Effects of steam flaking on the carbon footprint of finishing beef cattle[1,2]

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INTRODUCTION

Grain processing has been used for many decades to improve the digestibility of feed grains fed to finishing beef cattle and to improve animal performance (Owens et al., 1997). The most common corn processing methods currently used by feedyards in the United States are dry rolling (DRC) and steam flaking (SFC; Samuelson et al., 2016). For many years, SFC has been the dominant form of grain processing in the Southern Great Plains and West, whereas DRC has dominated in the Corn Belt and Northern Great Plains. This has been primarily dictated by the price of natural gas (less expensive in the south) and corn (less expensive in the north), as well as the size of feedyards. However, the use of SFC has increased somewhat in the Northern Plains as natural gas prices have declined. Macken (2006) noted that SFC generates economic returns in both small and large feedlots.

The increased use of wet distiller's grains with solubles (WDGS) in finishing diets has resulted in a decrease in the amount of corn included in finishing diets. Today beef cattle finishing diets in the United States contain between 60% and 95% grain (mean = 78.2%) and between 15 and 25% WDGS (Samuelson et al., 2016) on a dry matter (DM) basis.

There is minimal research looking at the effects of grain processing on environmental issues facing the cattle industry. Therefore, we used published data to estimate the effects of SFC on the carbon footprint (C footprint) of finishing beef cattle fed diets with and without 20% WDGS.

MATERIALS AND METHODS

No animals were used in the research and, therefore, no Institutional Animal Care and Use Committee approvals were required. The calculated C footprint for feeding beef cattle included the following carbon dioxide equivalent (CO_{2e}) sources: enteric methane (CH_4), manure CH_4 and nitrous oxide (N_2O); indirect N_2O, production of feed crops; processing of grain; and transport of feed and manure. The C footprints of feedlot equipment, facilities, etc. were not included in the analysis. Animal respiratory CO_2 emissions and net emissions of soil C from manure application were assumed to be 0 because animal respiration CO_{2e} is not a net source of greenhouse gases (Beauchemin et al., 2010).

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Results from two performance studies (Corrigan et al., 2009; Buttrey et al., 2012) and two energy metabolism studies (Hales et al., 2012, 2013) were the basis for the values and assumptions used in the C-footprint analysis (Tables 1 and 2). To simplify the C-footprint analysis, we used standardized finishing diets containing DRC or SFC and 0% or 20% WDGS similar to Buttrey et al. (2012) and Corrigan et al. (2009; Table 2). The 20% inclusion rate for WDGS was used because it is the most common concentration used in U.S. finishing diets (Samuelson et al., 2016).

Greenhouse gas emissions were converted to a constant CO_{2e} assuming the global warming potential (GWP) of CH_4 to be 25 × CO_2 and of N_2O to be 298 × CO_2 (IPCC, 2019). The GWP of natural gas used to flake corn was assumed to be 25 × CO_2.

Animal performance, digestion, and emissions data set

The assumed performance, digestion, and methane and reactive N emissions of cattle fed the standardized finishing diets were based on the studies of Buttrey et al. (2012), Corrigan et al. (2009), and Hales et al. (2012; 2013). The following is a brief summary and the assumed values are given in Table 2.

1) Average daily gain (ADG) was not affected by flaking; 2) gain:feed (G:F) was increased 10% by flaking; 3) dry matter intake (DMI) was decreased 8.5% by flaking; 4) dressing percentage was not affected by flaking; 5) SFC decreased daily enteric CH_4 production (L/d) by 26% and Mcal of CH_4/Mcal gross energy intake (GEI; Ym) by 23%; 6) SFC increased energy digestibility by 4 % and N digestibility by 9%; and 7) SFC decreased manure volatile solids (VS) excretion by 35–50% and decreased starch in manure by 20–80%.

Compared to 0% WDGS, feeding 20% WDGS did the following: 1) increased ADG by 4% in DRC- and 2% in SFC-based diets; 2) increased G:F by 4.5% in DRC- and 2% in SFC-based diets; 3) did not affect DMI, dressing percentage, or energy digestibility; 4) did not affect enteric CH_4 production per kilogram of DMI when diets were balanced for fat content; and 5) increased N digestibility by 10%.

Table 1. Characteristics of the two studies (Corrigan et al., 2009 and Buttrey et al., 2012) used in the carbon-footprint analysis

Item	Corrigan et al. (2009)	Buttrey et al. 2012	Average
Total animals	160	264	—
Pens (animals)/treatment	4 (40)	6 (66)	—
Gender	Steers	Heifers	—
Breed	Angus	Crossbred	—
Initial implant	Synovex-S[a]	Revalor-H[a]	—
Second implant	Synovex-Choice[b]	None	—
Initial BW, kg	318	354	336
Final BW, kg	600	539	570
Days on feed	168	154	161
Diet composition[b]			
Corn, % DM basis	60 or 72.5	61 or 76	—
Alfalfa, % DM	7.5	10	—
Urea, % DM	0.5 or 1.36	1.2	—
WDGS, % DM	0 or 15	0 or 20	—
Composition of WDGS, % DM basis			
DM	34.1	33.9	—
Crude protein	30.9	28.8	—
Ether extract	12.2	12.3	—
Diet crude protein, % DM	14.1 or 15.1	14.0 or 16.0	—
Animal performance			—
DMI, kg/d	9.65	9.45	9.55
Daily gain, kg	1.68	1.21	1.45
Gain:feed, kg/kg	0.175	0.128	0.152
Dressing percentage	63.1	64.5	63.8

[a]Synovex-S contained 20 mg estradiol and 200 mg progesterone and Synovex-choice contained 14 mg estradiol and 100 mg trenbolone acetate (TBA; Zoetis, Inc., Kalamazoo, MI); Revalor-H contained 14 mg estradiol and 140 mg TBA and Revalor-IS contained 16 mg estradiol and 80 mg TBA (Merck Animal Health, Rahway, NJ).

[b]Diets contained Monensin and Tylan (Elanco Animal Health, Indianapolis, IN).

Table 2. Standardized diets and assumed animal performance estimated from the studies of Buttrey et al (2012), Corrigan et al. (2009), and Hales et al. (2012, 2013) used in the carbon-footprint analysis (% DM basis)

Item	DRC-0[a]	SFC-0	DRC-20	SFC-20
Ingredients				
Corn	79.25	79.25	66.75	66.75
Corn silage	9	9	9	9
Soybean meal	5	5	0	0
Urea	1.2	1.2	0.6	0.6
WDGS	0	0	20	20
Nutrient content[b]				
Crude protein	13	13	15	15
DM	82.8	77.7	71.4	67.1
ME, mcal/kg	2.91	3.17	2.99	3.22
Density, g/L	723	510	776	596
Animal performance				
Init. BW, kg	336	336	336	336
Final BW, kg	564	567	572	572
Dressing percentage	64.0	63.7	63.9	63.7
ADG, kg	1.415	1.430	1.470	1.465
DMI, kg	9.95	9.12	9.96	9.18
Gain:feed	0.142	0.157	0.147	0.159
Days fed	161	161	161	161
CH_4, % of GEI (Ym)	3.04	2.47	2.93	2.46
CH_4, L/kg DMI	13.70	11.28	13.42	11.42
N intake, kg	35.9	33.0	38.4	35.5
N retained, kg	4.22	4.25	4.30	4.31
N excreted, kg	31.69	28.75	34.08	31.18
Ammonia-N, kg	17.96	16.50	19.19	17.75
OM digestion, %	71.25	74.15	69.60	72.50
Manure, kg DM/animal	435	290	470	345

[a]DR-0 = DRC-based diet containing 0% WDGS; SFC-0 = SFC-based diet containing 0% WDGS; DRC-20 = DRC-based diet containing 20% WDGS; SFC-20 = SFC-based diet containing 20% WDGS.

Manure methane and nitrous oxide emissions

Manure CH_4 production was determined from VS excretion using the methods of IPCC (2019) in which CH_4 production = VS excretion × the maximum potential CH_4 emission (Bo) × the CH_4 conversion factor (MCF). Volatile solids excretion was estimated from DMI and organic matter (OM) digestion assuming the diet contained 95% OM. We assumed drylot conditions and a temperate environment: thus, a Bo of 0.19 m^3/kg VS and an MCF of 1.5% was used (IPCC 2019).

Nitrogen excreted was calculated as N intake minus N retention calculated from ADG and BW (Owens et al 1997). Manure direct N_2O emissions were assumed to be 2% of N excreted (IPCC, 2019). Indirect N_2O emissions were estimated assuming 50% of fed N was lost as ammonia (Todd et al., 2008) and that 1% of the ammonia-N was subsequently lost as N_2O (IPCC 2019).

Carbon Costs to Process Corn

To calculate the carbon costs of grain processing, we assumed the following: 1) SFC uses 26.3 kL of natural gas and 17.5 kwh of electricity/1,000 kg of corn DM; and 2) DRC uses 3 kwh of electricity/1,000 kg of corn DM (17% of SFC). These are based on the values of Brown et al. (2000) and Reinhardt et al (1997) using small experimental research flakers and unpublished results from a commercial feedyard (Kendall Karr, personal communication). The C footprint of electrical generation was assumed to be the national average of 0.823 kg CO_{2e}/kWh (Adom et al., 2012).

Carbon Costs to Grow Feed Crops

The following C footprints of crop production (kg CO_{2e}/1,000 kg DM) reported by Adom et al. (2012) were used: 1) for corn grain—390 kg; 2) for corn silage—200 kg; 3) for soybean meal and miscellaneous ingredients—460 kg; and 4) for dried distillers grains with solubles (DDGS)—910 kg. We assumed that the CO_{2e} emissions of WDGS were 27% less (660 kg) than DDGS (Bremer et al., 2011).

Transportation of Feed and Manure

The C footprints of transporting feed grains to the feedyard, to feed cattle within the feedyard, and to collect and transport manure to fields for fertilization were calculated assuming a constant energy cost of 146.9 kg CO_{2e}/t-km (Hunerberg et al., 2014). It was assumed that all feeds were transported an average of 200 km to the feedyard and that manure was hauled an average of 20 km. The quantity of manure collected and transported to fields was estimated from the values of Buttrey et al. (2012) who noted that feeding SFC-based diets decreased manure DM per animal by 28% and feeding 20% WDGS diets increased total manure DM per animal by 15% compared to 0% WDGS diets.

RESULTS AND DISCUSSION

Overall Average C Footprint

On average, total CO_{2e} emissions were 1,294 kg/animal over a 161-d feeding period (Table 3). This is somewhat less than emissions reported by Stackhouse-Lawson et al. (2012: 1,593 kg CO_{2e}) and Heflin et al. (2019: 1,799 kg CO_{2e}) but greater than Rotz et al. (2015: 1,080 kg CO_{2e}). Multiple studies report that feedlot emissions represent 8–12% of the total North American beef cattle C footprint (Beauchemin et al., 2010; Stackhouse-Lawson et al., 2012).

Total CO_{2e} emissions per kilogram of final BW, per kilogram of hot carcass weight (HCW), and per kilogram of BW gain averaged 2.28, 3.56, and

Table 3. Carbon footprint (kg CO_{2e}/animal for 161-d feeding period) of finishing diets that vary in grain processing and WDGS content

Item	DRC-0[a]	SFC-0	DRC-20	SFC-20	Average
Animal and manure					
Enteric CH_4	395.2	299.3	386.1	303.8	346.1
Manure N_2O	188.9	171.4	203.1	185.8	187.3
Manure CH_4	26.0	21.5	27.4	22.9	24.5
Indirect N_2O	26.8	24.6	28.6	26.4	26.6
Crop production					
Corn	495.5	455.3	416.3	385.0	438.0
Corn silage	28.9	26.5	28.8	26.6	27.7
Soybean meal	36.9	33.9	0	0	17.7
WDGS	0	0	184.7	170.8	88.9
Other ingredients	49.8	45.7	49.6	45.9	47.8
Transport					
Feed	54.5	52.6	65.3	63.3	58.9
Manure	2.0	1.3	2.1	1.6	1.8
Grain processing energy					
Natural gas	0	35.0	0	29.6	16.2
Electricity	5.8	21.0	4.9	17.6	12.3
Total CO_{2e}	1,310.2	1,188.0	1,397.0	1,279.4	1,293.6
kg CO_{2e}/kg BW	2.32	2.10	2.44	2.24	2.28
kg CO_{2e}/kg HCW	3.63	3.29	3.82	3.51	3.56
kg CO_{2e}/kg BW gain	5.75	5.14	5.92	5.42	5.56
Summary, % of total CO_{2e}					
Enteric	30.2	25.2	27.6	23.8	26.7
Manure	18.4	18.3	18.6	18.4	18.4
Feed production	46.6	47.3	48.6	49.1	47.9
Transport	4.3	4.5	4.8	5.1	4.7
Grain processing	0.4	4.7	0.4	3.7	2.3
Reactive N					
kg/animal	18.4	16.9	19.7	18.2	18.3
g/kg HCW	51.0	46.8	53.8	50.0	50.4

[a]DR-0 = DRC-based diet containing 0% WDGS; SFC-0 = SFC-based diet containing 0% WDGS; DRC-20 = DRC-based diet containing 20% WDGS; SFC-20 = SFC-based diet containing 20% WDGS.

5.56 kg, respectively (Table 3), which are within the range of values reported by Stackhouse-Lawson et al. (2012), Rotz et al. (2015), Hunerberg et al. (2014), Beauchemin et al. (2010), Stanley et al. (2018), and Heflin et al. (2019).

Enteric CH_4 accounted for 346 kg or 26.7% of total emissions. These quantities are similar to Stackhouse-Lawson et al. (2012), Rotz et al. (2015), and Heflin et al. (2019) but less than Stanley et al. (2018). These differences are primarily attributable to the assumed Ym used in the calculations and to the length of the feeding period.

Direct and indirect N_2O emissions were 214 kg or 16.5% of total emissions with the vast majority from direct manure emissions. The actual emissions are similar to Rotz et al. (2015; 268 kg CO_{2e}) but less than Stackhouse-Lawson et al. (2012; 563 kg), and Stanley et al. (2018; 733 kg). Manure CH_4 emissions were approximately 24.5 kg or 1.9% of total CO_{2e} emissions.

Feed production accounted for 620 kg or 47.9% of total CO_{2e} emissions. This is somewhat less than emissions of Stackhouse-Lawson et al. (2012; 697–729 kg and 56% of total) but greater than reported by Stanley et al. (2018; 37%).

Transport of feed and manure was only about 60.7 kg of CO_{2e} or 4.8% of the total C footprint. Fossil fuel use for grain processing averaged 47.2 kg CO_{2e}/animal or 2.6% of the total C footprint. This agrees with other studies that also reported that transportation and on-farm energy use were small contributors to the overall C footprint of feedyards.

Total reactive N emissions averaged 18.3 kg/animal or 50.4 g/kg HCW (Table 3), with over 97% being from ammonia-N. This is somewhat greater than emissions of Rotz et al. (2015; 37.9 g/kg HCW) but within the range of ammonia-N emissions reported by Stackhouse-Lawson et al. (2012; 17.9–30.2 kg/animal and 43–73 g/kg HCW).

Effects of Grain Processing on the C Footprint

Steam flaking decreased enteric and manure CH_4 emissions compared to DRC-based diets (Table 3). The decrease in enteric CH_4 was due to a lower DMI and Ym for SFC-based diets. Enteric CH_4, as a proportion of total CO_{2e} emissions, was also less in SFC- than DRC-based diets. The lower manure CH_4 of SFC-based diets was due to less OM excretion and greater OM digestibility in SFC- than DRC-based diets. In reality, the difference in manure CH_4 might be greater than we report because the IPCC (2019) assumes that the Bo and MCF of manures are the same for all VS and does not partition manure VS by fermentability (starch vs. fiber). Buttrey et al. (2012) noted that the energy content of manure of heifers fed DRC-based diets was 44% greater than manure of heifers fed SFC-based diets.

Steam flaking also decreased the quantity of indirect and direct manure N_2O emissions (Table 3) due, in part, to a lower DM and N intake. However, N_2O emissions as a percentage of total CO_{2e} emissions were not affected by grain processing (Table 3). Steam flaking also decreased the CO_{2e} of crop production, primarily because less feed and corn DM was required over the feeding period than when DRC-based diets were fed. The total hectares of cropland required to grow the corn (including for WDGS) and silage, assuming corn yield of 10.76 Mg/ha (160 bu/acre) and corn silage yield of 44.83 Mg/ha (20 wet tons/ac), to feed 100 cattle were 6.6, 6.1, 9.7, and 8.9 for DRC-0, SFC-0, DRC-20, and SFC-20 diets, respectively. Feeding SFC decreased land needed by 8–9% and feeding WDGS increased land needed by about 47%. However, if all land needed to grow corn for WDGS is allocated to ethanol, the land required to feed 100 cattle is decreased by about 17% (to 5.7 and 5.0 ha for DRC-20 and SFC-20, respectively).

Steam flaking had small effects on transport emissions (Table 3). As expected, natural gas and electrical energy CO_{2e} emissions were greater for SFC- than DRC-based diets (Table 3); however, grain processing comprised a small proportion (0.4–4.6%) of total CO_{2e} emissions.

Total CO_{2e} emissions were approximately 10% less for SFC- than DRC-based diets. Because grain processing did not affect ADG or dressing percentage, CO_{2e} emissions per kilogram of final BW, per kilogram HCW, and per kilogram BW gain were also about 10% less for SFC- than DRC-based diets. Total reactive N emissions were about 8.5% less for SFC- than DRC-based diets (Table 3).

IMPLICATIONS

We used an empirical model to estimate the effects of grain processing (dry-rolled corn vs. steam-flaked corn) on the carbon footprint of cattle feeding. Although SFC required more fossil fuel than DRC, feeding steam-flaked corn improved corn utilization and, thus, decreased the total carbon footprint by 9–13% per steer, which is similar to the use of other growth promoting technologies.

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