	374.4	468.0
CO_2e from CH_4, lb 23x	3136.4	2502.3	3770.6	2419.3	2152.2	2689.9
CO2e per hd per d, lb	8.1	6.3	11.0	5.4	4.6	6.1

and ALT. Total CO_2 production was greater in ALT calves since they had greater DOF ($P = 0.02$)

Animal performance in the two systems had a profound effect on emissions. Calves in the ALT system were 99 lb lighter at weaning. This weight difference was maintained through the end of the finishing phase, requiring calves from the ALT to be fed 35 days longer to achieve similar weight and backfat. Total production of CO_2e from the CONV system was greater (15,795 ± 2522 vs 12,758 ± 1715 lb CO_2e from CO_2 and CH_4 for CONV and ALT, respectively) and production per unit of beef produced (22.9 ± 3.5 and 19.1 ± 2.6 lb CO2e per lb HCW). Controlling intake by delivering harvested feed when cows were in drylot resulted in less over all CH_4 and CO_2 across the entire production system even though ALT calves were fed an additional 35 days to reach market weight.

While DMI is reported, values for DMI during open-air measurements of grazing cattle were not directly measured. Intake was predicted in these scenarios based on observed emissions and a GHG emissions model. Feed intake during all drylot scenarios was measured.

Carbon Balance

Cows in the CONV system grazed smooth bromegrass for, on average, 179 days with 3 acres per cow-calf pair. Cows in the ALT system grazed oat forage for 85 days with 2.6 acres per cow-calf pair. The carbon sequestered during these two periods was compared to all emissions from

Table 5. Production of CH4 and CO2 in pasture-based (CONV) or partial-confinement (ALT) production systems during growing and finishing phases.

	CONV			ALT		
Growing	Mean	Lower	Upper	Mean	Lower	Upper
DMI, lb	19.6	19.1	20.2	19.1	18.4	19.7
Days	183.0	183.0	183.0	183.0	183.0	183.0
CH4						
CH_4 per lb DMI, g	7.3	6.6	8.0	7.1	6.8	7.0
CH_4 per hd per day, g	121.8	109.7	134.1	122.9	107.0	138.7
Total CH_4, lb	36.8	33.4	40.2	35.0	32.4	37.6
CO_2						
CO_2 per lb DMI, g	297.8	262.6	331.0	271.9	246.6	297.2
CO_2 per hd per day, g	4948.0	4430.0	5466.0	4713.0	3893.0	5534.0
Total CO_2, lb	1498.0	1328.5	1668.0	1330.0	1213.9	1382.5
Global warming potential						
CO_2e from CH_4, lb 4x CO2	147.2	133.4	160.9	140.0	129.5	150.6
CO_2e from CH_4, lb 23x CO2	846.2	767.2	925.4	805.0	744.5	865.7
CO2e per hd per d, lb	1.6	1.5	1.8	1.5	1.3	1.5
CO_2e per lb HCW	5.1	4.6	5.7	4.8	4.4	5.1
Finishing						
DMI, lb	23.3	22.3	24.3	23.8	23.1	24.5
Days	148.0	148.0	148.0	183.0	183.0	183.0
CH4						
CH_4 per lb DMI, g	5.3	4.6	6.1	6.1	4.5	7.7
CH_4 per hd per day, g	125.0	105.0	145.0	145.2	104.7	185.7
Total CH_4, lb	40.6	35.7	45.3	59.5	39.5	79.6
CO_2						
CO_2 per lb DMI, g	325.2	297.1	353.2	300.3	242.1	358.4
CO_2 per hd per day, g	7551.0	7151.0	7953.0	7111.0	5892.0	8330.0
Total CO_2, lb	2485.0	2213.4	2740.3	2852.0	2376.6	3336.3
Global warming potential						
CO_2e from CH_4, lb 4x CO2	162.4	142.7	181.4	238.0	157.9	318.3
CO_2e from CH_4, lb 23x CO2	933.8	820.3	1042.9	1368.5	907.6	1830.5
CO2e per hd per d, lb	2.6	2.4	2.9	3.1	2.5	3.7
CO_2e per lb HCW	8.2	7.3	9.1	10.2	8.4	12.1
HCW per cow exposed, lb	707.7	707.7	707.7	668.4	668.4	668.4

gestation, lactation, growing and finishing phases (Table 6). Carbon sequestration during bromegrass pasture and oat cover crop was 2,524 and 1,228 lb C per acre per year or 7,523 and 3,255 lb C per cow for CONV and ALT, respectively. When considering GWP of CH_4 as 23 and N_2O as 298, total emissions from the CONV system were 7,388 and 6,295 lb CO_2e per cow for CONV and ALT respectively. This resulted in a balance of 135 and -3040 lb C for CONV and ALT, respectively. Using the traditional method of GHG accounting, the CONV system is C neutral and the ALT system is a source of emissions. When considering GWP of CH_4 as 4 and N_2O as 234, this changes the production, but carbon sequestration remains unchanged. The balance using these new values for GWP result in a balance of 2096 and -1,288 lb C per cow for CONV and ALT, respectively. This means the CONV system would sequester 138% of emissions from the entire production system. Sequestration from grazing oat forage sequestered 70% of all emissions from the ALT system. This was reduced to 103 and 52% for CONV and ALT when using 23 and 298 for GWP of CH_4 and N_2O, respectively. The positive carbon balance in the CONV system can likely be attributed to increases in soil carbon and root growth.

Conclusion

The partial-confinement system resulted in less over all emissions of CO_2 and CH_4. Calves from this system were smaller at weaning and required more days on feed to achieve market weight. The pasture-based production system produced more emissions of CO_2 and CH_4 but more carbon was sequestered from the annual forages grazed in that system. Cows from this system were either carbon neutral or a carbon sink depending on the GHG accounting metrics

Table 6 Carbon balance of pasture based (CONV) or partial confinement (ALT) beef production system from emissions and carbon sequestration

Net CO_2e after C sequestration[1]	CONV			ALT		
	Mean	Lower	Upper	Mean	Lower	Upper
Emissions, lb per lb HCW						
CO_2	20.6	17.4	25.4	17.5	15.2	19.8
CH_4 (23x CO2)	9.7	8.1	11.5	9.0	7.6	10.5
CH_4 (4x CO_2)	1.7	1.4	2.0	1.6	1.3	1.8
Modeled N_2O emissions (298x CO_2)	8.0			8.0		
Modeled N_2O emissions (234x CO_2)	5.8			5.8		
Total						
CO_2e per lb HCW (23x CO_2)	38.3	33.4	44.9	34.5	30.8	38.2
CO_2e per lb HCW (4x CO_2)	28.1	24.6	33.3	24.9	22.4	27.4
CH_4 23x CO_2 and N_2O 298 x CO_2						
Production						
C per cow exposed lb	7388	6450	8671	6295	5610	6966
Sequestration						
C per cow exposed, lb	7523	6429	8616	3255	2241	4270
Balance						
C per cow exposed, lb	135	-21	-55	-3040	-3369	-2696
CH_4 4x CO_2 and N_2O 234 x CO_2						
Production						
C per cow exposed lb	5426	4747	6418	4544	4074	4998
Sequestration						
C per cow exposed, lb	7523	6429	8616	3255	2241	4270
Balance						
C per cow exposed, lb	2096	1682	2198	-1288	-1834	-728

used. Traditional research in beef production considers only emissions. The data for these grazing situations indicate that soil carbon uptake is greater than all emissions from beef production. Additional research is needed to measure carbon sequestration over multiple years, varying types of forages and stocking densities to determine how much carbon can be sequestered within the beef production system.

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