Evaluation of net protein contribution, methane production, and net returns from beef production as duration of confinement increases in the cow–calf sector¹

Jessica R. Baber, Jason E. Sawyer,² and Tryon A. Wickersham^{2,3}

Department of Animal Science, Texas A&M University, College Station, TX 77843

ABSTRACT: Intensification of cow–calf production may provide a sustainable solution for meeting increasing beef demand in the face of diminishing resources. However, intensification with its greater reliance on cereal grains potentially decreases the upcycling of human-inedible protein into beef. A previously described model was used to evaluate cow–calf intensification on beef's ability to meet human protein requirements. Four scenarios were compared, based on a 1,000 cow herd: 1) Conventional cow–calf production system (0CON), 2) cows limit-fed in confinement for 4 mo after weaning (4CON), 3) cows limit-fed in confinement for 8 mo after breeding (8CON), or 4) cows limit-fed in confinement year-round (12CON). Changes were not made to either the stocker or feedlot segments of the beef value chain. Net protein contribution (NPC) was calculated by multiplying the ratio of human-edible protein (HeP) in beef produced to HeP in feed by the protein quality ratio. A NPC >1 indicates that the production system is positively contributing to meeting human requirements, whereas a NPC <1 indicates the sector or value chain is competing with humans for HeP. Methane was estimated based on proportion of forage in diet and total methane production was reported per

kg HeP. In the cow–calf sector, HeP conversion efficiency (HePCE) decreased from 2,640.83 to 0.37 while methane production decreased from 4.53 to 1.82 kg/kg HeP produced as the length of intensification increased from 0CON to 12CON. Decreased HePCE resulted in NPC values for cow–calf sector of 8,036.80, 4.93, 2.19, and 1.28 for 0CON, 4CON, 8CON, and 12CON, respectively. Protein quality ratio of the entire beef value chain increased from 3.15 to 3.33, while HePCE decreased from 0.99 to 0.39 as length of intensification increased from 0CON to 12CON. For the beef value chain, NPC was 3.11, 2.30, 1.73, and 1.31 for 0CON, 4CON, 8CON, and 12CON, respectively. Across the value chain, confinement of cows for 12 mo decreased enteric methane from 3.05 to 1.53 kg/kg HeP (0CON and 12CON, respectively). Additionally, profitability of the cow–calf operation decreased from \$249.34 to \$102.16 per cow as intensification increased. Of confinement scenarios, probability of loss to an operation was least (4%) for 4CON. Feed costs increased by \$260.79 per cow for 0CON when drought conditions existed (0COND). Total methane production was reduced by intensification and none of the scenarios evaluated competed with humans for HeP.

Key words: cow–calf, human-edible protein, intensification, methane, net protein contribution

© The Author(s) 2019. Published by Oxford University Press on behalf of the American Society of Animal Science. All rights reserved. For permissions, please e-mail: journals.permissions@oup.com.

J. Anim. Sci. 2019.97:2675–2686

doi: 10.1093/jas/skz145

¹The Beef Checkoff

²Corresponding author: tryon@tamu.edu

Received October 1, 2018.

Accepted April 25, 2019.

INTRODUCTION

Intensification of cow–calf production can involve providing a limited amount of an energy-dense diet to cows in drylots for either a portion

of the year or year-round. During periods of limited forage availability (i.e., drought), confinement can be a particularly useful tool as nutrient requirements are met without damaging future forage production and preventing partial or complete herd liquidation. Drought can result in substantial economic loss to ranchers because of increased feed and supplementation costs (Eakin and Conley, 2002) and/or decreased revenues (Ziolkowska, 2016). Additionally, sustainable intensification can help meet the increasing demand for animal protein without increasing land requirements for cow–calf production (Sawyer and Wickersham, 2013).

Upcycling of human-inedible feed protein into high-quality beef potentially decreases with intensification as dependence on human-edible feedstuffs tends to increase when cattle are fed in confinement. Intensified production (i.e., feedlots) had lower human-edible protein conversion efficiency (HePCE) when compared to extensive grazing settings (i.e., conventional cow–calf production), but methane production decreased when cattle were moved from an extensive to intensive production system (Baber et al., 2018; Wilkinson and Lee, 2018). Utilization of byproducts and other less expensive, human-inedible feeds in limit-fed, high-energy diets in intensive systems can mitigate the tradeoff between HePCE and methane production while creating a more economically sustainable operation. When more dried distillers' grains (DDG) were fed in feedlots, HePCE increased (Flachowsky et al., 2017; Baber et al., 2018); a similar effect was observed when evaluating coproduct usage in dairy production systems (Ertl et al., 2015).

Thus, our objective was to evaluate tradeoffs between human-edible protein (HeP) consumed and methane produced in the cow–calf sector and the beef value chain as length of confinement increases in cow–calf systems. Additionally, an economic analysis was conducted to compare intensified cow–calf systems to conventional pasture-based grazing during periods of adequate or limited forage availability.

MATERIALS AND METHODS

Model Overview

Our summative model of net protein contribution (NPC) incorporated common production practices in the United States and prediction equations established by National Academies of Sciences, Engineering, and Medicine (NASEM, 2016). Calves from the cow–calf sector flowed

into the stocker sector and calves from the stocker sector flowed into the feedlot sector. Therefore, the cow–calf sector was representative of an entire production year, and the stocker and feedlot sectors were representative of the time the calves occupied those facilities. Production parameters were consistent with common beef cattle practices combined with the systems approach of Peters et al. (2014). Additionally, we used methodology presented by Wilkinson (2011), Ertl et al. (2015, 2016a,b), and Baber et al. (2018) to estimate the NPC to the human food supply from various beef cattle production scenarios in the United States. Human-edible protein conversion efficiency, digestible indispensable amino acid score (DIAAS), protein quality ratio (PQR), and NPC were estimated for each sector and the entire system according to methods described in Baber et al. (2018). Protein quality ratio is calculated by dividing the DIAAS of HeP produced by the DIAAS of HeP fed to capture the change in protein quality resulting from the livestock feeding system.

To begin to balance environmental effects with societal benefits, total enteric methane production was reported relative to kg HeP produced. Summation of enteric methane production and HeP was used to calculate enteric methane per kg HeP for the entire beef cattle value chain (Baber et al., 2018). Enteric methane production was based on diet consumed and proportion of forage and was calculated according to equations from NASEM (2016). Equations presented in NASEM (2016) within each category (3 categories based on percent forage of diet) were averaged according percent of forage in the diet. Equivalents of CO₂ were calculated as methane (kg) multiplied by 25 (IPCC, 2007).

Scenario Design

Four management scenarios were compared to determine the effect of increasing intensification of cow–calf production on NPC of beef cattle. Scenarios were based on a 1,000 cow herd. Management scenarios considered were: 1) cow–calf production sector grazed pasture continuously for the production year (0CON), 2) cows were confined in drylots and limit-fed from time of weaning until 30 d prior to calving (approximately 120 d; 4CON), 3) cows were confined in drylots and limit-fed from the day of weaning until breeding (approximately 240 d; 8CON), and 4) cows were confined in drylots and limit-fed for the entire production year (12CON). When cows were not limit-fed in drylots,

cows were grazing pasture and managed under conditions of 0CON. Management scenarios focused only on the cow–calf sector, with stocker and feedlot sectors held constant. Responses were analyzed for cow–calf sector and entire beef value chain.

Production System and Parameters

Three subsystems were considered in the beef value chain: cow–calf, stocker, and feedlot sector. Production parameters used in our model were described by Baber et al. (2018). A portion of the heifer calves were retained as replacement heifers, and the remainder along with steer calves were sent to either the stocker sector or feedlot sector. For all scenarios, the production parameters were held constant and all calves flowed into the stocker and feedlot sectors in a similar manner.

Diet Descriptions and Intakes

Cattle in the cow–calf sector either grazed Bermudagrass pasture (inedible to humans) and were supplemented with protein (dry distillers' grains; inedible to humans) or were placed in a drylot and limit-fed a high-energy ration (Table 1). Placing cattle in drylots allows producers to precisely deliver nutrients required by the animal. Pasture and supplement intakes for dry cows, lactating cows, bulls, replacement heifers, and calves were estimated

using the NASEM (2016). When cattle were confined, all cattle except replacement heifers were fed a ration consisting of wheat straw (36%; inedible), corn (29%; source of HeP), DDG (28%), and supplement (7%). Replacement heifers were fed a separate growing ration consisting primarily of alfalfa hay (26%; inedible), corn (40%), DDG (27%), and supplement (7%). The supplement included in the limit-fed diet and replacement heifer diet contained molasses which was considered a source of HeP.

Total energy requirement of each animal class, intake of each diet, and energy provided by those diets are presented in Table 2. Nursing calves were predicted to consume 1% of BW while in confinement for the 12CON scenario according to research conducted by Jenkins et al. (2015). Nursing calves were predicted to consume less feed DM and feed energy in confinement than on pasture; however, the consumption of milk was not accounted for in our DM or energy calculations. During confinement, dry cows and bulls were fed to meet 80% of NASEM (2016) predicted maintenance requirements (6.40 and 10.42 Mcal NE_m/d, respectively). Cows were limit-fed at 80% maintenance based on previous research demonstrating cows increase maintenance efficiency under these conditions (Freetly and Nienaber, 1998; Trubenbach et al., 2018). Lactating cows were fed to meet 80% of NASEM (2016) predicted maintenance requirements plus the energy to meet lactation requirements (10.41 Mcal NE_m/d).

Table 1. Ingredient and nutrient composition of diets fed in the cow–calf sector

Item	Diet ¹		
	GRASS	CON	CONH
Ingredients, % DM basis			
Alfalfa hay			25.59
Bermudagrass, fresh	94.08		
Wheat straw		35.63	
Corn	0.01	28.90	40.13
Distillers' grains	4.71	27.79	26.91
Urea		2.74	
Molasses		3.71	4.56
Mineral	1.20	1.23	2.81
Nutrient composition, %DM basis ²			
OM	91.43	94.97	94.52
CP	16.62	16.67	16.89
NDF	64.97	38.41	23.11
ME	2.09	2.55	2.70
NE _m , Mcal/kg	1.24	1.65	1.78
NE _g , Mcal/kg	0.67	1.04	1.16

¹GRASS = pasture-based system; CON = diet fed during confinement; CONH = diet fed to replacement heifers during confinement.

²Estimated using NASEM (2016).

Table 2. Dry matter and energy intake of animal classes in production sectors

	Total energy requirement ¹	Diet ²		
		GRASS	CON	CONH
Cow–calf sector intakes, kg DM/d				
Heifer calf		3.33	1.83	
Steer calf		3.47	1.92	
Replacement heifers		6.47		7.06
Bred heifers		8.43	8.40	
Dry cow		10.53	3.88	
Lactating cow		12.85	5.31	
Bull		18.54	6.32	
Cow–calf sector NE intake, Mcal/d				
Heifer calf	5.38	4.13	3.01	
Steer calf	5.46	4.30	3.16	
Replacement heifers	8.25	8.03		10.14
Bred heifers	10.72	10.44	10.72	
Dry cow	8.00	13.05	6.40	
Lactating cow	12.01	15.93	10.41	
Bull	13.02	22.98	10.42	

¹Predicted using NASEM (2016).

²GRASS = pasture-based system; CON = diet fed during confinement; CONH = diet fed to replacement heifers during confinement.

Bred heifers were fed to meet maintenance energy requirements plus energy requirements for 0.50 kg BW gain/d and pregnancy (10.72 Mcal NE_m/d). Dietary energy was not restricted for lactation or bred heifers because research is limited determining the effects of moderate energy restriction in confinement during these stages of production. For all scenarios with confinement, replacement heifers were developed on a stair-step nutrition program. When heifers reached approximately 300 d of age, they were limit-fed for 41 d at 1.7% BW, decreasing their maintenance requirement and then fed at a greater rate (3.0%) for the remainder of the 90-d period to capture the benefits from the increased metabolic efficiency (Stribling et al., 2018). For the 0CON, replacement heifers were developed on pasture and managed as all other cattle grazing pasture with 4.71% of DMI as a protein supplement (DDG).

Economic Analysis

An economic feasibility analysis was completed for each of the 4 management scenarios (0CON, 4CON, 8CON, and 12CON). In addition, a 5th scenario (0COND) was added to compare the grazing scenario during limited forage availability to the confinement options. Scenarios 4CON, 8CON, and 12CON require capital investment in a mixer wagon and bunks (\$6.20 per cow), but creates an alternative for the operation when limited forage is available for grazing. Extra costs for fencing, panels, and feed storage were not considered in this economic evaluation as confinement feeding can occur within an existing pasture or a small trap. Cows under the 0COND scenario were fed ad libitum Bermudagrass hay for 4 mo of the year, to model an operation under drought conditions.

A stochastic simulation model using empirical distributions of key input variables was used to estimate returns for a cow–calf operation that calves in the spring. Stochastic variables in the model included weaning weights, price of weaned steers and heifers, and input prices of feed ingredients. A budget for each system was developed to include these stochastic variables. Stochastic feed prices were linked to intake and days on feed to develop a total feed cost for each system. Costs for labor, fuel and repairs, as well as ration mixing and delivery were calculated from feed intakes and machinery capacity to reflect changes required by scenarios. Additionally, 4CON, 8CON, and 12CON had added fixed costs for a mixer wagon and concrete bunks needed to produce and deliver a total mixed ration (TMR). Bunks were accounted for using straight

line depreciation and a useful life of 10 yr with no salvage value. Straight line depreciation was used for the mixer wagon with a useful life of 15 yr and a \$2,000 salvage value. Other production costs in the model included mineral supplementation while cattle were on pasture, vet supplies, utilities, and livestock interest. Land costs were estimated from USDA-NASS (2018) where pasture rental rate was \$12/0.4 ha and each cow was allotted 4.05 ha.

Simulated probability distributions of net returns for each system for the 2018–2019 production year were used to determine which production system provided the least risk with greatest chance of profitability. Average net return for each system provides little information on the risk associated with each system. To choose, or to evaluate, the best option among risky alternatives, stochastic efficiency with respect to a negative exponential utility function (SERF) was used to rank these alternatives while accounting for differing levels of risk aversion of the decision maker (Hardaker et al., 2004; Ribera et al., 2004). This simulation was based on an annual enterprise budget; therefore, a negative exponential function was used instead of a power utility function. Certainty equivalence (CE) at differing levels of risk aversion can be used to determine the best alternative for individual producers, and the alternative with the greatest CE will be preferred over all others at a given risk aversion coefficient.

Production data from a Brangus cow herd with an average weight of 503 kg were used in this simulation. A previous experiment was conducted to determine the effects of limit-feeding on cow and calf performance (Baber et al., 2016). Weaning weights from Baber et al. (2016) were used to estimate parameters in an empirical distribution of weaning weight. A mean weaning weight of steers (261 kg) and heifers (215 kg) and the percent deviation from the mean of experimental data were used as parameters in the empirical distribution.

Monthly historical cash prices from 1995 to 2017 were obtained from Livestock Marketing Information Center (LMIC, 2018a,b) for corn, DDG, alfalfa hay, and other hay. Historical price data were used to estimate parameters for prices using multivariate empirical (MVE) distributions. To estimate a stochastic forecasted wheat straw price, the stochastic forecasted hay price was discounted based on a TDN adjustment factor (TDN value of wheat straw was considered to be 72% of the TDN value of Bermudagrass hay). Monthly historical prices were detrended using linear regression, and fractional deviations from trend were calculated from residuals then used to simulate

risk about the forecasted monthly mean prices for October 2018. Our model was developed to assume that all feed would be purchased at the start of the feeding period and feed would be delivered monthly in truck loads. Monthly historical price data for urea and molasses were also obtained from USDA reports (USDA-NASS, 2018). These prices were not included in MVE-simulated prices mentioned previously due to lack of data and of linear trend in the historical data ($P > 0.85$). Both urea and molasses price distributions were simulated empirically using historical 5-yr averages and fractional deviations from the average as the parameters.

Monthly historical prices from 1999 to 2017 were obtained from LMIC (2018c) for steers and heifers at auctions in Texas to estimate parameters for MVE distribution of prices. Steer and heifer prices were detrended using linear regression, and fractional deviations from trend were calculated from residuals then used to simulate risk about the forecasted mean prices for October of 2019, which is based on when calves would be weaned and sold. Multivariate empirical distributions were chosen for estimating ingredient prices and cattle prices to ensure that historical variability and price correlations were reflected in the stochastic forecast prices (Richardson et al., 2000).

RESULTS AND DISCUSSION

Protein quality was estimated using DIAAS (%) and assigned to each human-edible feed ingredient to estimate the suitability of diets fed to cattle for human consumption. As stated in FAO (2011), DIAAS represents the ability of a human-edible feedstuff to meet the protein requirements of a 0.5- to 3-yr-old child. Protein quality of the diet (DIAAS) for the cow-calf sector decreased from 36.81 to 32.47 as intensification increased from 0CON to 12CON (Table 3). The decrease in HeP quality in the limit-fed diet was driven by the inclusion of molasses, a poor source of amino acids with a DIAAS of 5.9. Corn, the sole source of HeP in 0CON, has a DIAAS of 36.81. In contrast to cattle diets, beef has a fixed DIAAS of 112, indicating the indispensable amino acid profile of beef is superior to reference protein used for children from 0.5 to 3 yr of old. Because the DIAAS of beef is fixed and DIAAS of diets decreased as intensification increased, the PQR of cow-calf sector increased from 3.04 (0CON) to 3.45 (12CON). Protein quality ratio for the beef value chain increased from 3.15 to 3.33 as intensification in the cow-calf sector increased from 0CON to 12CON. For the

entire value chain, PQR is calculated as a weighted average based on HeP consumption in each sector. Because HeP consumption in the cow-calf sector increased with increased duration of confinement, the cow-calf PQR exerted greater influence on the beef value chain's PQR. Protein quality is separate of consumption, and while consumption increases due to length of confinement

Incorporating intensification into management practices of cow-calf operations results in a decreased reliance on forage production (Sawyer and Wickersham, 2013). Although this is beneficial for operations when forage availability is limiting, intensification increased human-edible protein fed (HeP_f) from 11 to 81,202 kg for 0CON to 12CON for the 1,000 cow herd, respectively. While consumption of HeP increased with confinement length, it is important to note that the quality of HeP_f was reduced from inclusion of molasses (DIAAS of 5.9). The cow-calf sector consumed <0.1%, 28%, 47%, and 60% of the total HeP_f for the value chain for 0CON, 4CON, 8CON, and 12CON. When comparing the cow-calf sector to the feedlot sector, only 12CON consumed more HeP_f (81,202 kg) than the feedlot (53,125 kg). Consequently, the total HeP_f consumed by the beef value chain increased from 54,128 to 135,348 kg when intensification of the cow-calf sector increased from 0CON to 12CON. Total HeP_f represents total amount of HeP consumed by the 1,000 cow herd and all downstream HeP intake by calves produced from the cow herd. Although HeP_f increased, human-edible protein produced (HeP_p) remained constant for both the cow-calf sector and beef value chain (30,004 and 53,437 kg HeP_p, respectively) because gross beef production was not affected by strategy in this model.

Human-edible feed conversion efficiency (HePCE) is the ratio of HeP_p (numerator) to HeP_f (denominator). Because of an increasing denominator and constant numerator, HePCE decreased from 2,640.83 to 0.37 for cow-calf sector when intensification of the cow-calf sector increased from 0CON to 12CON. Both 0CON and 4CON (2,640.83 and 1.43, respectively) were above 1, indicating these scenarios were producing more HeP than they were consuming. Mottet et al. (2017) estimated a ratio of 2.00 for HePCE when 441 kg of concentrates (70% human-edible) were fed per cow, which is greater than our 1.43 estimate for 4CON where approximately 456 kg of concentrate was fed per cow, of which about 50% was human-edible. However, when intensification increased to 8CON and 12CON (0.64 and 0.37), HePCE for cow-calf sector decreased below 1. These 2 scenarios

Table 3. Effect of increasing duration of cow–calf confinement on key output variables of net protein contribution (NPC) from beef production

Item	Scenario ¹			
	0CON	4CON	8CON	12CON
Cow–calf				
Diet DIAAS ²	36.81	32.50	32.45	32.47
PQR ³	3.04	3.45	3.45	3.45
Total HeP _f , kg/herd ⁴	11	20,989	47,220	81,202
Total HeP _p , kg/herd ⁵	30,004	30,004	30,004	30,004
HePCE ⁶	2,640.83	1.43	0.64	0.37
NPC	8,036.80	4.93	2.19	1.28
Stocker				
Diet DIAAS	36.81	36.81	36.81	36.81
PQR	3.04	3.04	3.04	3.04
Total HeP _f , kg/herd	1,021	1,021	1,021	1,021
Total HeP _p , kg/herd	6,062	6,062	6,062	6,062
HePCE	5.94	5.94	5.94	5.94
NPC	18.07	18.07	18.07	18.07
Feedlot				
Diet DIAAS	35.51	35.51	35.51	35.51
PQR	3.15	3.15	3.15	3.15
Total HeP _f , kg/herd	53,125	53,125	53,125	53,125
Total HeP _p , kg/herd	18,105	18,105	18,105	18,105
HePCE	0.34	0.34	0.34	0.34
NPC	1.07	1.07	1.07	1.07
Beef value chain				
PQR	3.15	3.23	3.29	3.33
HeP _f , kg/herd	54,128	75,135	101,366	135,348
HeP _p , kg/herd	53,437	53,437	53,437	53,437
HePCE	0.99	0.71	0.53	0.39
NPC	3.11	2.30	1.73	1.31

¹0CON = conventional pasture grazing system for cow–calf sector; 4CON = cow–calf sector limit-fed in confinement for 4 mo; 8CON = cow–calf sector limit-fed in confinement for 8 mo; 12CON = cow–calf sector limit-fed in confinement for 12 mo.

²DIAAS = digestible indispensable amino acid score.

³PQR = protein quality ratio.

⁴HeP_f = human-edible protein fed.

⁵HeP_p = human-edible protein produced.

⁶HePCE = human-edible protein conversion efficiency.

consumed more HeP than the cow–calf sector produced. Flachowsky *et al.* (2017) reported the beef production system had a HePCE ranging from 0.70 (0% coproduct inclusion in concentrate) to 1.3 (50% coproducts). Diets fed during intensified production of the cow–calf sector in our model contained approximately 30% coproducts (human-inedible) and 30% corn (human-edible), whereas Flachowsky *et al.* (2017) assumed a 15% concentrate inclusion in the diet. Total confinement (12CON) of the cow–calf production system resulted in a HePCE similar to a common feedlot in the United States (0.34).

The HePCE of the entire beef value chain decreased from 0.99 to 0.39 when intensification of the cow–calf sector increased from 0CON to 12CON. For the value chain, all scenarios consumed more

HeP than was produced. A greater HePCE for the beef value chain than the cow–calf sector in 12CON was due to the contributions of the stocker sector, which had a HePCE of 5.94. For all other scenarios, HePCE was greater for the cow–calf sector compared to the beef value chain. According to Wilkinson (2011), cereal beef production in the United Kingdom was similar (0.33) to 12CON in our model, whereas lowland-suckler beef production was more similar (0.50) to the 8CON scenario.

Although HePCE was below 1 for scenarios 8CON and 12CON, all scenarios in the cow–calf sector positively contributed to meeting human protein requirements (i.e., NPC > 1) by improving protein quality. For the cow–calf sector, NPC was greatest when cattle were grazing pasture

continuously (8,036.80; 0CON), and NPC decreased to 1.28 (12CON) as intensification increased; importantly, this value remained above 1. Ertl et al. (2016b) reported that cattle production in Austria had an NPC value of 2.81, intermediate to the scenarios in our model. The 12CON scenario had a similar NPC to that of a United States feedlot (1.07), but was greater than growing-fattening bull production systems (0.73) in Austria (Ertl et al., 2016b).

Furthermore, the entire beef value chain positively contributed to meeting human protein requirements. Net protein contribution for the entire value chain ranged from 3.11 (0CON) to 1.31 (12CON) with approximately a 0.4 decrease for every additional 4 mo that cows spent in confined feeding systems. Overall, protein quality was greater in the beef produced than the diets fed offsetting the reductions in HePCE observed as duration of confinement increased. Although not explored in this study, it is possible to maintain a cow herd on a diet consisting of only human-inedible ingredients during confinement which would improve the HePCE and NPC values reported.

Enteric Methane Production

Enteric methane production from the cow–calf sector is a major contributor to total methane production from the beef value chain. Estimates of methane production from the cow–calf sector have ranged from 69% to 81% of total methane produced from the beef value chain (Beauchemin et al., 2010; Stackhouse-Lawson et al., 2012; Baber et al., 2018). In our model, if cattle continuously grazed pastureland, 82% of total enteric methane produced by the value chain was derived from the cow–calf sector. As intensification was incorporated into cow–calf management strategies, enteric methane production decreased to 66% (12CON; Table 4) of the total. When estimating enteric methane production, the NASEM (2016) equations utilize intake level as well as diet composition (percentage of forage, fat, starch, etc). Johnson and Johnson (1995) listed diet type and level of intake as 2 of the main factors that influence enteric methane production. Main differences between 0CON and our limit-fed systems that resulted in enteric methane reductions were decreases in forage percentage consumed in the diet and in reductions in total DMI.

To balance environmental costs and societal benefit of beef production, enteric methane was estimated relative to HeP production. Intensification of the cow–calf sector decreased methane production from 4.53 kg enteric methane per kg HeP_p

(0CON) to 1.82 kg (12CON). Converting a pasture-based operation (0CON) into a partially confined system (4CON) resulted in a 16% decrease of enteric methane. Further confinement for 8 and 12 mo resulted in 32% and 48% enteric methane reductions for the cow–calf sector compared to 0CON. When cattle were placed in the 12CON scenario, the cow–calf sector produced less enteric methane than 1.89 kg of enteric methane per kg HeP_p for stocker sector. Ultimately, reduction in enteric methane production by the cow–calf sector while the other 2 sectors remained constant, reduced enteric methane by the beef value chain by 47%. Enteric methane production decreased from 3.05 to 1.53 kg per kg of HeP_p (0CON and 12CON, respectively) for the entire value chain.

Capper (2012) evaluated grass-fed systems and estimated that 4.52 kg of enteric methane was produced per kg HeP_p. Additionally, Pelletier et al. (2010) estimated grass-fed systems in the upper Midwest of the United States and reported that 3.84 kg enteric methane was produced per kg HeP_p. As expected, results by both authors (Pelletier et al., 2010; Capper, 2012) were greater than our scenarios because cattle were finished in grass-fed systems. Capper (2011) estimated that 2.76 kg of enteric methane was produced per kg HeP_p for the beef value chain, intermediate of our scenarios 0CON (3.05 kg) and 4CON (2.32 kg). In the European Union, enteric methane from beef production was approximately 2.09 kg per kg HeP_p (Nguyen et al., 2010), which was more similar to our 4CON and 8CON scenarios. Lower methane emissions observed by Nguyen et al. (2010) in the European Union was likely because of the amount of barley and soy meal fed resulting in that system being comparable to our intensified scenarios. In agreement with our results, Peters et al. (2010) concluded a more intensive (feedlot-fed) production system results in lower greenhouse gas emissions (approximate reduction of 0.42 kg enteric methane per kg HeP_p).

Economic Analysis

Deterministic results. Average gross revenues for scenarios were \$761.60 per cow (Table 5). Gross revenues were slightly greater for 0CON and 0COND than the confined scenarios because weaning weights were not equally distributed around the mean in a study examining the effects of confinement (Baber et al., 2016). Feed cost was lowest for 0CON (\$16.63 per cow; only DDG was supplemented) and greatest for 12CON (\$331.92 per

Table 4. Effect of increasing duration of cow–calf confinement on enteric methane production from beef production

Item	Scenario ¹			
	0CON	4CON	8CON	12CON
Cow–calf				
Methane, kg/herd	135,953	114,384	76,568	54,461
Methane, kg/kg HeP ²	4.53	3.81	2.55	1.82
CO ₂ equivalents/kg HeP	127.67	103.30	61.99	46.70
Stocker				
Methane, kg/herd	10,085	10,085	10,085	10,085
Methane/kg HeP	1.89	1.89	1.89	1.89
CO ₂ equivalents/kg HeP	47.32	47.32	47.32	47.32
Feedlot				
Methane, kg/herd	16,946	16,946	16,946	16,946
Methane, kg/kg HeP	0.94	0.94	0.94	0.94
CO ₂ equivalents/kg HeP	23.55	23.55	23.55	23.55
Beef production system				
Methane, kg/herd	154,079	141,415	103,599	81,492
Methane, kg/kg HeP	3.05	2.32	1.94	1.53
CO ₂ Equivalents/kg HeP	84.38	62.06	47.50	38.91

¹0CON = conventional pasture grazing system for cow–calf sector; 4CON = cow–calf sector limit-fed in confinement for 4 mo; 8CON = cow–calf sector limit-fed in confinement for 8 mo; 12CON = cow–calf sector limit-fed in confinement for 12 mo.

²HeP = human-edible protein.

Table 5. Enterprise budget per cow for alternative management strategies

	Scenario ¹				
	0CON	0COND	4CON	8CON	12CON
Gross revenues	759.98	759.98	762.68	762.68	762.68
Costs					
Feed	16.63	277.42	97.83	195.33	331.92
Labor	47.47	54.36	57.20	52.77	52.14
Fuel and lube	17.19	23.12	20.03	25.15	34.33
Repairs and maintenance	13.33	13.90	14.12	15.23	16.79
Interest on loans	15.58	34.23	23.39	28.97	37.77
Other production costs	147.76	147.76	129.83	112.61	95.40
Total variable costs	257.96	550.79	342.39	430.07	568.35
New fixed costs	–	–	6.20	6.20	6.20
Land cost	120.00	120.00	78.90	39.45	0.12
Other fixed costs	85.85	85.85	85.85	85.85	85.85
Total fixed costs	205.85	205.85	170.95	131.50	92.17
Net return	296.16	3.34	249.34	201.11	102.16

¹0CON = conventional pasture-based system for cow–calf sector; 0COND = conventional pasture-based system supplemented hay during drought in cow–calf sector; 4CON = cow–calf sector limit-fed in confinement for 4 mo; 8CON = cow–calf sector limit-fed in confinement for 8 mo; 12CON = cow–calf sector limit-fed in confinement for 12 mo.

cow). As expected, feed costs increased as length of intensification increased from 4 mo (\$97.83 per cow) to 12 mo. Feed costs included mineral costs when cattle were in confinement, but mineral costs were accounted for in other production costs when cattle were grazing pasture. Accordingly, other production costs decreased when intensification increased. During drought, producers must secure a source of feed in order to meet cow requirements

if production is to be maintained. Hay cost is increased in drought years versus normal forage producing years (\$150 vs. \$85 per 907 kg; [Young et al., 2018](#)). Accordingly, the cost of feed per cow for a pasture-based cow–calf operation increased from \$16.63 for 0CON to \$277.42 for 0COND because of the requirement to provide hay under 0COND.

Labor cost was greatest for 4CON (\$57.20 per cow) and decreased to \$52.14 as intensification

increased to 12CON. Drought (0COND; \$54.36 per cow) resulted in a similar labor cost to 4CON as a result of feeding hay. Based on our results, confining cattle in pens in scenarios 8CON and 12CON was less labor intensive than providing hay to cattle in pastures (0COND), but more labor intensive than 0CON (\$47.47 per cow). Confinement strategies allow a producer to mix and deliver feed to all cows in one location which is likely near the feed. For grazing systems (0CON and 0COND), cattle require more land which creates more distance when calculating the cost of delivering hay to cattle.

Fuel, lube, repairs, and maintenance costs increased when cow-calf production was intensified. However, scenario 4CON (\$20.03 per cow) had slightly lower fuel costs compared to 0COND (\$23.12 per cow). These scenarios had to supplement feed for the same number of days; however, 4CON confined cows in a smaller area and closer to the feed being mixed and delivered than 0COND.

Interest costs increased as all other variable costs increased. Total variable costs were greatest for 12CON (\$568.35 per cow) and lowest for 0CON (\$257.96 per cow). Feed costs were a major portion (58%) of total variable costs for 12CON; whereas labor was the greatest single cost item for 0CON. Provision of hay for 4 mo during a drought (0COND) cost \$189.25 per cow more than placing cattle in a drylot and providing a limit-fed diet to meet maintenance requirements for 4 mo. Overall, the limit-fed systems lessen the impact of a drought by creating an opportunity to utilize inexpensive feedstuffs and byproducts.

Feed mixer wagon and bunks were new fixed costs incorporated in the cow-calf production enterprise budget when cattle were fed a TMR (\$6.20). Land/pasture costs were similar for 0CON and 0COND (\$120.00 per cow). As intensification increased, land costs reflected the length of time land was used and/or the amount of land used; thus, land costs decreased per cow from \$120.00 for 0CON to \$0.12 for 12CON scenario. Net return was greatest for 0CON (\$296.16 per cow) and lowest for 0COND (\$3.34 per cow). Net return was \$249.34 per cow for 4CON and decreased to \$102.16 per cow during total confinement (12CON). Grazing was a lower cost source of feed (pasture and supplement costs; \$136.63 per cow) than providing feed to a cow in confinement year-round (\$331.92 per cow); however, fertilizer and herbicide costs were not included in this analysis. Thus, an advantage of 4CON compared to 12CON could be the ability of those systems to take advantage of grazing pasture during lactation when the cow's nutrient requirements are

the greatest. Although not quantified in this study, confinement scenarios have the ability to collect and spread manure for fertilizer resulting in additional benefits. Additionally, a fixed land base partial confinement system creates the opportunity to increase the number of cows, utilize forages when quality is higher, and utilize feed delivery systems when forage availability is limiting.

Stochastic results. Mean return does not describe risk associated with each scenario evaluated; however, summary statistics (Table 6) describe the distribution of possible outcomes. Standard deviation was lowest for 0CON (\$161.39 per cow) followed by 0COND and 4CON (\$164.72 and 166.34 per cow, respectively) which is in agreement with ranking of scenarios by the mean. Differences in standard deviation observed were caused by ingredient usage differences and distributions of ingredient prices.

Although the standard deviation observed for each scenario was not substantially different, it is an indicator of the degree of variability in net return. When ranked by variation in outcomes, 0COND (\$164.72 per cow) would be preferred over all limit-fed systems evaluated. For all scenarios evaluated, part of the distribution of outcomes included negative returns. The maximum predicted loss was \$343.65 per cow (0COND), whereas there was a \$5.91 and \$55.26 maximum loss per cow for 0CON and 4CON, respectively. Although 0CON has greater maximum and minimum net return than confinement scenarios, some years 0CON would be forced to become 0COND during drought, creating a riskiness associated with not having an intensification strategy in place.

Probabilities of negative net returns are presented in Figure 1. Risk averse operators tend to minimize the probability of losses (i.e., red bar = net return less than zero). In this case, 0CON would be the preferred scenario (0.4%); however, this option exposes the producer to risk of 0COND unless they are capable of implementing 4CON. Comparing scenarios feasible during a drought, 4CON (3.6%) would be the most preferred scenario. Other scenarios (0COND, 8CON, and 12CON) had a probability of 52.2%, 9.6%, and 29.2% of a loss for net return. Maximum net return observed was \$996.64 per cow (0CON) followed by \$908.07 per cow for 4CON. Observations of the minima and maxima of each scenario suggest there is an upside tail on all probability distributions. This tail is likely caused by the distribution of revenues more than variation in feed ingredient prices.

Table 6. Summary statistics of net return per cow for alternative scenarios

	Scenario ¹				
	0CON	0COND	4CON	8CON	12CON
Mean	296.16	3.34	249.34	201.11	102.16
SD	161.39	164.72	166.34	170.21	179.00
Minimum	-5.91	-343.65	-55.26	-140.76	-292.04
Maximum	996.64	691.61	908.07	875.32	798.06

¹0CON = conventional pasture-based system for cow-calf sector; 0COND = conventional pasture-based system supplemented hay during drought in cow-calf sector; 4CON = cow-calf sector limit-fed in confinement for 4 mo; 8CON = cow-calf sector limit-fed in confinement for 8 mo; 12CON = cow-calf sector limit-fed in confinement for 12 mo.

Figure 1. Probability of net return per cow for intensified and conventional cow-calf production. Green bar = net return > \$200 per cow; red bar = net return < \$0 per cow; yellow bar = net return > \$0 per cow but < \$200 per cow.

Certainty equivalent is the risk-free amount of wealth that brings a producer the same utility as the risky scenario being evaluated, and risk premium is the amount of money required to convince a producer to switch from one scenario to another (Hardaker et al., 2004). Risk premiums (CE of intensified scenarios minus the CE of 0COND) were determined at 3 levels of risk (risk neutral, moderately risk averse, and extremely risk averse; Table 7). For our analysis, it represents the amount of money that would need to be paid to a producer for them to choose 0COND over one of the limit-fed systems. When a producer is more risk averse, CE associated with net returns of a scenario decreases because the scenario is seen as risky. Comparison to the drought scenario was chosen to simulate how an operation would react when no forage was available for grazing. At any level of risk aversion, the difference in CE represents the value placed on the limit-fed scenario over 0COND. Overall, 4CON had the greatest risk premium, followed by 8CON and 12CON. As risk aversion increased from neutral to extreme, the risk premiums associated with 4CON (\$246.00 to 244.59 per cow, respectively) and 8CON (\$197.78 to 194.35

per cow, respectively) decreased. The small differences in risk premiums within a scenario indicate that producers of all risk aversion level have a similar attitude in these 2 scenarios. Similarly, the risk premium for 12CON decreased as a producer increased its risk aversion (\$98.83 to 90.16 per cow for risk neutral to extremely risk averse, respectively), but the risk premium decreased at a greater rate for 12CON than 4CON and 8CON. The greater discount applied to the risk premium for the 12CON scenario was likely driven by the observation that this scenario had the greatest variation in net returns. Scenario 12CON may be viewed as a risky alternative because of the uncertainty associated with feed prices when cattle are continuously fed in confinement. A negative risk premium would indicate that at that point 0COND would be preferred to the limit-fed system, this was not observed in our analysis.

It is important to recognize that in the current model, the number of cows was held constant; however, increasing the total inventory without incurring excessive utilization is possible for 4CON and 8CON scenarios because there is always a portion of the herd in a drylot. Adding more cattle to

Table 7. Risk premiums between intensified management strategies and conventional drought mitigation strategy (0COND¹)

Production system ³	Level of risk aversion ²		
	Risk neutral	Moderately risk averse	Extremely risk averse
4CON	246.00	245.32	244.59
8CON	197.78	196.03	194.35
12CON	98.83	94.41	90.16

¹0COND = conventional pasture-based system supplemented hay during drought in cow–calf sector.

²Values indicate a dollar per cow benefit of intensification over hay systems.

³4CON = cow–calf sector limit-fed in confinement for 4 mo; 8CON = cow–calf sector limit-fed in confinement for 8 mo; 12CON = cow–calf sector limit-fed in confinement for 12 mo.

the herd would have similar returns per cow, but would increase the enterprise's total net return. Additionally, the limit-fed systems could allow a producer to utilize the drylot for another enterprise while cattle were on pasture, increasing the potential income for the operation.

CONCLUSIONS

Sustainable beef cattle production involves minimizing environmental costs while also creating societal benefit and maintaining a profitable business. Choosing one scenario as the most preferred scenario in our model is difficult since these 3 variables have to be balanced. Although 0CON consumed the least amount of HeP and had the greatest NPC, this scenario also produced the most enteric methane and had increased risk for economic losses during droughts. However, 12CON still had an increased risk of economic losses to the operation, but had lower methane production and contributed positively to meeting human protein requirements because of improvement in protein quality. Other intensified scenarios (4CON and 8CON) were intermediate and are viable options for producers during times of drought. Intensified cow–calf management strategies can be incorporated into a sustainable beef value chain while maintaining the ability of the value chain to be a net contributor to human protein requirements. Additionally, these intensified strategies can help decrease the environmental footprint of the value chain, and may confer some advantages to economic sustainability.

LITERATURE CITED

- Baber, J. R., J. E. Sawyer, L. A. Trubenbach, and T. A. Wickersham. 2016. Effect of feeding method on performance of mid-gestation cows. *J. Anim. Sci.* 95(suppl. 1):43. doi:10.2527/ssasas2017.087
- Baber, J. R., J. E. Sawyer, and T. A. Wickersham. 2018. Estimation of human-edible protein conversion efficiency, net protein contribution, and enteric methane production from beef production in the United States. *Trans. Anim. Sci.* doi:10.1093/tas/txy086
- Beauchemin, K. A., H. H. Janzen, S. M. Little, T. A. McAllister, and S. M. McGinn. 2010. Life cycle assessment of greenhouse gas emissions from beef production in western Canada: a case study. *Agr. Syst.* 103(6):371–379. doi:10.1016/j.agsy.2010.03.008
- Capper, J. L. 2011. The environmental impact of beef production in the United States: 1977 compared with 2007. *J. Anim. Sci.* 89:4249–4261. doi:10.2527/jas.2010-3784
- Capper, J. L. 2012. Is the grass always greener? Comparing the environmental impact of conventional, natural and grass-fed beef production systems. *Animals (Basel)* 2:127–143. doi:10.3390/ani2020127
- Eakin, H., and J. Conley. 2002. Climate variability and the vulnerability of ranching in southeastern Arizona: a pilot study. *Climate Res.* 21:271–281. doi:10.3354/cr021271
- Ertl, P., H. Klocker, S. Hortenhuber, W. Knaus, and W. Zollitsch. 2015. The net contribution of dairy production to human food supply: the case of Austrian dairy farms. *Agr. Syst.* 137:119–125. doi:10.1016/j.agsy.2015.04.004
- Ertl, P., W. Knaus, and W. Zollitsch. 2016b. An approach to including protein quality when assessing the net contribution of livestock to human food supply. *Animal* 10:1883–1889. doi:10.1017/S1751731116000902
- Ertl, P., A. Steinwider, M. Schönauer, K. Krimberger, W. Knaus, and W. Zollitsch. 2016a. Net food production of different livestock: a national analysis for Austria including relative occupation of different land categories/ Netto-Lebensmittelproduktion der Nutztierhaltung: Eine nationale Analyse für Österreich inklusive relativer Flächenbeanspruchung. *Die Bodenkultur: J. Land Manage. Food Environ.* 67(2):91–103. doi:10.1515/boku-2016-0009
- FAO. 2011. Dietary protein quality evaluation in human nutrition. *FAO Food and Nutrition Paper* 92.
- Flachowsky, G., U. Meyer, and K. H. Sudekum. 2017. Land use for edible protein of animal origin—a review. *Animals (Basel)* 7(3):1–19. doi:10.3390/ani7030025
- Freetly, H. C., and J. A. Nienaber. 1998. Efficiency of energy and nitrogen loss and gain in mature cows. *J. Anim. Sci.* 76:896–905. doi:10.2527/1998.763896x
- Hardaker, J. B., J. W. Richardson, G. Lien, and K. D. Schumann. 2004. Stochastic efficiency analysis with risk aversion bounds: a simplified approach. *Aust. J. Agric. Resour. Econ.* 48:253–270. doi:10.1111/j.1467-8489.2004.00239.x
- IPCC. 2007. Climate change 2007. The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, Switzerland.
- Jenkins, K. H., J. Warner, R. Rasby, and T. Klopfenstein. 2015. Limit feeding production cows in an intensively managed system. In: *Plains Nutrition Council Spring Conference*, San Antonio, TX. p. 58–69.
- Johnson, K. A., and D. E. Johnson. 1995. Methane emissions from cattle. *J. Anim. Sci.* 73:2483–2492. doi:10.2527/1995.7382483x
- Livestock Marketing Information Center (LMIC). 2018a. Monthly U.S. Ag. Prices Feedgrains and Hay. <http://lmic.info> (Accessed 27 June 2018).
- Livestock Marketing Information Center (LMIC). 2018b. Weekly dried distillers grains prices for various markets. <http://lmic.info> (Accessed 27 June 2018).

- Livestock Marketing Information Center (LMIC). 2018c. Weekly and monthly combined Texas auction cattle prices. <http://lmic.info> (Accessed 28 June 2018).
- Mottet, A., C. de Haan, A. Falcucci, G. Tempio, C. Opio, and P. Gerber. 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Glob. Food Secur. Agr.* 14:1–8. doi:10.1016/j.gfs.2017.01.001
- National Academies of Sciences, Engineering, and Medicine (NASEM). 2016. Nutrient requirements of beef cattle. 8th rev. ed. The National Academies Press, Washington, DC. doi:10.17226/19014
- Nguyen, T. L. T., J. E. Hermansen, and L. Mogensen. 2010. Environmental consequences of different beef production systems in the EU. *J. Cleaner Production* 18(8):756–766. doi:10.1016/j.jclepro.2009.12.023
- Pelletier, N., R. Pirog, and R. Rasmussen. 2010. Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. *Agr. Syst.* 103(6):380–389. doi:10.1016/j.agsy.2010.03.009
- Peters, C. J., J. A. Picardy, A. Darrouzet-Nardi, and T. S. Griffin. 2014. Feed conversions, ration compositions, and land use efficiencies of major livestock products in US agricultural systems. *Agr. Syst.* 130:35–43. doi:10.1016/j.agsy.2014.06.005
- Peters, G. M., H. V. Rowley, S. Wiedemann, R. Tucker, M. D. Short, and M. Schulz. 2010. Red meat production in Australia: life cycle assessment and comparison with overseas studies. *Environ. Sci. Technol.* 44:1327–1332. doi:10.1021/es901131e
- Ribera, L. A., F. M. Hons, and J. W. Richardson. 2004. An economic comparison between conventional and no-tillage farming systems in Burleson County, Texas. *Agron. J.* 96:415. doi:10.2134/agronj2004.4150
- Richardson, J. W., S. L. Klose, and A. W. Gray. 2000. An applied procedure for estimating and simulating multivariate empirical (MVE) probability distributions in farm-level risk assessment and policy analysis. *J. Agric. Appl. Econ.* 32:299–315. doi:10.1017/S107407080002037X
- Sawyer, J. E., and T. A. Wickersham. 2013. Defining value and requirements in cow rations: What is a calorie worth? Dr. Kenneth S. and Caroline McDonald Eng Foundation Symposium, Lincoln, NE. p. 31–36.
- Stackhouse-Lawson, K. R., C. A. Rotz, J. W. Oltjen, and F. M. Mitloehner. 2012. Carbon footprint and ammonia emissions of California beef production systems. *J. Anim. Sci.* 90:4641–4655. doi:10.2527/jas.2011-4653
- Stribling, E. J., T. A. Wickersham, R. C. Cardoso, and J. E. Sawyer. 2018. Production and economic effects of developing heifers on three different levels of single stair-step nutrition programs. *J. Anim. Sci.* 96(suppl. 1):49–50. doi:10.1093/jas/sky027.093
- Trubenbach, L. A., T. A. Wickersham, V. P. Briani, and J. E. Sawyer. 2018. Effects of dietary energy density and intake on energy requirements in beef cows. *J. Anim. Sci.* 96(suppl. 1):53. doi:10.1093/jas/sky027.100
- USDA-NASS. 2018. Data and statistics. http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/index.asp (Accessed July 2018).
- Wilkinson, J. M. 2011. Re-defining efficiency of feed use by livestock. *Animal* 5:1014–1022. doi:10.1017/S175173111100005X
- Wilkinson, J. M., and M. R. F. Lee. 2018. Review: use of human-edible animal feeds by ruminant livestock. *Animal* 12:1735–1743. doi:10.1017/S175173111700218X
- Young, A. M., M. K. Clayton, J. C. Paschal, and S. L. Klose. 2018. Economic impact of beef cattle best management practices in South Texas: stocking strategies during drought. *J. Appl. Farm Econ.* 2(1):1–8.
- Ziolkowska, J. R. 2016. Socio-economic implications of drought in the agricultural sector and the state economy. *Economies* 4:19. doi:10.3390/economies4030019