LIFE–CYCLE GREENHOUSE–GAS EMISSIONS OF FIVE BEEF PRODUCTION SYSTEMS TYPICAL OF THE SOUTHERN HIGH PLAINS

by

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ABSTRACT

A life cycle assessment (LCA) of the beef cattle feeding systems in the Southern High Plains is needed to acknowledge climate change legislation concerns and the sustainability of the industry as it currently operates. The goal of this research was to develop a systems-based model capable of generating carbon-footprint estimates for five typical Southern High Plains beef-production systems. The systems included a native grass pasture (System One); a native grass pasture with feedlot finishing (System Two); a modified pasture (wheat) with feedlot finishing (System Three); a feedlot-only system (System Four); and a native grass pasture, modified pasture (wheat), and feedlot (System Five). The spreadsheet-based model estimates net emissions of greenhouse gases (CO_2, N_2O and CH_4), expressed as CO_2e, from the individual processes within each system. The net emissions from production System One (NGP) totaled 6,632 kg CO_2e, resulting in 26.49 kg CO_2e/kg gain. System Two (NGP-FY) net emissions totaled 2,918 kg CO_2e, resulting in 7.61 kg CO_2e/kg gain. The net emissions from production System Three (MP-FY) totaled 3,255 kg CO_2e, resulting in 7.64 kg CO_2e/kg gain. Production System Four (FY) net emissions totaled 1,799 kg CO_2e, resulting in 4.84 kg CO_2e/kg gain. System Five (NGP-MP-FY) net emissions totaled 3,737 kg CO_2e resulting in 8.15 kg CO_2e/kg gain. Greenhouse gas emissions were lower in System Four (feedlot only) than in all other systems.

Key words: Life cycle analysis, beef production, greenhouse gas, CO_2e emissions

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ACRONYMS AND VARIABLES

AAR – Association of American Railroads

ABW – Actual Body Weight (kg)

AFO – Animal Feeding Operation

A_{Thermo} – Animal Thermoneutrality

BF% – Percentage of Body Fat

BMP – Best Management Practice

CAA – Clean Air Act

CF – Carbon footprint

CFR – Code of Federal Regulations

CH_4 – Methane

CO_2 – Carbon Dioxide

CO_2e – Carbon Dioxide Equivalent

COP7 – Seventh Session of the Conference of the Parties

CP – Crude Protein

$DirectN_2O_{man\ soils}$ – Direct N_2O Emissions from Managed Soils

DM – Dry Matter

DMI – Dry Matter Intake (kg/day)

$DMI_{NEg\ Animal}$ – Animal Net Energy for Gain from Dry Matter Intake (Mcal/day)

$DMI_{NEm\ Animal}$ – Animal Net Energy for Maintenance from Dry Matter Intake (Mcal/day)

DOF – Days on Feed

DSHS – Department of State and Health Services

EBG – Empty Body Gain (kg)

EBW – Empty Body Weight (kg)

EF – Emission Factor (kg)

EPA – Environmental Protection Agency

EQSBW – Equivalent Shrunk Body Weight (kg)

FAO – Food and Agricultural Organization of the United Nations

$Frac_{GasMS}$ – Percent of Managed Manure Nitrogen that Volatilizes

FSBW – Final Shrunk Body Weight (kg)

FY – Feedlot

GE – Gross Energy (MJ)

GHG – Greenhouse Gas

GWP – Global Warming Potential

HCW – Hot Carcass Weight

IPCC – Intergovernmental Panel on Climate Change

LCA – Life Cycle Analysis

MCF – Methane Conversion Factor

ME – Metabolizble Energy

MP – Modified Pasture

MS – Manure Management System

$N_{(T)}$ – Number of Livestock Species

N_2O – Nitrous Oxide

$N_2O_{D(m,m)}$ – Direct N_2O Emissions from Manure Management (kg)

$N_2O_{g(m,m)}$ – Indirect Emissions Due to Volatilization from Manure Management (kg)

NE_g – Net Energy for Gain (Mcal)

$NE_{g\ Animal}$ – Net Energy for Gain after Maintenance Requirements (Mcal)

$NE_{g\ Fat}$ – Fat Proportion of Gain (%)

$NE_{g\ feed}$ – Net Energy for Gain Supplied by the Feed (Mcal)

$NE_{g\ Protein}$ – Protein Proportion of Gain (%)

NE_m – Net Energy for Maintenance (Mcal)

$NE_{m\ animal}$ – Net Energy for Maintenance Required by the Animal (Mcal)

$NE_{m\ feed}$ – Net Energy for Maintenance Supplied by the Feed (Mcal)

$NE_{m\ temperature}$ – Net Energy for Maintenance Temperature Influence (Mcal/kg SBW)

Nex – Annual Average Nitrogen Excretion (kg)

NGP – Natural Grass Pasture

NRC – National Research Council

RE_{Demand} – Retained Energy Animal Demand (Mcal/hd/day)

S – Manure Management System

SBW – Shrunk Body Weight (kg)

SHP – Southern High Plains

SRW – Standard Reference Weight (kg)

SWG – Shrunk Body Gain (kg)

SWG_{Fat}- Shrunk Weight Gain in Fat (kg)

T – Species/Category of Livestock

TCFA – Texas Cattle Feeders Association

UE – Urinary Energy

UN – United Nations

UNFCC – United Nations Framework Convention on Climate Change

USDA – United States Department of Agriculture

USDA-NASS - United States Dept. of Agriculture National Agricultural Statistics Service

USDA-NRCS – United States Dept. of Agriculture Natural Resources Conservation Service

VS – Volatile Solids (kg)

Y_m – Methane Conversion Factor (%)

$Y_{m\ Feedlot}$ – Methane Conversion Factor for Feedlots (3%)

$Y_{m\ grazing}$ – Methane Conversion Factor for Grazing Cattle (6.5%)

CHAPTER 1

INTRODUCTION

A life cycle assessment (LCA) of the beef cattle feeding systems in the Southern High Plains is needed to acknowledge climate change legislation concerns and the sustainability of the industry as it currently operates. The environmental burdens, defined as resource use output per functional unit produced, may be used to quantify the "footprint" of the cattle feeding industry as a whole or as smaller functioning units within the system. The compilation and evaluation of the inputs, outputs, emissions, recycling, and the environmental stress of this system throughout its life cycle are needed to clearly understand the ramifications of climate change legislation on the beef cattle feeding industry. Establishing an emission rate specific to the various Southern High Plains cattle feeding systems could be used to determine the sustainability and environmental stress of these systems in this region.

Carbon footprint (CF) estimates are based on the ecological footprint concept introduced by Wackernagel and Rees (1996). They described an ecological footprint analysis as "*an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area.*" The ecological footprint estimates the land area required per person (or population) to sustain a standard of living, rather than carrying capacity (Wackernagel and Rees, 1996). Wackernagel and Rees describe further that every economic activity imposes a demand on the ecosphere, and an ecological footprint demonstrates how all these demands for food and fiber, non-renewable resources, waste absorption, urban development, and biodiversity compete for ecological space.

For the purposes of this study the "carbon footprint" is a generically used term to describe greenhouse gas (GHG) emissions, via carbon dioxide equivalent (CO_2e) emissions that are attributed to the production of beef cattle. CO_2e is universally accepted as the standard by which all GHG emissions are reported. Current literature and peer-reviewed articles refer to GHG emission rates by using this standardized CO_2e unit. This equivalent comprises the three most prevalent GHGs that are addressed by climate change legislation and environmental regulations. The three primary listed GHGs are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These emissions are assigned a global warming potential (GWP) multiplier that is then used to calculate CO_2e. The GWP of N_2O and CH_4 is 298 and 25 times higher than CO_2, respectively (CFR, 2015).

An LCA having realistic, clearly defined methods and assumptions can be used to assess the impact of climate change legislation on the sustainability of the beef industry and resource use attributed to animal agriculture in the Southern High Plains beef production systems. Systems based modeling and research efforts are needed to better understand the emissions and nutrient flows from the different beef production systems.

SOUTHERN HIGH PLAINS REGION

The Southern High Plains (SHP) region is characterized by short and mid-mixed grasses that grow to less than 60 cm, in response to the reduced amount of water available, cool temperatures, and shorter growing season (BLM, 2012). This area includes portions of Colorado, Kansas, Oklahoma, New Mexico, and Texas for a total of 14.3 million hectares (USDA-NRCS, 2006). Although there are approximately 7 million hectares of grassland (USDA-NRCS, 2006), beef cattle production occurs primarily in cattle feedlots. According to the Texas Cattle Feeders Association (TCFA) approximately 30% of the United States annually fed cattle are in the Texas Panhandle region (TCFA, 2007). This amounts to 3.3 million head of cattle on feed every day, producing more than 7 million finished cattle every year (TCFA, 2007).

The topography of the region is relatively flat with elevations ranging from 670 m to 1,448 m above sea level (Bureau of Economic Geology, 1996). According to the Texas Department of State and Health Services (DSHS), the population of the the Texas Panhandle area is 439,694, which is less than 2% of the total Texas population. These residents live in an area encompassing 10% of the land (6.6 million hectares) in Texas (DSHS Center for Health Statistics, 2011).

Crop and animal production has thrived in this rural landscape due in part to low population density that is amenable to agriculture, a semi-arid climate, and a good source of ground water from the Ogallala Aquifer. This agriculturally intensive region is ideal for producing cattle, even though the total amount of grain produced and harvested locally is inadequate to feed them. Furthermore, grain production, primarily corn, in the High Plains can only be achieved via irrigation using limited groundwater resources primarily from the Ogallala Aquifer. Corn production in the SHP has steadily increased, but there is still not enough produced to meet the needs of animal agriculture in this area. This grain deficit increases the demand for imported corn while area crop producers cope with declining water tables in the Ogallala Aquifer, withdrawal rules adopted by regional groundwater conservation districts, and increasing fuel costs that are reducing irrigation water use per acre (Sweeten et al., 2012). To fill this grain deficit, feed grain is imported by rail from Midwest corn-producing states.

The lack of rivers, lakes, and low annual rainfall in the SHP makes surface water a scarce resource. Approximately 75% of the annual precipitation results from thunderstorm activity between April and September; rainfall ranges from 432 to 536 mm (NOAA, 2011). The low precipitation and lack of surface waters have forced farmers, ranchers and municipalities to rely on the abundant, yet essentially non-renewable, Ogallala Aquifer. The Ogallala Aquifer, North America's largest underground water source, lies beneath parts of Nebraska, Kansas, Colorado, and Oklahoma, extending north into South Dakota, west into Wyoming, and south into New Mexico and Texas (BLM, 2012). Approximately 95% of pumped groundwater in the SHP is used for irrigated agriculture (HPUWCD, 2010).

Future demands for manure as fertilizer on a per-acre basis could decline if irrigated agriculture is reduced in this region. This reduction would require longer manure hauling distances to achieve P- or N-based nutrient balances on deficit-irrigated and dryland cropping systems (Sweeten et al. 2012). Manure produced by the 7.2 million beef cattle fed each year amounts to more than 4.5 million metric tons/year on an as-collected basis (Sweeten et al., 2012). The increased expense of using manure beneficially via land application at agronomic rates could increase environmental stress from increased manure stockpiles, nutrient overloading during land application, increased GHG emissions from manure storage, and increased fuel consumption required for greater hauling distances. New manure management strategies are becoming necessary for an environmentally sustainable beef cattle feeding industry. Innovative technology and multi-media environmental approaches to manure management that address water and air quality, soil quality, energy usage, climate change, and biomass energy use are needed to accommodate future environmental policies (Auvermann and Sweeten, 2005).

CATTLE FEEDING SYSTEMS

There are many different feeding systems used by producers depending upon herd size, cattle breed, profit margins, and how they are marketed. Although there is an infinite array of cattle feeding systems, there appear to be five distinct production systems from weaned calf to mature marketable animal used in the SHP. These five production systems use three different feeding components: native grass pastures, modified pastures (such as winter wheat), and feedlot finishing. These systems can be described as:

- System 1: Native grass pasture (NGP)
  - Weaned calf is kept in the same native grass pasture based system until finished
- System 2: Native grass pasture – Feedlot (NGP – FY)
  - Weaned calf is grass fed until it reaches an appropriate size based on a management choice, and is then moved to a feedlot to finish
- System 3: Modified Pasture – Feedlot (MP – FY)
  - Weaned calf goes directly to a modified pasture (such as wheat) and is allowed to consume high quality forage prior to finishing at a feedlot
- System 4: Feedlot (FY)
  - Weaned calf is moved directly to a feedlot to finish
- System 5: Native Grass pasture – Modified Pasture – Feedlot (NGP – MP – FY)

- Weaned calf stays in the native grass pasture until it is moved to a modified pasture (such as wheat pasture) for a short duration to maximize weight gain on high quality forage, then the calf is placed in a feedlot to finish

These systems are initially described with the most basic of terms to limit the complexity involved with describing each feeding regime. These systems have many variations and allow for a wide array of management inputs such as time on feed, breed genetics, pasture modification, supplements, amount of feed available, cattle sourcing, feed sourcing, hormone implants, feed additives, and governmental regulations. These feeding systems and the associated management choices affect the resources required to produce a marketable beef product.

CATTLE MARKETING

Cattle are marketed based on weight, age, sex, time of year, and origin. Cattle classifications include, but are not limited to stockers, feeders, slaughter cattle, replacement heifers, and feedlot cattle (Garrett, 2007). Calves are considered to be less than one year of age, feeder/stocker calves are six months to one year old, and mature cattle are one year or older (Garrett, 2007). Calves weaned at approximately 205 days of age (Cook, 2002) average 250 kg (550 pounds) for steers and 238 kg (525 pounds) for heifers. Weaned calves can be marketed directly for placement in a feedlot, modified pasture, or a native grass pasture. A heavier feeder calf generally commands a lower price per kilogram, and steer calves cost more than heifer calves due to increased feed-to-gain performance (Meyer, 1997). Another factor that influences cattle marketing is distance from source to feedlot; feeder cattle sourced at greater distances bring lower premiums to offset increased transportation cost and cattle stress.

There are several options for marketing cattle for slaughter. Packers pay for cattle based on either live weight basis or a carcass weight basis, also known as grid pricing (Meyer, 1997). Cattle sold on the live weight basis have an estimated carcass quality and weight, and then are priced accordingly based on market conditions. Using grid pricing producers are paid based on quality grade, yield grade, carcass weight, and other factors such as Certified Angus (Meyer, 1997).

The quality grades Prime, Choice, Select, or Standard are generally assigned to cattle that are <42 months old by USDA graders (Woerner, 2009). Cattle older than 42 months are eligible for USDA carcass quality grades of Commercial, Utility, Cutter, and Canner. Each classification is associated with a certain meat quality where the value is greatest for meat that is graded “Prime.” Although “Prime” is the most desirable grade, most cattle grade “Choice” (57.9%) or “Select” (39.1%) (Parish et al., 2009).

The yield grade of a beef carcass is determined by considering four characteristics: (1) the amount of external fat, (2) the amount of kidney, pelvic, and heart fat, (3) the area of the ribeye muscle, and (4) the carcass weight (USDA, 1997). The USDA categorize beef carcasses into five different yield grades. Yield grade one refers to the greatest amount of closely trimmed retail cuts; yield grade five refers to the least (Tatum, 2007). Most packer grids list a base price for a “Choice,” yield grade three, 250-408 kg (550-900 lb.) steer carcass (Hogan, et al. 2009). Carcasses above and below those thresholds can be discounted. The USDA, national five-day, accumulated weighted average on March 25, 2015 reports that the average steer live weight at harvest was 650 kg (1,432 lbs.) with a dressing percentage of 63.65% (USDA, 2015), yielding an average carcass weight of 414 kg (911 lbs).

CATTLE SOURCING

Cattle fed in the SHP originate from all regions of the United States, Canada, and Mexico. The January 2014 cattle inventory for the United States was estimated at 89.8 million (USDA-NASS, 2015) (Table 1). That cattle inventory includes all beef cattle, dairy cows, calves, and cattle fed in feedlots or pastures in all 50 states. The top five states in 2014 with the largest cattle inventories were Texas (10.9 million), Nebraska (6.15 million), Kansas (5.8 million), California (5.25 million), and Oklahoma (4.3 million) (USDA-NASS, 2014). As of January 2015, the total cattle on feed accounted for 10.7 million head or 12% of the total inventory (USDA-NASS, 2015) (Table 2). The top five states with the largest inventories of cattle and calves are also the states that typically have the greatest number of feedlots or aggregate one-time capacity (Table 1). These top five states account for 37% of the total cattle inventory in the United States being fed in confinement or in a grazing system. These feedlots may source cattle from local producers (if available) or other states depending on price, breed, size, market conditions, and distance.

Table 1. Beef and Dairy Cattle Inventory in the United States, as of January 2014 (USDA – NASS, 2015).

Cattle Inventory in the United States, Jan 1, 2014					
1	Texas	10,900,000	26	Alabama	1,240,000
2	Nebraska	6,150,000	27	Illinois	1,130,000
3	Kansas	5,800,000	28	Michigan	1,120,000
4	California	5,250,000	29	Washington	1,100,000
5	Oklahoma	4,300,000	30	Georgia	1,000,000
6	Missouri	3,800,000	31	Mississippi	930,000
7	Iowa	3,700,000	32	Arizona	920,000
8	South Dakota	3,650,000	33	Indiana	870,000
9	Wisconsin	3,350,000	34	North Carolina	810,000
10	Montana	2,550,000	35	Utah	800,000
11	Colorado	2,480,000	36	Louisiana	790,000
12	Minnesota	2,280,000	37	Nevada	455,000
13	Idaho	2,190,000	38	West Virginia	380,000
14	Kentucky	2,090,000	39	South Carolina	360,000
15	North Dakota	1,770,000	40	Vermont	260,000
16	Tennessee	1,760,000	41	Maryland	182,000
17	Arkansas	1,660,000	42	Hawaii	130,000
18	Florida	1,620,000	43	Maine	85,000
19	Pennsylvania	1,620,000	44	Connecticut	47,000
20	Virginia	1,530,000	45	Massachusetts	39,000
21	New York	1,450,000	46	New Hampshire	32,000
22	New Mexico	1,290,000	47	New Jersey	29,000
23	Oregon	1,280,000	48	Delaware	16,000
24	Wyoming	1,270,000	49	Alaska	10,000
25	Ohio	1,250,000	50	Rhode Island	5,000
				Total	87,730,000

Table 2. Cattle Capacity, Class, and on Feed in the United States, as of January 2015 (USDA – NASS Feb. 20, 2015).

United States: January 1, 2015	(x1,000 head)
Total Capacity of 1,000+ Head feedlots	16,900
Cattle Inventory on Feed	(x1,000 head)
Steers and Steer Calves	6,948
Heifers and Heifer Calves	3,678
Total	10,626
Feedlot Inventory by State	(x1,000 head)
Texas	2,500
Nebraska	2,460
Kansas	2,050
Colorado	900
Iowa	640
California	425
Oklahoma	255
Arizona	249
Idaho	230
South Dakota	230
Washington	210
Minnesota	137
Other States	340
Total	10,626

Cattle/calves on feed for slaughter being fed a ration of grain or other concentrates and expected to produce a carcass that will grade select or better.

OBJECTIVES OF RESEARCH

The goal of this research was to bring scientific transparency, methodological clarity, and credible estimates to previously published life cycle analysis (LCA) and carbon-footprint (CF) studies for beef cattle production. These goals were achieved by developing a dynamic, systems-based model generating life-cycle carbon-footprint estimates for five SHP beef-production systems. The model allowed for the identification and quantification of inputs from multiple industrial sectors that contribute to overall CO_2e emissions that might otherwise be attributed only to the livestock production sector.

CHAPTER 2

LITERATURE REVIEW

CATTLE PRODUCTION AND GREENHOUSE GAS EMISSIONS

The resources available for agricultural production are likely to decrease concurrently with population growth due to competition for land, water, and depletion of fossil fuels. Therefore livestock industries face the challenge of producing sufficient, safe, and affordable animal protein to meet consumer demand, using a finite and shrinking resource base – a challenge exacerbated by political and social concerns relating to the environment (Capper et al., 2009). The global population is currently 7.3 billion people and is expected to increase to more than 9.5 billion by the year 2050 (FAO, 2009). This increase in population is projected to increase demand for agricultural products by 70%. Diets will likely include more animal products, which in turn will challenge the livestock industry to produce more animal protein using fewer inputs while competition intensifies for energy, land, and water resources.

A report published by FAO, *Tackling Climate Change Through Livestock,* estimates that the annual GHG emissions attributed to the livestock supply chain account for 14.5% (7.1 GT CO_2e) of all human-induced emissions using the most recent IPCC estimates (FAO, 2013). This estimate is similar to the previous FAO report, *Livestock's Long Shadow*, which estimated that the livestock sector was responsible for 18% of all GHG emissions (FAO, 2006). The FAO (2013) report estimates that beef cattle contribute 41% of the total emissions attributed to animal agriculture. Feed production and processing and enteric fermentation from ruminants are the two main sources of emissions, representing 45% and 39% of the total emissions, respectively. Manure storage and processing account for 10% and the remaining 6% is attributed to the processing and transportation of animal products (FAO, 2013).

The development and implementation of feeding and management strategies to reduce methane emissions resulting in an increase in efficiency of dietary energy use will not only reduce the contribution of livestock to the atmospheric methane budget, but will also enhance production efficiency (Johnson and Johnson, 1995). Increasing production efficiency could reduce the overall herd size while maintaining or increasing production and decrease the environmental burdens associated with livestock production. Efficiency improvements from genetics, animal health, and improved nutrition at all levels of cattle production may decrease the maintenance need, and lower the GHG emissions of beef (Mitloehner and Place, 2009). Increasing animal performance is seen as one of the most effective strategies to lower GHG emissions that are attributed to beef cattle production (Stackhouse, 2012).

Current cattle production strategies for increased body size from higher rates of gain and longer feeding periods lower GHG emissions per kilogram of beef, but the cattle eat more feed and excrete more manure than the smaller animals of the past (Capper et al., 2009). Together, those strategies may reduce the feed energy intake per unit of body weight, but that is primarily attained through less total time on feed (Capper, 2011). Enhancing productivity decreases the maintenance subsidy and, thus, decreases methane emissions from fermentation of the feed associated with animal maintenance (Johnson and Johnson, 1995). Thus, GHG emissions should not be simply computed per animal or per facility but rather based on system productivity using a LCA approach (Capper et al., 2009).

Methane emissions can be reduced with diets containing higher levels of nonstructural carbohydrates, such as sugars (glucose, fructose, lactose, and sucrose), or with the inclusion of starchy feeds (Johnson and Johnson, 1995). Pasture-based diets increase enteric methane production and energy use per unit of gain (MJ/kg gain) (Johnson and Johnson, 1995). Decreasing the ruminal retention time could also reduce enteric CH_4 emissions (Guan et al., 2006). As feed consumption increases, the percentage of dietary gross energy (GE) lost as methane decreases by an average of 1.6% for a given level of intake (Johnson and Johnson, 1995). At high intakes of highly digestible diets, low fractional methane losses occur (Johnson and Johnson, 1995). The type of carbohydrate fermented also influences the amount of methane by changing ruminal pH and the microbial population (Johnson and Johnson, 1995). In addition, the fermentation of brewery and distillery products containing relatively high fiber results in lower methane production, generally one-half to one-third of that seen with common feedstuffs of comparable digestibility (Wainman et al., 1984). The very high grain diets (90+ % concentrate) commonly fed in U.S. feedlots have methane loss rates approximately one-half of the commonly predicted 6% of diet GE lost as methane compared to grass-based systems (Johnson and Johnson, 1995). Other feeding strategies that effectively reduce emissions include supplementation of ionophores, hormones, steroid implants, and beta-adrenergic agonists in cattle and cattle diets.

The most commonly used organic soil amendment applied to agricultural lands is animal waste, such as poultry litter and cattle manure. In 2007, there were approximately 9 million hectares of cropland receiving manure fertilizers in the U.S. (USDA, Agricultural Chemical Useage 2006 Vegtables Summary, 2007). However, high nutrient variability in manure makes efficient nutrient management more complex compared to commercial fertilizer. Nevertheless, the nutrient benefits and possible fertilizer/cost savings, combined with GHG mitigation, are renewing interest in the use of organic soil amendments (Eagle et al., 2010). There are three possible pathways for GHG mitigation due to organic amendments. Livestock manure can be applied in excess, resulting in lost opportunity for broader land application on surrounding farmland that could result in greater carbon sequestration and reduced emissions from land. Second, using organic amendments in place of commercial fertilizer, rather than in addition to it, will reduce upstream and process emissions associated with fertilizer production.

HISTORY OF GLOBAL WARMING/CLIMATE CHANGE SCIENCE

Joseph Fourier is credited with being the first scientist in the 1820s to understand that gases in the atmosphere might trap heat received from the sun. As Fourier put it, energy in the form of visible light from the sun easily penetrates the atmosphere to reach the surface and heat it up, but heat cannot so easily escape back into space. The air absorbs “invisible heat rays” (infrared radiation) rising from the surface, helping it stay warm (Weart, 2008). John Tyndall is credited as being the first scientist to determine which gases in the atmosphere could trap heat. In an 1859 laboratory experiment, Tyndall identified several gases that could trap heat, the two most prominent being water vapor and carbon dioxide (Graham, 1999). Tyndall also predicted that methane would affect the climate (Weart, 2008).

The next major scientist to consider the "greenhouse effect" was Svante Arrhenius. In an 1896 experiment, he concluded that CO_2 acted as a regulator of water vapor, and ultimately determined the planet's long-term equilibrium temperature (Weart, 2008). Similar to the other scientists, he was not trying to determine long-term negative effects of global warming, only what caused global cooling and the prehistoric ice ages. He theorized that changing the composition of the earth's atmosphere could radically change the climate. Arrhenius estimated that it would take 3,000 years to double the CO_2 concentration in the atmosphere, and this doubling would raise the Earth's temperature by 5-6°C (Weart, 2008).

A colleague of Arrhenius named Arvid Högbom calculated the amounts of CO_2 emitted by factories and other industrial sources and concluded these activities were adding CO_2 to the atmosphere at a rate comparable to the natural geochemical processes that emitted or absorbed the gas. He hypothesized that the next CO_2 change might increase temperature. In 1938, an English engineer named Guy Stewart revived the old theory of greenhouse warming. He estimated that the doubling of atmospheric CO_2 could gradually bring a 2°C temperature increase, but admitted that the actual climate change would depend on interactions involving changes of cloud cover and other processes that no scientist of the time could reliably calculate (American Institute of Physics, 2015).

In the 1960s, Charles David Keeling measured CO_2 concentrations in Antarctica and atop the Mauna Loa volcano in Hawaii for 2 years, and reported that the baseline emissions had risen at a rate approximately equal to industrial emissions for that 2 year period. He then developed a curve from his measurements, known as Keeling's Curve. This curve showed a small but steady increase in CO_2 concentrations during his measurements. For both scientists and the public it became the primary icon of the greenhouse effect (American Institute of Physics, 2015). As computer models and measuring techniques improved in the 1980s and 1990s, the predicted negative effects of global warming increased. These predictions eventually led to the Kyoto Protocol, in which member nations would attempt to cap and reduce GHG emissions.

KYOTO PROTOCOL

The Kyoto Protocol was negotiated in Kyoto, Japan on December 11, 1997, and became legally binding to member countries that ratified it on February 16, 2005 (UNFCC, 2011). The detailed rules for implementation of the Protocol were adopted at the *Conference of Parties 7th session* (COP7) in Marrakesh, Morocco in 2001, and are called the "Marrakesh Accords" (UNFCC, 2011). This international agreement is linked to the United Nations Framework Convention on Climate Change (UNFCC). This protocol sets limits for 37 industrialized countries and the European community to reduce GHG emissions by 5% of the 1990 levels. This reduction was to occur over 5 years from 2008-2012.

The Protocol outlined three systems to reduce GHGs in addition to a national reduction plan. These additional methods to reduce the emissions included: (1) emissions trading through a carbon market, (2) clean development mechanism, (3) and joint implementation. The carbon market would allow emitters the option to buy and trade carbon credits. The clean development mechanism would allow a country with Kyoto commitments to implement a reduction project in a developing country to earn emission reduction credits which could be used to meet the Kyoto reduction requirements. The joint implementation is similar to the CDM, except a country (Annex B Party) that is part of the Kyoto Protocol could earn emission-reduction units by implementing emission reduction projects in other countries (Annex B Party) participating in the treaty.

Emission targets for industrialized countries participating in the Kyoto Protocol are expressed as levels of allowed emissions, or "assigned amounts," over the 2008-2012 commitment periods. The assigned amounts are denominated in tonnes of CO_2e emissions, known uniformly as "Kyoto units" (Kyoto Protocol, 2004). The Kyoto Protocol was signed by the United States on November 12, 1998, but the Clinton Administration did not submit the Protocol to the Senate for ratification. The Bush Administration in 2001 rejected the Kyoto Protocol and decided to rely on domestic, voluntary actions to reduce GHG intensity (Saundry, 2006).

CARBON MARKETS IN A CAP AND TRADE SYSTEM

Under a cap-and-trade system, the government imposes a cap on the amount of pollutant that is allowed to be released into the environment. The government either auctions off the credits or gives the credits to the polluting industries. The polluters are then allowed to trade their excess allowances (assuming they adopt BMPs to reduce emissions), in the hope of reducing the cost of complying with the new regulation. In this instance, the government would cap the total amount of carbon (or carbon equivalent) that could be emitted within the US. The cap would then be reduced in the future and reductions would have to meet new cap requirements. By reducing the total number of credits available for trading, the government would effectively reduce the total amount of emissions emitted. The framework for this policy is based upon the successful implementation of the sulfur dioxide cap-and-trade market that was used to reduce sulfur emissions from burning coal used to generate electricity (EPA, 2003). This carbon-trading policy proposed for the United States is also modeled after the European markets currently trading carbon credits.

EPA ROLE IN CLIMATE CHANGE REGULATION

Although the European carbon market model has yet to be implemented in the United States, carbon emissions are still listed as a regulated GHG pollutant by the EPA (EPA , 2009). The EPA has also ruled that GHGs are harmful to human health and are a detriment to the environment. At present, instead of a carbon market, GHGs are regulated by the EPA using the Clean Air Act (CAA) human health protection standard. The following is a summary published in the Federal Register (2009):

> Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act
>
> SUMMARY: The EPA Administrator (Lisa P. Jackson) finds that six greenhouse gases taken in combination endanger both the public health and the public welfare of current and future generations. The Administrator also finds that the combined emissions of these greenhouse gases from new motor vehicles and new motor vehicle engines contribute to the greenhouse gas air pollution that endangers public health and welfare under CAA section 202(a). These Findings are based on careful consideration of the full weight of scientific evidence and a thorough review of numerous public comments received on the Proposed Findings published April 24, 2009. DATES: These Findings are effective on January 14, 2010.
>
> Specifically, the Administrator is defining the ‘‘air pollution’’ referred to in CAA section 202(a) to be the mix of six long-lived and directly-emitted greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

It is not clear if the US will continue to regulate greenhouse gases exclusively via the EPA, or if they will choose to follow a different regulatory framework like the European carbon market. However, as GHG regulations materialize, animal agriculture should be prepared to respond to changing regulations in order to remain a competitive and viable industry. The consensus on the GHG emissions generated, sequestered, or recycled by large AFOs in a livestock intensive region of the Southern High Plains is unclear and depends greatly on the model assumptions and model boundaries.

UNITED NATIONS ROLE IN CLIMATE CHANGE SCIENCE AND TREATIES

The authors of the United Nations Food and Agriculture Organization (FAO) report *Livestock's Long Shadow* (Steinfeld et al., 2006) state that there is an urgent need to develop suitable institutional and policy framework at the local, national, and international level to implement changes in the livestock sector's environmental impact. This policy framework would be achieved through political commitments and an increased knowledge and awareness of the environmental risks and benefits of the actions in the livestock sector. All food production has an environmental impact and livestock production has been singled out as a major contributor to climate change (Steinfeld et al., 2006; Koneswaran and Nierenberg, 2008). However, consumer and governmental perceptions of strategies and production systems used to reduce environmental impact are often simplistic and appear to be based on misconceptions that do not consider negative trade-offs (Capper et al., 2009).

The FAO report concluded that Intensification – in terms of increased productivity both in livestock production and in feedcrop agriculture – may reduce GHG emissions from deforestation and pasture degradation (Steinfeld et al., 2006). The FAO report also suggests livestock production should be decentralized to accessible croplands where wastes can be recycled without overloading soils and freshwater (Steinfeld et al., 2006). According to this FAO report, land degradation can also be mitigated by better managing grazing systems, implementing grazing fees, limiting grazing in sensitive areas, improving soil conservation, and developing silvopastoralism. Other environmental risks associated with GHGs could be reduced through improved diets (to reduce enteric fermentation) and improved manure management strategies (Steinfeld et al., 2006).

The livestock sector is credited with being the biggest anthropogenic user of land at 30% of the ice-free terrestrial surface of the planet (Steinfeld et al., 2006). *Livestock's Long Shadow* concluded that global livestock agriculture contributes 18% of the anthropogenic GHGs and stated that livestock contribute more to climate change than the global transportation sector; however, the global transportation sector was not evaluated with an LCA (Mitloehner and Place, 2009). The UN report admits that in many countries the estimates are imprecise due to lack of data. Of the estimated 7 billion metric tons of CO_2e emitted from livestock production, over half is designated as "imprecise estimates." The 7 billion metric tons could be viewed as an upper bound, rather than an accurate estimate (Massey and Ulmer, 2008).

A newer published report, *Tackling Climate Change Through Livestock* (FAO, 2013), refined some of the previous findings of the FAO 2006 report. This assessment estimated the environmental burdens of the existing situation under current production and market conditions, and then allocated impacts to the various co-products of the production system (FAO, 2013). This differs from the previous LCA approach that only considered the possible consequences of changes in production, and relied on a system expansion analysis to allocate impacts of co-products (Thomassen, 2008).

TRANSPORTATION AND GREENHOUSE GAS EMISSIONS

As a result of high-capacity cargo volumes in modern transportation systems, goods can be efficiently moved over long distances and remain highly fuel efficient and thus environmentally friendly compared to locally grown food. Those results also strongly suggest that food should be grown where the agricultural resources and capacity are most suited to efficient food production rather than converting low-yielding land that is better suited for other purposes such as human occupation or wildlife habitat (Capper et al., 2009).

According to the Association of American Railroads (AAR) the nation's freight railroads in 2010 averaged 71.8 MT/km/liter of diesel (483 ton-miles per gallon of diesel), equating to a 106% fuel efficiency gain since 1980 (AAR, 2011). Railroads are moving more while consuming less fuel, which means they are emitting fewer GHGs and easing highway congestion (AAR, 2011). Freight trains on average carried 3,252 MT (3,585 tons) of freight in 2010, a 61% increase since 1980. The AAR reported data derived from the EPA *Inventory of Greenhouse Gas Emissions and Sinks from 1990-2009* stated that the freight railroads accounted for 0.6% of the total GHG emitted in 2009 and 2.1% of the transportation-related emissions (AAR, 2011). By comparison it would take 280 semi-trucks to haul the same freight as one train.

LIFE CYCLE ANALYSIS

A life cycle analysis is a compilation and evaluation of the inputs, outputs, and the environmental impacts of a product system throughout its life cycle (ISO, 2006). The LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end-of-life treatment and final disposal. Through such a systematic overview and perspective, the shifting of environmental burdens between life cycle stages or individual processes can be identified and possibly avoided (ISO, 2006). When assessing environmental impact, it is essential to use a standardized assessment tool to express impact per functional unit of food, e.g. resource use and waste output per liter or kg of product (Schau and Fet, 2008). The International Standard 14040 describes the principles and framework for a LCA, which include these 4 phases:

1. the goal and scope definition
2. life cycle inventory analysis
3. life cycle impact assessment
4. interpretation of the life cycle

CARBON FOOTPRINT VERSUS CARBON EMISSION

The original ecological footprint concept made popular by Wackernagel and Rees (1996) was used to describe the amount of resource consumption and waste assimilation requirements of a defined human population or economy in terms of corresponding productive land area. This ecological footprint concept has been used by researchers to determine the rate at which carbon, or CO_2e, can be sequestered by productive land areas, but it is most often used to quantify the amount of CO_2e emitted by an activity. These activities can include any process that is not naturally occurring or naturally part of the carbon cycling. Examples include crop production, intensive animal feeding, petroleum production, and transportation. A carbon footprint can be determined for any process that artificially causes carbon to be released after it has been sequestered. It is generally accepted that the term "carbon footprint" is used to describe an emission per unit of product and not the amount of productive land required to sequester carbon emissions or even the amount of land area required to produce said unit. It is generally acceptable to use the term "carbon footprint" when discussing an emission rate related to CO_2e

emissions. The EPA defines carbon footprint as the total amount of GHGs emitted into the atmosphere each year by a person, family, building, organization, or company (EPA, 2015).

CHAPTER 3

MODEL DEVELOPMENT

The LCA/CF model incorporates the regionally distinctive features of the Southern High Plains beef industry including waste management practices, fed-cattle sourcing, concentrate sourcing, and slaughter capacity, while providing a realistic, industry-relevant, and evolving modeling platform for case studies.

A spreadsheet-based model to calculate the emissions based on inputs used per animal in each of the five different systems estimates the carbon footprint/emissions of the feeding industry relative to the production system. The beef cattle systems include a native grass pasture (System One); a native grass pasture with feedlot finishing (System Two); a modified pasture (winter wheat) and feedlot (System Three); a feedlot only system (System Four); and a native grass pasture, modified pasture (winter wheat), and a feedlot (System Five). The model was used to calculate daily net emissions of GHGs from the multiple processes within each system, variable by time. The modeling tool responded dynamically to simulated changes in temperature, diet quality, and feeding strategies common to the SHP. This type of analysis can be scaled for evaluating the entire industry or refined to estimate the footprint of a single animal.

The model simulates different feeding systems and management strategies that are linked and ultimately impact the CF of the industry. The design of the model was to accumulate the CO_2e emissions starting with a weaned steer and ending when the mature steer reaches a common marketable endpoint for each of the five production scenarios. This accounting process, along with a sensitivity analysis, is needed to assess the impacts on resources and CO_2e emissions produced per kilogram of marketed product from a mature, marketable animal. The LCA model was used to determine if the CO_2e emissions per kilogram of marketable beef are different for each of the five described production scenarios that produce a mature, marketable, <30 months of age steer that has a USDA quality grade of "Choice."

MODEL ASSUMPTIONS

This model was built upon several assumptions that were applied to all of the production scenarios equally. The assumptions were:

- The weaned steer that enters each simulated production system had a starting weight of 250 kg and was 205 days old. Each steer entered on the same calendar date (September 1) under the same daily environmental conditions.
- Stocking density was not a component of this model, thus all food sources were assumed to be available *ad libitum* to the growing steer.
- Steers were fed reference diets based on the type of feeding system modeled.
- Daily water consumption by cattle averaged 40.9 liters/day (Parker et al., 2000)
- Native grass pasture diets varied seasonally in nutritional quality.
- Native grass pastures were not modeled as intensively managed systems.
- All systems were modeled with the same daily average temperatures.
- Reference CO_2e values were used for agricultural crop production in the portions of the model where these crops were used as feed in the feedlot system.

- Freight trains and semi-trucks were used as the basis for transporting cattle and agricultural products into the system.
- Corn was shipped into the SHP via unit trains from the Midwest. The CO_2e emissions associated with dryland corn production and grain transport were based on the top corn producing states in the Midwest region of the United States to the Texas Panhandle. (Appendix).
- All other feed sources were assumed to be in the High Plains region.
- All constituents consumed by livestock were reported on a dry matter basis.
- CO_2e emissions were calculated using the equations detailed in chapters 10 and 11 of the IPCC (2006).
- The portion of the model simulating cattle growth was constructed using NRC (1996) *Nutrient Requirements of Beef Cattle*.
- The model concluded when the steer reached an estimated 28% body fat, or 30 months of age, whichever occurred first.
- Functional units (FU) for the model include CO_2e emissions reported as kg CO_2e/kg of gain, kg CO_2e emitted per day, and total kg CO_2e emitted by the system.
- Emissions before the steer entered the system as a weaned calf and emissions associated with transport and slaughter of the finished animal were not included in this LCA.
- CO_2e calculations for transporting the weaned calf to any system were based on the average distance from each of the lower 48 states to the Texas Panhandle.

- CO_2e calculations for water use were based on the amount of electricity used to pump 1,135 liters per minute from a depth of 91 meters.

SYSTEM BOUNDARY

The carbon footprint of CO_2e emissions attributed to beef production was calculated once the system boundary was defined and the stocks and input flows were estimated. Deciding where the system boundary ends is often the most challenging aspect of developing systems based models involving multiple industries. The system boundary selected here begins with a weaned steer calf and ends with a mature, marketable animal at 28% body fat and/or 30 months of age, whichever comes first. The model then tracks the life cycle processes (i.e. resources consumed and wastes generated) of a calf throughout the various growth stages and management systems used to produce beef cattle. The model includes four of the most reasonable pathways by which cattle may be produced in the SHP region, plus a grass-only reference system advocated by some environmental activists, and then estimates the CO_2e emissions from each of the five systems.

CONCEPTUAL MODEL

A conceptual model of the five production systems showing the different management decision/pathways used to produce a mature, marketable animal for slaughter starting from a weaned calf is shown in Figure 1. The pathways do not show the inputs and outputs for each of the sub-systems within the boundaries of the system and are shown only to describe/outline the different pathways/management decisions producers can use to produce a mature, marketable animal.

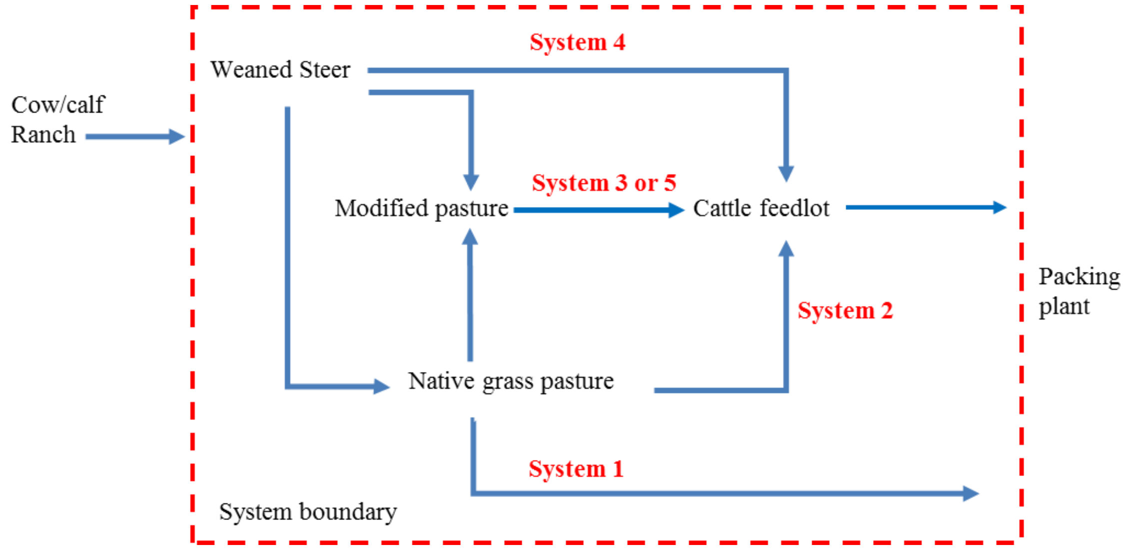

Figure 1. Conceptual model detailing the five production systems and pathways used to produce a mature, marketable animal.

EXPLICIT MODEL DESIGN

This model uses an Excel® spreadsheet-based accounting system that compiles inputs from published literature values, commercially available LCA models, and regionally district practices used in the SHP that contribute to overall CO_2e emissions from five different production strategies. The beef cattle production systems include native pasture grazing only (NGP); a weaned calf placed on a native grass pasture prior to finishing in a feedlot (NGP-FY); a weaned calf shipped directly to a feedlot (FY); a weaned calf placed on a wheat pasture prior to being placed in a feedlot (MP-FY); and a weaned calf placed on a native grass pasture, then moved to wheat pasture prior to finishing in a feedlot (NGP-MP-FY). This LCA considers every major component used by producers and includes agricultural crop production, waste disposal, fossil fuel use, and transportation. The downstream system boundary is reached when the steer reaches 28% body fat or 30 months of age, whichever comes first. This LCA does not include capital goods such as barns, trucks, fencing, roads, tractors, and their associated carbon footprint/environmental burden.

LIVESTOCK GROWTH MODEL

In the National Research Council (NRC, 1996) standard, the requirements for cattle growth are calculated using many variables related to body weight, shrunk weight gain (SWG), empty body weight (EBW), body composition (% fat), and standard reference weight (SRW). The prediction of average daily gain (ADG) from the available metabolizable energy and protein consumed is dependent upon the energy required for maintenance and the composition of the gain. A growth modeling system was used to adjust the shrunk body weight (SBW) to an equivalent shrunk body weight (EQSBW) reference animal given a SRW. The SRW animal used in this model is based on the NRC (1984) medium-frame steer (478 kg steer at 28% body fat) produced from a typical, two-phase feeding program (NRC, 1996) This reference weight was derived from comparative slaughter experiments reported by NRC (1996).

Cattle body weights are typically reported on a shrunk weight basis to remove variation in the actual body weight caused from environmental stressors incurred from shipping, shipping distance, environmental conditions, and handling techniques (MSU, 2008). Shrunk body weight is more specifically the weight of the animal after food and water are withheld for a period of time. Producers use SBW as a marketing tool to deal with the weight loss incurred when an animal leaves one system for the next. The SBW is typically 4% of the actual body weight (ABW), but can be higher depending upon the stressors (NRC, 1996) . Four percent shrink was used in this model for all production systems.

$$SBW = ABW * 0.96 \quad [1]$$

To predict net energy for gain (NE_g) required for SBW and SWG, the empty body weight (EBW) and empty body weight gain (EBG) must be determined using NRC chapter 3 Eq. 3-4, Eq. 3-5, and Eq. 3-6.

$$EBW = 0.891 * SBW \quad [2]$$

$$EBG = 0.956 * SWG \quad [3]$$

$$SWG = 13.91 * \left(NE_{g_{Animal}}{}^{0.9116}\right) * \left(EQSBW^{-0.6837}\right) \quad [4]$$

The EQSBW used in the equation for SWG is detailed in NRC 1996, Chapter 3, Eq. 3-9, and calculated as

$$EQSBW = SBW * \frac{Initial\ SBW}{FSBW} \quad [5]$$

Final shrunk body weight (FSBW) in this model is determined by the endpoint that produces an animal that will grade choice and have a body fat composition near 28%. This model uses data published by Hicks et al. (1989) that relate dry matter intake (DMI) to initial weight, days on feed, and seasonal differences. The main challenge for predicting feed-to-gain conversion is predicting DMI accurately. Since DMI is difficult to predict this model uses the feedlot DMI data collected and published by Hicks et al. (1989) where feedlot growth is modeled. The DMI measurements were reported on a weekly basis, and a simple linear interpolation was used to simulate daily DMI used in this model. The average measured DMI for this first week was estimated to be on day 4 and then every 7th day after that as shown in Figure 2 (Hicks et al., 1989). This method of calculating daily DMI with the modeled feedlot diets is comparable with Hicks findings related to SWG and FSBW of steers at a given starting weight.

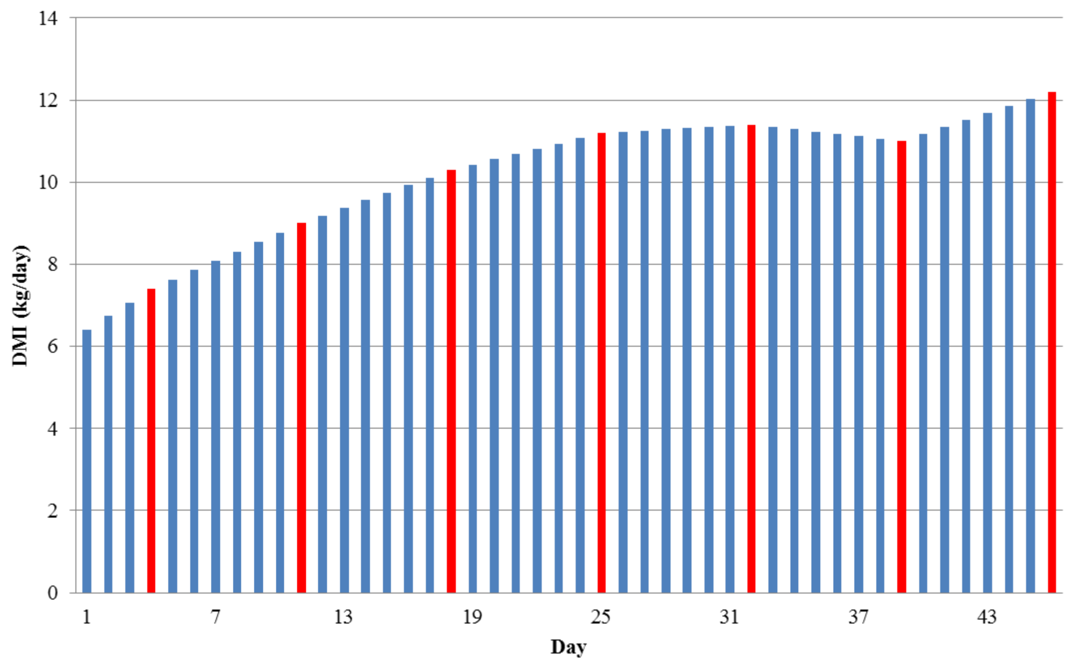

Figure 2. Example of the method used to estimate daily dry matter intake from average weekly values for feedlot cattle using previously published data from Hicks et al. (1989).

Intake calculations for forage-based feeding systems used the published NRC (1984 and 1996) Chapter 7, Eq. 7-a, which describes DMI as a function of dietary NEm_{feed} concentration with adjustments for frame size or sex.

$$DMI = SBW^{0.75} * (0.1493 * NEm_{feed} * NEm_{feed}{}^{2} - 0.0196) \quad [6]$$

This equation for DMI based on NEm_{feed} and SBW was determined by the NRC 1996 subcommittee to be as reasonable as the forage based DMI calculation (referred to as Eq. CP_ADF, NRC 1996), which uses crude protein (CP) and acid detergent fiber (ADF) values to predict DMI for forage-based diets (NRC, 1996).

Net energy feed values for maintenance (NEm_{feed} Mcal day^{-1}) and gain (NEg_{feed} Mcal day^{-1}) were literature values based upon common feedstocks used within the different simulated feeding systems.

$$NEm_{feed} = NRC\ 1996\ Literature\ values\ for\ feed\ type$$

$$NEg_{feed} = NRC\ 1996\ Literature\ values\ for\ feed\ type$$

Forage values and feedlot diet formulations were obtained from the *Beef Cattle Diet Formulation Program* (Galyean, 2015) using values from the 1996 NRC feed library. These diets represent four diets that could be used commercially at feedlots and five range/pasture forage-based diets with seasonal variations. The forage diets and feedlot diets are detailed in Tables 3 and 4.

Table 3. Feedlot Dietary Analysis for Growth Model Inputs (Galyean, 2015).

	Diet 1	Diet 2	Diet 3	Diet 4
Feedlot Ration	65% Concentrate	75% Concentrate	83.5% Concentrate	92% Concentrate
Ingredient	**% of Diet, DM basis**	**% of Diet, DM basis**	**% of Diet, DM basis**	**% of Diet, DM basis**
Corn Grain, Steam Flaked	47.76	59.2	67.15	76.00
Alfalfa Hay, Mid Bloom	20	12.5	8.25	4.00
Cottonseed, Hulls	15	12.5	8.25	4.00
Molasses, Cane	4	4	4	4.00
Tallow	2	2.5	3	3.00
Urea	0.54	0.8	0.85	0.95
Cottonseed, Meal - Sol-41%CP	8.2	6	6	5.55
TTU-2.5 Supplement	2.5	2.5	2.5	2.50
DM Total, %	100	100	100	100
Diet Nutrient Summary				
CP,%	14.00	13.51	13.49	13.50
DIP, % of DM	9.00	8.62	8.41	8.28
NEm, Mcal/kg	1.81	1.94	2.05	2.17
NEg, Mcal/kg	1.17	1.28	1.39	1.49
eNDF, % of DM	24.97	19.69	14.44	9.19
Ca, %	0.79	0.69	0.63	0.56
P, %	0.32	0.31	0.32	0.33
K, %	1.01	0.88	0.80	0.72
Mg, %	0.29	0.26	0.25	0.23
S, %	0.24	0.22	0.22	0.21
Co, mg/kg	0.60	0.62	0.64	0.66
Cu, mg/kg	21.99	20.64	19.80	18.86
Fe, mg/kg	164.21	146.34	136.01	122.80
I, mg/kg	0.60	0.60	0.60	0.60
Mn, mg/kg	78.68	71.55	64.66	57.48
Se, mg/kg	0.25	0.19	0.16	0.13
Zn, mg/kg	92.25	87.97	85.93	83.35
Na, %	0.17	0.16	0.15	0.15
Cl, %	0.43	0.44	0.44	0.44
DCAD, mEq/kg	61.49	33.52	8.69	-5.55

Table 4. Range and Wheat Pasture Dietary Analysis for Growth Model Inputs (Galyean, 2015).

	Diet 10	Diet 11	Diet 12	Diet 13	Diet 14	Diet 15
Range/Pasture	Range (June Diet)	Range (July Diet)	Range (August Diet)	Range (Sept Diet)	Range (Winter Diet)	Wheat
	% of Diet, DM basis	**% of Diet, DM basis**	**% of Diet, DM basis**	**% of Diet, DM basis**	**% of Diet, DM basis**	**% of Diet, DM basis**
DM Total, %	100	100	100	100	100	100
Diet Nutrient Summary						
CP,%	11.00	10.50	9.70	6.90	4.70	11.00
DIP, % of DM	7.92	7.35	6.40	4.62	2.96	
NEm, Mcal/kg	1.48	1.39	1.30	1.21	0.99	1.73
NEg, Mcal/kg	0.88	0.82	0.73	0.64	0.44	1.11
eNDF, % of DM	26.90	27.76	26.12	27.31	27.10	46.20
Ca, %	0.26	0.26	0.26	0.26	0.26	0.42
P, %	0.15	0.15	0.15	0.15	0.15	0.40
K, %	0.00	0.00	0.00	0.00	0.00	3.50
Mg, %	0.00	0.00	0.00	0.00	0.00	0.21
S, %	0.00	0.00	0.00	0.00	0.00	0.22
Co, mg/kg	0.24	0.24	0.24	0.24	0.24	0.00
Cu, mg/kg	0.00	0.00	0.00	0.00	0.00	0.00
Fe, mg/kg	0.00	0.00	0.00	0.00	0.00	100
I, mg/kg	0.00	0.00	0.00	0.00	0.00	0.00
Mn, mg/kg	0.00	0.00	0.00	0.00	0.00	0.00
Se, mg/kg	0.00	0.00	0.00	0.00	0.00	0.00
Zn, mg/kg	0.00	0.00	0.00	0.00	0.00	0.00
Na, %	0.00	0.00	0.00	0.00	0.00	0.18
Cl, %	0.00	0.00	0.00	0.00	0.00	0.00
DCAD, mEq/kg	0.00	0.00	0.00	0.00	0.00	0.00

The animal requirements associated with maintenance and gain have been estimated using NRC (1996) Chapter 1, p. 6, NE_m requirements

$$NEm_{Animal} = (0.077 * EBW^{0.75}) \quad [7]$$

Temperature influences NEm_{animal} requirements for each degree that previous ambient differed from 20°C, NRC (1996) Chapter 1, p. 9, and can be rewritten as:

$$NEm_{Animal} = (0.077 * EBW^{0.75}) + NEm_{temperature} \quad [8]$$

$NEm_{temperature}$ for each system is computed using the 20-year average daily temperature recorded at the USDA Agricultural Research Service Conservation and Production Research Laboratory (CPRL) located in Bushland, Texas (Marek et al., 2005). The daily average temperature was compiled to give a realistic average temperature for any given day in the model. When a feeding system runs longer than a year the temperature data repeat. The daily average temperature is used to reflect the increase in animal maintenance requirements when the temperature differs from 20 °C. This difference from 20°C is termed animal thermoneutrality and the equation is as follows:

$$A_{Thermo} = |Avg\ temp\ ℃ - 20\ ℃| \qquad [9]$$

The temperature effects on animal net energy for maintenance are calculated once A_{thermo} is known. The increase in maintenance is written as:

$$NEm_{Temperature} = (0.00077\ * SBW^{0.75}) * A_{Thermo} \qquad [10]$$

This calculation indicates that the NEm_{animal} requirement changes by 0.00077 Mcal/(kg SBW)$^{0.75}$ for each degree that the previous ambient temperature differs from 20°C (NRC, 1996).

To determine the energy required for animal maintenance and gain, daily DMI must be calculated based on feed composition and feeding regime. Animal net energy for maintenance based on dry matter intake (kg day^{-1}) is calculated as:

$$DMI_{NEm_{Animal}} = \frac{NEm_{Animal}}{NEm_{feed}} \qquad [11]$$

Animal net energy for gain based on dry matter intake (Mcal kg^{-1}) is calculated as:

$$DMI_{NEg_{Animal}} = DMI - DMI_{NEm_{Animal}} \qquad [12]$$

Retained Energy Demand, NRC (1996) Chapter 3, Eq. 3-1, is calculated as:

$$RE_{Demand} = 0.0635 * EBW^{0.75} * EBG^{1.097} \quad [13]$$

Cattle weight gain after maintenance requirements have been met is calculated as:

$$NEg_{Animal} = DMI_{NEg} * NEg_{feed} \quad [14]$$

Cattle weight gain is retained as fat and protein, and the rate at which either is deposited depends on the diet composition and animal weight. The proportions of fat and protein gain were calculated using the following equations, which are based on the 1996 NRC equations 3-2 and 3-3 (Tedeschi, 2004).

$$NEg_{fat} = 0.123 * \frac{NEg_{Animal}}{EBG - 0.154} \quad [15]$$

$$NEg_{Protein} = 0.253908 - 0.0271067 * \frac{NEg_{Animal}}{EBG} \quad [16]$$

Calculating gain based on fat and protein is important to determine the endpoint for each of the different production simulations. The targeted 28% body fat composition was used as the model endpoint since >60% of the cattle marketed nationally graded choice, which is approximately 28% fat content (USDA, 2015). Daily shrunk weight gain in fat was calculated as:

$$SWG_{Fat} = NEg_{fat} * SWG \quad [17]$$

The total shrunk weight gain in fat was used to estimate the body fat content on a daily basis until the animal reached the targeted body fat content. The estimated percentage of body fat on any given day was calculated as:

$$\%BF = \left(\frac{\Sigma SWG_{Fat}}{SBW}\right) * 100 \quad [18]$$

LIVESTOCK EMISSIONS MODEL

The 2006 IPCC guidelines for GHG inventories (chapters 10 and 11) were used to estimate GHG emissions from each of the livestock feeding systems modeled. Methane from enteric fermentation and methane and nitrous oxide emissions from manure management were estimated in each of the feeding systems, along with direct and indirect N_2O emissions from soils. Respiration by livestock was not included, as it is not a net source of CO_2 (FAO, 2006). Emissions from livestock respiration are part of a rapidly cycling biological system in which the plant matter consumed was itself created through the conversion of atmospheric CO_2 into organic compounds, and is not considered a net source under the Kyoto Protocol (FAO, 2006).

Tier One methods for estimating GHG emissions were used when data were insufficient to conduct a more detailed Tier Two assessment. The methods for estimating GHGs emissions on a Tier Two level, or higher, require detailed information about feed digestibility, time on feed, type of animal fed, gross energy of the diet, dietary crude protein, volatile solid (VS) excretion rates, environmental conditions, and the type of manure management system. Tier Two CH_4 emission estimates require feed intake and growth data using the NRC 1996 methods previously described. Once the feed source and intake have been determined, the Tier Two GHG emissions were estimated.

Determining the methane emissions from enteric fermentation was the first step in estimating livestock emissions using the Tier Two approach.

Enteric CH_4 (IPCC 2006, Chapter 10, Eq. 10.21)

$$EF_{CH_4} = \frac{GE * \left(\frac{Y_m}{100}\right) * DOF}{55.65} \qquad [19]$$

EF_{CH4} = Emission factor, kg CH_4 head^{-1} day^{-1}

GE = Gross energy intake, MJ head^{-1} day^{-1}

- GE of the feedstocks used in the model are detailed Table 5

Y_m = CH_4 conversion factor, % of gross energy in feed converted to CH_4

- Y_m feedlot cattle = 3.0% ± 1.0% (IPCC 2006, Chapter 10, Table 10.12)
- Y_m grazing cattle = 6.5% ± 1.0% (IPCC 2006, Chapter 10, Table 10.12)

DOF = Days on feed

The factor 55.65 (MJ/kg CH_4) is the energy content of methane

Table 5. Dietary Gross Energy Values for Model Inputs (INRA, 2015)

Feedstock	GE (MJ/kg DM)
Corn	18.7
Alfalfa	18.2
Cotton Seed Hulls	19.8
Molasses (Cane)	14.7
Tallow	39.0
Urea	0.0
Cotton seed meal	21.2
TTU supplement	0.0
Winter wheat	17.9
Generic grass	18.0

Methane produced from the treatment and storage of manure and manure deposited on pastures is estimated using the detailed Tier Two approach according to IPCC 2006 guidelines. The IPCC term "manure" is used to describe both urine and feces.

CH_4 emissions from manure management (IPCC 2006, Chapter 10, Eq. 10.23)

$$\mathrm{EF}_{CH_4M_{(T)}} = \left(VS_{(T)} * DOF\right) * \left[B_{o_{(T)}} * 0.67 * \sum_{S,k} \frac{MCF_{S,k}}{100} * MS_{T,S,k}\right] \quad [20]$$

$EF_{CH4M(T)}$ = Manure CH_4 emission factor for livestock category *T*, kg CH_4 head^{-1} day^{-1}

Livestock category *T* = cattle

$VS_{(T)}$ = Daily volatile solid excreted for livestock category *T*, kg DM animal^{-1} DOF^{-1}

0.67 kg/m^3 = Density of CH_4 at standard temperature and pressure (15°C and 101.3 kPa) (Air Liquide, 2015)

$B_{o(T)}$ = Maximum methane producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted

$MCF_{(S,k)}$ = Methane conversion factors for each manure management system S by climate region k, $MCF_{(S,k)} = 1.0\%\ drylot\ or\ range$

$MS_{(T,S,k)}$ = Fraction of livestock category T's manure handled using manure management system S by climate region k, dimensionless (IPCC, 2006).

$$MS_{(T,S,k)} = 0.184\ feedlot, annual, cool\ temperature\ (1.0\ if\ daily)$$

$$MS_{(T,S,k)} = 0.815\ Pasture/Range, annual, cool\ temp\ (1.0\ if\ daily)$$

Manure management system default values are based on annual average temperature ≤ 10-14°C, drylot (feedlot) or range/pasture (IPCC, 2006). Manure management systems are defined as pasture/range/paddock where manure from grazing animals is allowed to lie as deposited and is not managed. A dry lot is a paved or unpaved confinement area without any significant vegetative cover and from which accumulating manure may be periodically removed.

Maximum CH_4 producing capacity for manure (IPCC, 2006)

$$B_{o(T)} = 0.19 * VS \qquad [21]$$

Volatile solids (VS) are the organic material in the livestock manure and consist of both biodegradable and non-biodegradable fractions (IPCC, 2006). The VS value for Eq. 10.23 is the total VS as excreted by the livestock.

Volatile solids excretion rate (IPCC 2006, Chapter 10, Eq. 10.24) is written as

$$VS = \left[GE * \left(1 - \frac{DE\%}{100}\right) + (UE * GE)\right] * \left[\frac{1 - ASH}{18.45}\right] \quad [22]$$

GE = Gross energy of the feed derived from literature values

DE = Digestibility of the feed in percent (IPCC 2006, Table 10.2, DE = 75-85% for feedlot, 55-75% for pasture fed animals, and 45-55% animals fed low quality forage)

UE = Urinary energy expressed as fraction of GE. Typically 0.04 GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet)

ME = Metabolizble Energy

ME = DE – (UE + Gaseous Energy)

Ash = The ash content of manure calculated as a fraction of the dry matter feed intake (0.08 for cattle)

18.45 = Conversion factor for dietary GE per kg for dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain based feeds commonly consumed by livestock.

Direct N_2O emissions from manure management occur via combined nitrification and denitrification of nitrogen contained within the manure (IPCC, 2006). The Tier Two methodology for Direct N_2O emissions from manure management (feedlot) can be written as:

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T (N_{(T)} * Nex_{(T)} * MS_{(T,S)})\right] * EF_{3(S)}\right] * \frac{44}{28} \quad [23]$$

$N_2O_{D(mm)}$ = Direct N_2O emissions from manure management in the country, kg N_2O yr^{-1}

$N_{(T)}$ = Number of head of livestock species/category *T* in the country; set to one for this model

$Nex_{(T)}$ = Annual average N excretion per head of species/category *T* in the country, kg N animal^{-1} yr^{-1}

$MS_{(T,S)}$ = Fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$EF_{3(S)}$ = Emission factor for direct N_2O emissions from manure management *S* in the country, kg N_2O/kg N in manure management system *S*. (IPCC, Chapter 10, Table 10.21, EF_3 = 0.02 for dry lot manure management system)

44/28 = Conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

Indirect N_2O emissions from manure management (feedlot and pasture based systems) (IPCC 2006, Chapter 10, Eq. 10.26) can be calculated using Tier One or Tier Two methods. The Tier Two approach used in the model is a combination of equations 26 and 27 to estimate indirect N_2O emissions from manure management systems. The Tier Two equation for indirect N_2O emissions from manure management is:

$$N_{Volt-MMS} = \sum_S \left[\sum_T \left[(N_{(T)} * MS_{(T,S)}) * (Frac_{GasMS}/100)_{(T,S)}\right]\right] \qquad [24]$$

$N_{volt\text{-}MMS}$ = Amount of manure nitrogen that is lost due to volatilization of NH_3 and NO_x, kg N yr^{-1}

$N_{(T)}$ = Number of head of livestock species/category *T*; set to one for this model

$Nex_{(T)}$ = Annual average N excretion per head of species/category *T*, kg N animal^{-1} yr^{-1} (This number is converted to daily excretion based upon nitrogen in the diet)

$MS_{(T,S)}$ = Fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless (This number is converted to daily excretion based upon nitrogen in the diet)

$Frac_{GasMS}$ = Proportion of managed manure nitrogen for livestock category *T* that volatilizes as NH_3 and NO_x in the manure management system *S*, % (IPCC 2006, Chaper 11, Table 11.3 default value = 20% volatilization from all organic N applied or deposited by livestock)

Indirect N_2O emissions due to volatilization of N from manure management (IPCC 2006, Chapter 10, Eq. 10.27)

$$N_2O_{G(mm)} = (N_{volatilization-MMS} * EF_4) * \frac{44}{28} \quad [25]$$

$N_2O_{G(mm)}$ = Indirect N_2O emissions due to volatilization of N from manure management in the country, kg N_2O yr^{-1}

EF_4 = Emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O (kg NH_3-N + NO_x-N volatilized)$^{-1}$; default value is 0.01 kg N_2O (kg NH_3-N + NO_x-N volatilized)$^{-1}$, (IPCC 2006, Chapter 11, Table 11.3)

Direct N_2O (daily) emissions from managed soils (pasture and feedlot), default emission factor of 0.02 kg N_2O-N (kg N)$^{-1}$ of excreted or applied manure.

$$Direct\ N_2O_{man\ soils} = DMI_{kg\ day^{-1}} * \frac{\left(\frac{CP\%}{100}\right)}{6.25} * \left(1 - \frac{\%N\ retained}{100}\right) * MS_{(T,S,k)} * 0.02 \quad [26]$$

DMI = Livestock dry matter intake kg day^{-1}

$MS_{(T,S,k)}$ = Manure management system by livestock species/category *T* that is managed in manure management system *S*, in climatic condition *k*, in the country

%N retained = N retained by livestock (proportion of gain in protein*EBG/6.25)

0.02 = Default emission value (IPCC 2006, Chapter 11, Table 11.3)

Crude Protein = N * 6.25%

Nitrogen intake for cattle

$$N_{intake\ (T)} = \frac{DMI\ *\ \%CP}{625} \quad [27]$$

The carbon dioxide equivalent emission conversion factors can be written as:

$$\hat{Q}_{CO_2e} = \sum_{i=1}^{n} \left[Q_{CO_2,i} + 298 *\ Q_{N_2O,i} + 25 *\ Q_{CH_4,i} \right] \quad [28]$$

$\hat{Q}$= Cumulative emissions of CO_2e per animal (wean to harvest), (kg CO_2e/hd)

$Q_{CO_2,i}$= Daily emission of CO_2 attributed to the animal on day i, (kg CO_2/hd/day)

$Q_{N_2O,i}$= Daily emission of N_2O attributed to the animal on day i, (kg N_2O/hd/day)

$Q_{CH_4,i}$= Daily emission of CH_4 attributed to the animal on day i, (kg CH_4/hd/day)

Coefficients 298 and 25 have units of kg CO_2e/kg N_2O and kg/CO_2e/kg CH_4 respectively.

MODEL UNITS DERIVED FROM LITERATURE VALUES

Model units that were not directly calculated by using the IPCC (2006) or NRC (1996) methods were sourced from peer-reviewed, published manuscripts (Table 6). These values were primarily associated with the feedlot and modified pasture systems. All units derived from the literature values were converted to SI units, CO_2e units, and reported on a dry matter basis where appropriate.

Table 6. Model Units and Parameters Sourced from Literature Values.

Parameter	Units	Values	Source
Diesel Fuel Use	kg CO_2e/liter	2.681	USEIA, 2011
Electricity 1kW hr	MT CO_2e	0.0007	USEIA, 2011
Natural Gas to Steam Flake	CO_2e kg/m^3	0.176	Macken et al., 2006
Urea Production	kg CO_2e/liter	1.13	Skowronska and Filipek, 2014
Feed Grade Molasses	kg CO_2e/liter	0.425	Ingo et al., 2012
Tallow	kg CO_2e/liter	0.184	Mulvaney, 2014
Wheat Biomass	kg CO_2e/ha/yr	1.81	MSU, 2015 (Appendix)
Corn Grain	kg CO_2e/ha/yr	3.13	MSU, 2015 (Appendix)
Alfalfa Hay	kg CO_2e/ha/yr	0.23	Desjardins et.al, 2010
Cottonseed Meal	kg CO_2e/kg	0.508	Murphy et.al, 2010
Cottonseed Hull	kg CO_2e/kg	0.298	Murphy et.al, 2010
Corn Yield (grain + biomass)	MT/ha	11.14	MSU, 2015 (Appendix)
Wheat Biomass Yield	MT/ha	8.35	Xue et.al, 2013
Wheat Grain Yield	MT/ha	2.92	MSU, 2015 (Appendix)
Alfalfa Hay Yield	MT/ha	8.4	USDA, 2015
TTU Supplement	kg CO_2e/kg	0	NA
Digestible Energy	% FY diet	80	IPCC, 2006
Digestible Energy	% MP diet	65	IPCC, 2006
Digestible Energy	% NGP diet	50	IPCC, 2006
Water Consumption	liters/day	40.9	Parker et al., 2000
Diesel Semi-truck	MT/km/liter	51.7	CSX, 2015
Diesel Train	MT/km/liter	186.4	CSX, 2016

CHAPTER 4

RESULTS AND DISCUSSION

SYSTEM ONE – NATIVE GRASS PASTURE

System One was modeled as a native grass pasture (NGP) feeding system with minimal inputs. Inputs included a weaned steer, water consumption, a generic native range/pasture with seasonal nutritional variation, and transportation (semi-truck) of weaned calves to the system. Emissions from the system totaled 6,635 kg CO_2e to produce a FSBW 500 kg steer (Table 7) in 698 days. The emission rate/kg gain equaled 26.49 kg CO_2e, resulting in a daily average emission rate of 9.50 kg CO_2e. Methane from enteric fermentation was responsible for 41% of the total CO_2e emissions totaling 2,703 kg CO_2e, and averaged 3.9 kg CO_2e/day. Methane emissions from manure management totaled 67 kg CO_2e, and averaged 0.097 kg CO_2e/day. Direct N_2O emissions from manure management contributed 52% of the total CO_2e emissions at 3,459 kg CO_2e, and averaged 4.95 kg CO_2e/day. Indirect N_2O emissions from manure management totaled 0.543 kg CO_2e and averaged 0.0008 kg CO_2e/day. N_2O emissions from managed soils totaled 346 kg CO_2e and averaged 0.50 kg CO_2e daily.

The livestock growth model predicted the steer would reach the targeted FSBW of 500 kg in 698 days with a total production time (weaned age + modeled DOF) of 903 days (30.1 months) with a final body fat content of 21% (Table 7). The targeted fat content of 28% was not achievable in the model timeframe due to nutrient limitations of the native rangeland. Total gross energy consumed by the steer was 92,583 MJ and averaged 133 MJ/day. The gross energy required to produce 1 kg of gain was 370 MJ. Gross energy is not a measure of digestibility, and the high values for MJ/kg gain were expected. Livestock water consumption totaled 28,548 liters for days on feed or 114 liters/kg gain. Dry matter intake totaled 5,143 kg and averaged 20.57 kg DM/kg gain. Total manure dry matter excreted was 4,892 kg. The lack of a high quality diet during periods of the feeding process adversely affected the average daily gain (0.36 kg) and increased the total days on feed, thus increasing the feeding duration, total emissions, and resource consumption.

Table 7. System One, Native Grass Pasture (NGP) Model Summary.

System 1 NGP					
Total Production Days	903	Total GE Fed (MJ)	92,583	Manure Mgmt N_2O (kg CO_2e)	3,459
Total DOF	698	GE (MJ/kg gain)	370	Manure Mgmt N_2O (kg CO_2e/day)	4.95
FSBW (kg)	500	Avg. GE/day	133	% Emissions From Manure Mgmt N_2O	52
BW Gain (kg)	250	Water Consumed (liter)	28,548	Indirect Manure Mgmt N_2O (kg CO_2e)	0.543
ADG (SWG kg/day)	0.36	Water (liter/kg gain)	114	Managed Soils N_2O (kg CO_2e)	346
% Fat at FSBW	21	Enteric CH_4 (kg CO_2e)	2,703	Other CO_2e Emissions*	56.62
DM Consumed (kg)	5,143	Enteric CH_4 (kg CO_2e/day)	3.9	Total CO_2e Emissions (kg)	6,632
DM Excreted (kg)	4,892	% Emissions Enteric Ferm.	41	kg CO_2e /kg SBW Gain	26.5
DM/kg Gain	20.57	Manure Mgmt CH_4 (kg CO_2e)	67	kg CO_2e/day	9.5

Other CO_2e emissions* account for emissions not directly emitted by the animal. These emissions include: fossil fuels, fertilizer, crop production, electricity, feed, feed additives, and transportation.

SYSTEM TWO – NATIVE GRASS PASTURE – FEEDLOT

System Two was modeled as a NGP and feedlot system. Inputs included a weaned steer, water consumption, a generic native range/pasture with seasonal nutritional variation, transportation (semi-truck, and train), concentrated and nutritionally balanced feedlot rations. Emissions from this system totaled 2,918kg CO_2e to produce a FSBW 634 kg steer (Table 8) in 444 days. The emission rate/kg gain equaled 7.61 kg CO_2e, resulting in a daily average emission rate of 6.57 kg CO_2e. Methane from enteric fermentation was responsible for 42% of the CO_2e emissions totaling 1,212 kg CO_2e. Daily CO_2e emissions from enteric fermentation averaged 2.7 kg. Methane emissions from manure management totaled 20 kg CO_2e and averaged 0.045 kg CO_2e/day. Direct N_2O emissions from manure management totaled 1,068 kg CO_2e and averaged 2.41 kg CO_2e/day. Direct N_2O emissions from manure management contributed 37% of the total emissions and indirect N_2O emissions from manure management totaled 0.428 kg CO_2e and average 0.001 kg CO_2e/day. The N_2O emissions from managed soils totaled 273 kg CO_2e and averaged 0.61 kg CO_2e/day.

The livestock growth model predicted the steer would reach a targeted body fat content of 28% at a FSBW of 634 kg in 444 days (Table 8). The total production time, including the age of the weaned calf, was 649 days (21.6 months). Total gross energy consumed by the steer totaled 42,807 MJ and averaged 96 MJ/day, or 111 MJ/kg of gain. Livestock water consumption totaled 18,160 liters for days on feed or 47 liters/kg gain. The average daily gain was 0.86 kg/day. The feeding duration was decreased as compared to System One and total emissions and resource consumption were also decreased. Dry matter intake totaled 3,238 kg or 8.43 kg DM/kg gain, and manure dry matter excreted totaled 2,854 kg.

Table 8. System Two, Native Grass Pasture – Feedlot (NGP-FY) Model Summary.

System 2 NGP-FY					
Total Production Days	649	Total GE Fed (MJ)	42,807	Manure Mgmt N_2O (kg CO_2e)	1,068
Total DOF	444	GE (MJ/kg gain)	111	Manure Mgmt N_2O (kg CO_2e/day)	2.41
FSBW (kg)	634	Avg. GE/day	96	% Emissions From Manure Mgmt N_2O	37
BW Gain (kg)	384	Water Consumed (liter)	18,160	Indirect Manure Mgmt N_2O (kg CO_2e)	0.428
ADG (SWG kg/day)	0.86	Water (liter/kg gain)	47	Managed Soils N_2O (kg CO_2e)	273
% Fat at FSBW	28	Enteric CH_4 (kg CO_2e)	1,212	Other CO_2e Emissions*	344.97
DM Consumed (kg)	3,238	Enteric CH_4 (kg CO_2e/day)	2.7	Total CO_2e Emissions (kg)	2,918
DM Excreted (kg)	2,854	% Emissions Enteric Ferm.	42	kg CO_2e /kg SBW Gain	7.6
DM/kg Gain	8.43	Manure Mgmt CH_4 (kg CO_2e)	20	kg CO_2e/day	6.6

Other CO_2e emissions* account for emissions not directly emitted by the animal. These emissions include: fossil fuels, fertilizer, crop production, electricity, feed, feed additives, and transportation.

SYSTEM THREE – MODIFIED PASTURE – FEEDLOT

System Three was modeled as a wheat pasture and feedlot system. Inputs included a weaned steer, water consumption, fossil fuel use, wheat pasture, transportation (semi-truck, and train), concentrated and nutritionally balanced feedlot diets. Emissions from this system totaled 3,255 kg CO_2e to produce a FSBW 676 kg steer (Table 9) in 292 days. The emission rate/kg gain totaled 7.64 kg CO_2e, resulting in a daily average emission rate of 11.15 kg CO_2e. Methane from enteric fermentation was responsible for 30% of the CO_2e emissions totaling 992 kg CO_2e. Daily CO_2e emissions from enteric fermentation averaged 3.4 kg. Methane emissions from manure management totaled 15 kg CO_2e and averaged 0.051 kg CO_2e/day. Direct N_2O emissions from manure management totaled 1,273 kg CO2e and averaged 4.36 kg CO_2e/day, contributing 39% of the total CO_2e emissions. Indirect N_2O emissions from manure management totaled 0.408 kg CO2e and averaged 0.0014 kg CO_2e/day. N_2O emissions from managed soils totaled 259 kg CO_2e and averaged 0.89 kg CO_2e/day.

The livestock growth model predicted the steer would reach a targeted FSBW of 676 kg in 292 days with a total production time, including the age of the weaned calf, of 497 days (16.6 months) with a body fat content of 28% (Table 9). Total gross energy consumed by the steer totaled 33,724 MJ, and averaged 115 MJ/day, or 79 MJ/kg of gain. Livestock water consumption totaled 11,943 liters for days on feed or 28 liters/kg gain. The average daily gain was 1.46 kg/day. Feeding duration was decreased as compared to Systems One and Two, thus decreasing total emissions and resource consumption. Dry matter intake totaled 2,612 kg and the DM/kg gain totaled 6.13 kg DM/kg. The manure dry matter excreted totaled 2,185 kg.

Table 9. System Three, Modified Pasture – Feedlot (MP-FY) Model Summary.

System 3 MP-FY					
Total Production Days	497	Total GE Fed (MJ)	33,724	Manure Mgmt N_2O (kg CO_2e)	1,273
Total DOF	292	GE (MJ/kg gain)	79	Manure Mgmt N_2O (kg CO_2e/day)	4.36
FSBW (kg)	676	Avg. GE/day	115	% Emissions From Manure Mgmt N_2O	39
BW Gain (kg)	426	Water Consumed (liter)	11,943	Indirect Manure Mgmt N_2O (kg CO_2e)	0.408
ADG (SWG kg/day)	1.46	Water (liter/kg gain)	28	Managed Soils N_2O (kg CO_2e)	259
% Fat at FSBW	28	Enteric CH_4 (kg CO_2e)	992	Other CO_2e Emissions*	715.59
DM Consumed (kg)	2,612	Enteric CH_4 (kg CO_2e/day)	3.4	Total CO_2e Emissions (kg)	3,255
DM Excreted (kg)	2,185	% Emissions Enteric Ferm.	30	kg CO_2e /kg SBW Gain	7.6
DM/kg Gain	6.13	Manure Mgmt CH_4 (kg CO_2e)	15	kg CO_2e/day	11.1

Other CO_2e emissions* account for emissions not directly emitted by the animal. These emissions include: fossil fuels, fertilizer, crop production, electricity, feed, feed additives, and transportation.

SYSTEM FOUR – FEEDLOT

System Four was modeled as a feedlot system only. Inputs included a weaned steer, water consumption, fossil fuel use, transportation (semi-truck and train), concentrated and nutritionally balanced feedlot diets. Emissions from this system totaled 1,799 kg CO_2e to produce a FSBW 622 kg steer (Table 10) in 247 days. The emission rate/kg gain equaled 4.84 kg CO_2e, resulting in a daily average emission rate of 7.28 kg CO_2e.

Methane from enteric fermentation was responsible for 29% of the CO_2e emissions totaling 2,104 kg CO_2e and averaged 2.1 kg/day. Methane emissions from manure management totaled 15 kg CO_2e and averaged 0.061 kg CO_2e/day. Direct N_2O emissions from manure management totaled 363 kg CO_2e, averaged 1.47 kg CO_2e/day, and contributed 20% of the total CO_2e emissions. Indirect N_2O emissions from manure management totaled 0.363 kg CO_2e and average 0.0015 kg CO_2e/day. N_2O emissions from managed soils totaled 231 kg CO_2e and averaged 0.94 kg CO_2e daily.

The livestock growth model predicted the steer would reach the targeted body fat content of 28% and FSBW of 622 kg in 247 days (Table 10). Total production time including the age of the weaned calf totaled 452 days (15.1 months). Total gross energy consumed by the steer totaled 39,277 MJ, an average of 159 MJ/day, resulting in 106 MJ/kg of gain. Livestock water consumption totaled 10,102 liters for days on feed or 27 liters/kg gain. The average daily gain was 1.54 kg/day and the total feeding duration was decreased as compared to Systems One, Two and Three. Dry matter intake totaled 2,104 kg and the DM/kg gain totaled 5.66 kg. The manure dry matter excreted totaled 1,731 kg.

Table 10. System Four Feedlot (FY) Model Summary.

System 4 FY					
Total Production Days	452	Total GE Fed (MJ)	39,277	Manure Mgmt N_2O (kg CO_2e)	363
Total DOF	247	GE (MJ/kg gain)	106	Manure Mgmt N_2O (kg CO_2e/day)	1.47
FSBW (kg)	622	Avg. GE/day	159	% Emissions From Manure Mgmt N_2O	20
BW Gain (kg)	372	Water Consumed (liter)	10,102	Indirect Manure Mgmt N_2O (kg CO_2e)	0.363
ADG (SWG kg/day)	1.54	Water (liter/kg gain)	27	Managed Soils N_2O (kg CO_2e)	231
% Fat at FSBW	28	Enteric CH_4 (kg CO_2e)	529	Other CO_2e Emissions*	660.34
DM Consumed (kg)	2,104	Enteric CH_4 (kg CO_2e/day)	2.1	Total CO_2e Emissions (kg)	1,799
DM Excreted (kg)	1,731	% Emissions Enteric Ferm.	29	kg CO_2e /kg SBW Gain	4.8
DM/kg Gain	5.66	Manure Mgmt CH_4 (kg CO_2e)	15	kg CO_2e/day	7.3

Other CO_2e emissions* account for emissions not directly emitted by the animal. These emissions include: fossil fuels, fertilizer, crop production, electricity, feed, feed additives, and transportation.

SYSTEM FIVE – NATIVE GRASS PASTURE – MODIFIED PASTURE – FEEDLOT

System Five was modeled as a NGP, wheat pasture, and a feedlot system. Inputs included a weaned calf, water consumption, fossil fuel use, wheat pasture, generic native range/pasture with seasonal variation, transportation (semi-truck, and train), concentrated and nutritionally balanced feedlot rations. Emissions from this system totaled 3,737 kg CO_2e to produce a FSBW 709 kg steer (Table 11). The emission rate/kg gain equaled 8.15 kg CO_2e, resulting in a daily average emission rate of 11.12 kg CO_2e. Methane emissions from enteric fermentation were responsible for 32% of the CO_2e emissions totaling 1,209 kg CO_2e, or 3.6 kg CO_2e/day. Methane emissions from manure management totaled 29 kg CO_2e and averaged 0.086 kg CO_2e/day. Direct N_2O emissions from manure management totaled 1,489 kg CO_2e, averaged 4.43 kg CO_2e/day, and contributed 40% of the total emissions. Indirect N_2O emissions from manure management totaled 0.440 kg CO_2e and averaged 0.0013 kg CO_2e/day. N_2O emissions from managed soils totaled 280 kg CO_2e and averaged 0.83 kg CO_2e/day.

The livestock growth model predicted the steer would reach a targeted body fat content of 28% with FSBW of 709 kg in 336 days (Table 11). Total production time, including the age of the weaned calf, totaled 541 days (18.0 months). Total gross energy consumed by the steer totaled 55,197 MJ, and averaged 164 MJ/day or 120 MJ/kg of gain. Livestock water consumption totaled 13,742 liters for days on feed or 30 liters/kg gain. The average daily gain was 1.37 kg/day. The feeding duration was decreased compared to Systems One and Two, but was higher than Systems Three and Four. Dry matter intake totaled 3,023 kg and the DM/kg gain totaled 6.59 kg. The manure dry matter excreted totaled 2,562 kg.

Table 11. System Five, Native Grass Pasture – Modified Pasture – Feedlot (NGP-MP-FY) Model Summary.

System 5 NGP-MP-FY					
Total Production Days	541	Total GE Fed (MJ)	55,197	Manure Mgmt N_2O (kg CO_2e)	1,489
Total DOF	336	GE (MJ/kg gain)	120	Manure Mgmt N_2O (kg CO_2e/day)	4.43
FSBW (kg)	709	Avg. GE/day	164	% Emissions From Manure Mgmt N_2O	40
BW Gain (kg)	459	Water Consumed (liter)	13,742	Indirect Manure Mgmt N_2O (kg CO_2e)	0.440
ADG (SWG kg/day)	1.37	Water (liter/kg gain)	30	Managed Soils N_2O (kg CO_2e)	280
% Fat at FSBW	28	Enteric CH_4 (kg CO_2e)	1,209	Other CO_2e Emissions*	729.76
DM Consumed (kg)	3,023	Enteric CH_4 (kg CO_2e/day)	3.6	Total CO_2e Emissions (kg)	3,737
DM Excreted (kg)	2,562	% Emissions Enteric Ferm.	32	kg CO_2e /kg SBW Gain	8.1
DM/kg Gain	6.59	Manure Mgmt CH_4 (kg CO_2e)	29	kg CO_2e/day	11.1

Other CO_2e emissions* account for emissions not directly emitted by the animal. These emissions include: fossil fuels, fertilizer, crop production, electricity, feed, feed additives, and transportation.

SYSTEM COMPARISONS

Each of the modeled systems had different emission rates, FSBW, resource consumption, and production time. Tables 12-14 summarize the feeding systems inputs and corresponding CO_2e emissions for the five systems.

Table 12. CO_2e Emissions Summary by Production System.

CO_2e Emission Summary	System 1	System 2	System 3	System 4	System 5
Enteric CO_2e (kg/Total DOF)	2,703	1,212	992	529	1,209
Enteric CO_2e (kg/day)	3.9	2.7	3.4	2.1	3.6
% Emissions From Enteric Fermentation	41	42	30	29	32
Manure Mgmt. CH_4 (kg CO_2e/Total DOF)	67	20	15	15	29
Manure Mgmt. CH_4 (kg CO_2e/day)	0.097	0.045	0.051	0.061	0.086
Manure Mgmt. N_2O (kg CO_2e/Total DOF)	3,459	1,068	1,273	363	1,489
Manure Mgmt. N_2O (kg CO_2e/day)	4.95	2.41	4.36	1.47	4.43
% Emissions From Manure Mgmt. N_2O	52	37	39	20	40
Indirect Manure Mgmt. N_2O (kg CO_2e/DOF)	0.543	0.428	0.408	0.363	0.440
Indirect Manure Mgmt. N_2O (kg CO_2e/day)	0.0008	0.0010	0.0014	0.0015	0.0013
Mngd. Soils N_2O (kg CO_2e/Total DOF)	346	273	259	231	280
Mngd. Soils N_2O (kg CO_2e/day)	0.50	0.61	0.89	0.94	0.83
Total CO_2e Emissions (kg)	6,632	2,918	3,255	1,799	3,737
CO_2e kg/kg SBW Gain	26.49	7.61	7.64	4.84	8.15
CO_2e kg/LCA Day	9.50	6.57	11.15	7.28	11.12

Table 13. Livestock Growth Model Summary by Production System.

Growth Model Summary	System 1	System 2	System 3	System 4	System 5
Total Production Days	903	649	497	452	541
Total Production Months	30.1	21.6	16.6	15.1	18.0
DOF	698	444	292	247	336
Starting SBW (kg)	250	250	250	250	250
FSBW (kg)	500	634	676	622	709
Targeted FSBW	500	601	636	568	683
BW Gain (kg)	250	384	426	372	459
ADG (SWG kg/day)	0.36	0.86	1.46	1.54	1.37
% Fat At FSBW	21	28	28	28	28

Table 14. Mass and Energy Summary by Production System.

Mass and Energy Summary	System 1	System 2	System 3	System 4	System 5
DM Consumed (kg)	5,143	3,238	2,612	2,104	3,023
DM Excreted (kg/Manure)	4,892	2,854	2,185	1,731	2,562
DM Consumed/kg Gain (kg)	20.57	8.43	6.13	5.66	6.59
Total GE Fed (MJ)	92,583	42,807	33,724	39,277	55,197
Gross Energy/kg Gain (MJ/kg gain)	370	111	79	106	120
Average GE/Day (MJ)	133	96	115	159	164
Total Water Consumed (liter)	28,548	18,160	11,943	10,102	13,742
Daily Water Consumption (liter/day)	40.9	40.9	40.9	40.9	40.9
Water Consumption/kg Gain (liter/kg gain)	114	47	28	27	30

Cumulative CO_2e emissions from System One (NGP) were the highest while those of System Four (FY) was the lowest (Figure 2). Total CO_2e emissions from System One (NGP) were 56%, 51%, 73%, and 44% higher than Systems Two through Five, respectively. The reduction in total CO_2e emissions can be attributed to a nutritionally improved diet that decreased production time for the targeted FSBW at 28% body fat. Direct N_2O emissions from manure management and CH_4 emissions from enteric fermentation were the largest contributors to the overall CO_2e footprint of the modeled production systems (Tables 12-14; Figure 3-5). Other emissions not directly attributed to the steer, such as crop production, fossil fuels, transportation, electricity, feed, and feed additives were higher in the systems where steers where finished in the feedlot (Figure 3). These emissions totaled 1%, 12%, 22%, 37%, and 20% for Systems One through Five respectively. While System Four had the lowest footprint, the “other” emissions were higher than all other systems.

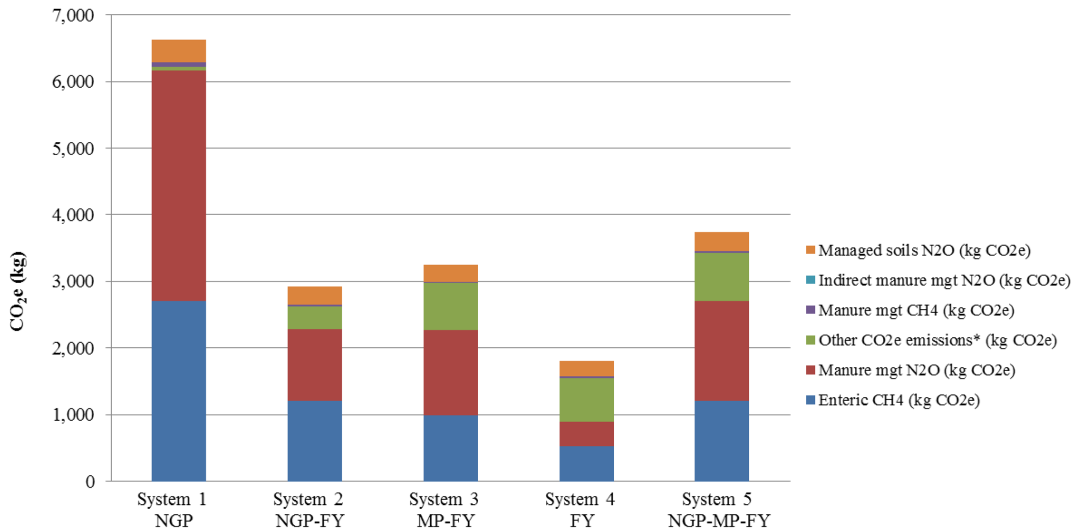

Figure 3. Cumulative CO_2e emissions to produce a marketable steer from five beef production systems in the Southern High Plains.

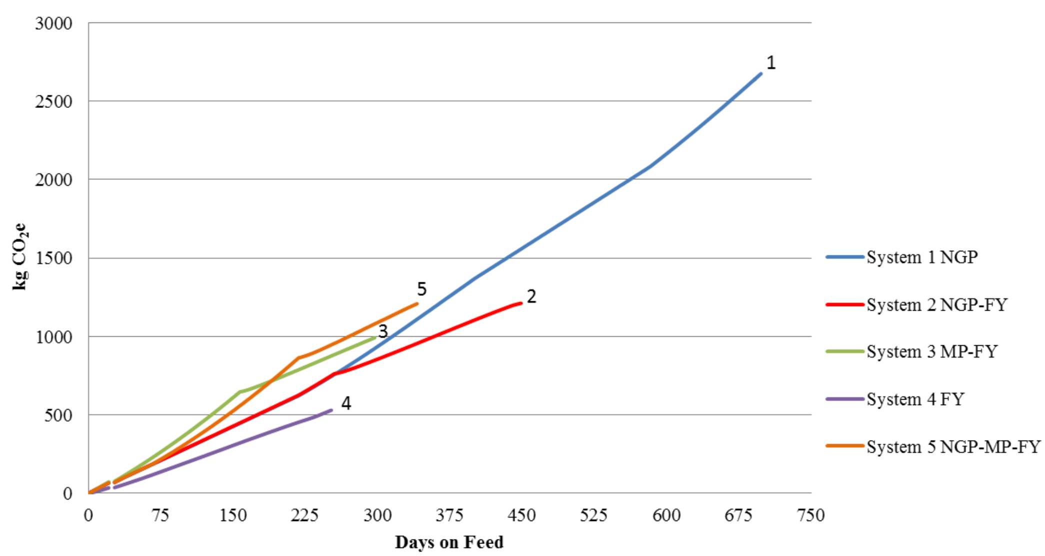

Figure 4. Methane emissions from enteric fermentation (kg CO_2e) by production system.

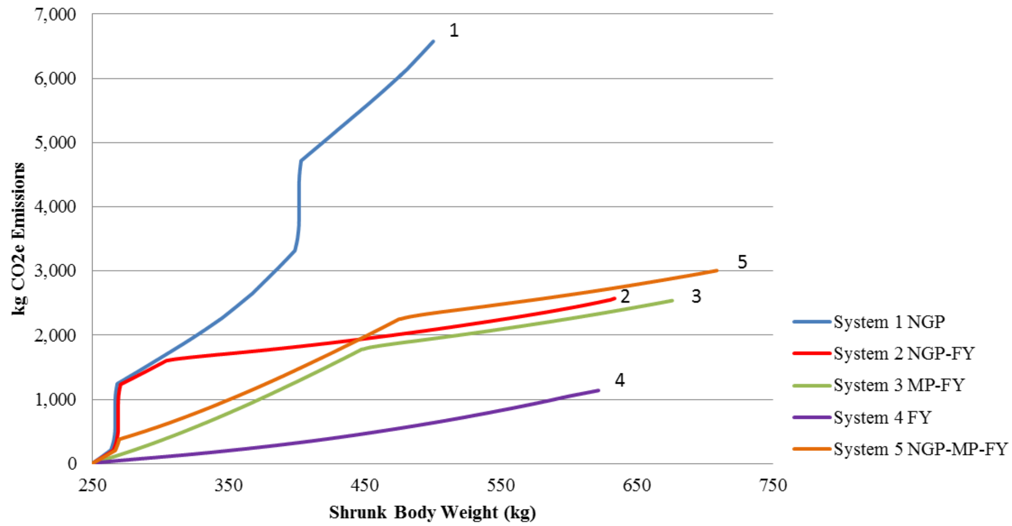

Figure 5. Cumulative CO_2e emissions vs. shrunk body weight for the five beef production systems in the Southern High Plains.

Production time for System One (NGP) was 50% longer than that of System Four, which had the shortest feeding duration of the modeled production systems (Tables 12-14; Figure 6). The FSBW for System One was also 122 kg less than the next lowest FSBW and 209 kg less than the System Five. The modeling endpoints, of ≤30 months of age or 28 % body fat content, dictate that the System One steer have a relatively small FSBW as compared to Systems Two through Five.

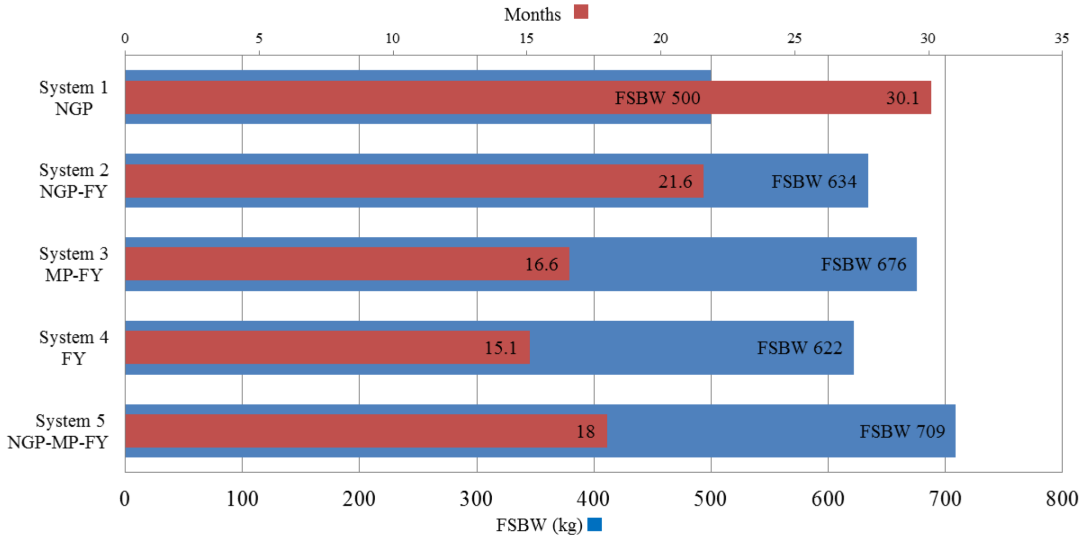

Figure 6. Production time to produce a marketable steer from five beef production systems in the Southern High Plains.

The simulated production systems produced a finished steer in as few as 247 days (post weaning) in System Four (FY) and as many as 698 days in System One (NGP) (Tables 12-14; Figures 6 and 7). The range of simulated feeding days reflects differences in diet quality and temperature effects on animal net energy for maintenance (Figure 6). The stair-stepped portions of the line graphs in Figure 7 reflect seasonal variation in gain when maintenance energy was met, but net energy for gain was not, due to the increased maintenance needs. This is prominent in Systems One through Three, where the NGP portion of the model coincided with cold winter temperatures typical of the Southern High Plains. A compounding effect of the cold temperatures causes the native grass pastures to go dormant, resulting in decreased quality and digestibility of the forage. The low temperatures and low digestibility of the dormant forages make weight gain negligible during this time of the year (October to March), even if *ab libitum* conditions are assumed. Highly digestible, concentrated diets typically fed by feedlots and high quality forages such as wheat pastures are affected less by colder seasonal temperatures. The net energy for maintenance and for gain are met with these diets. This is not to say that cold weather does not affect beef cattle on high quality forages, rather that there is less of an effect on weight gain/performance.

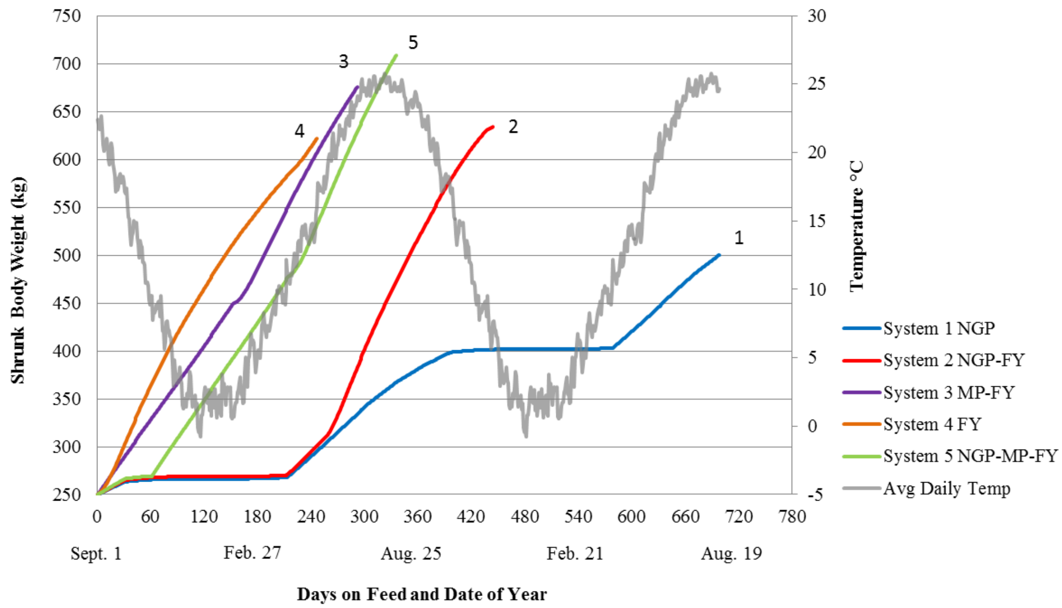

Figure 7. Days on feed for a weaned steer to achieve market size SBW at 28% body fat content, or ≤ 30 months of age, whichever comes first.

Dry matter intake and overall gross energy consumed from the five beef production systems varied with quality of the diet. Beef cattle modeled in the NGP portions of the systems had a higher total dry matter intake, GE consumed, and feed-to-gain ratio as compared to Systems Two through Five (Tables 12-14; Figures 8-10). The high quality, concentrated feedlot ration used to finish cattle in Systems Two through Five lowered the overall DMI, and GE, while decreasing DMI-to-gain ratios. Daily averages for GE intake were highest for Systems Four and Five as compared to Systems One through Three (Figure 11). The higher daily GE values decreased overall production time and increased FSBW for Systems Two through Five. Higher average daily GE values and increased feed digestibility increased the average daily gain in the Systems Two through Five (Figure 12).

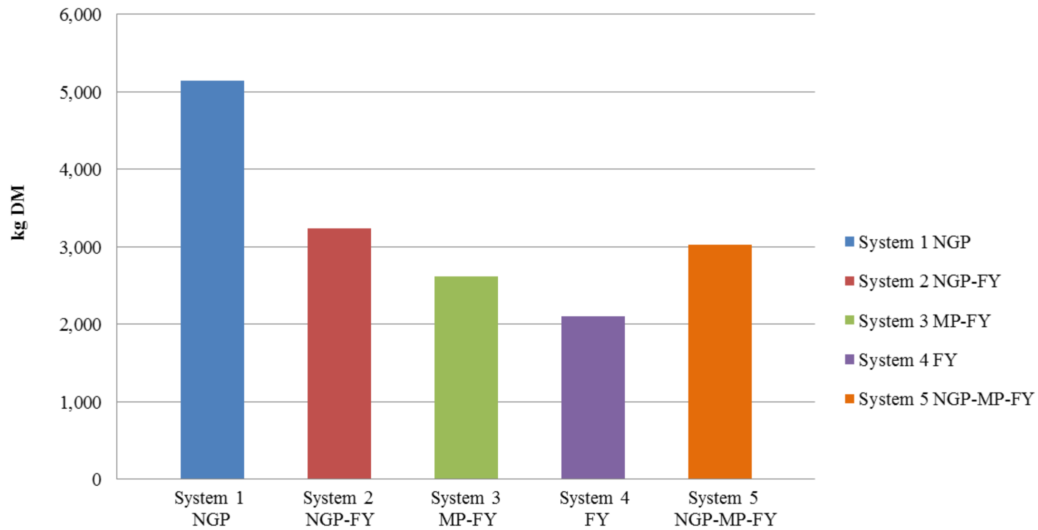

Figure 8. Cumulative dry matter intake to produce a marketable steer from the five modeled beef production systems.

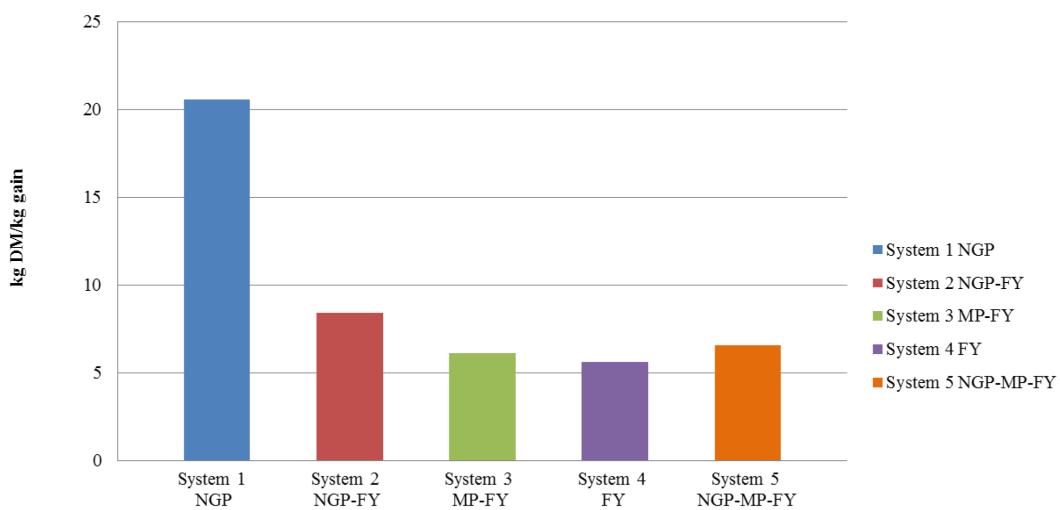

Figure 9. Dry matter intake per kilogram of gain to produce a marketable steer from the five modeled beef production systems.

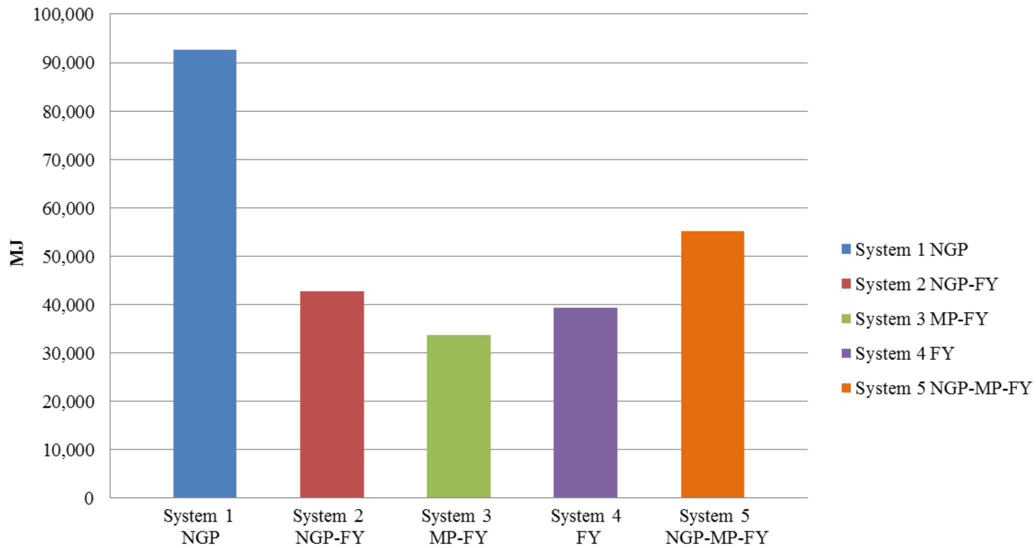

Figure 10. Cumulative dietary GE to produce a marketable steer from the five modeled beef production systems.

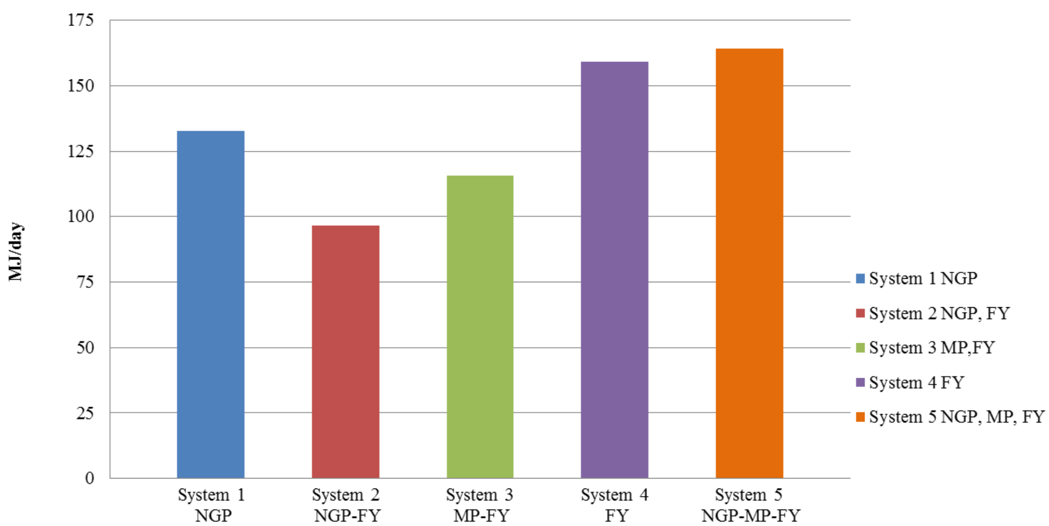

Figure 11. Average daily GE consumed to produce a marketable steer from the five modeled beef production systems.

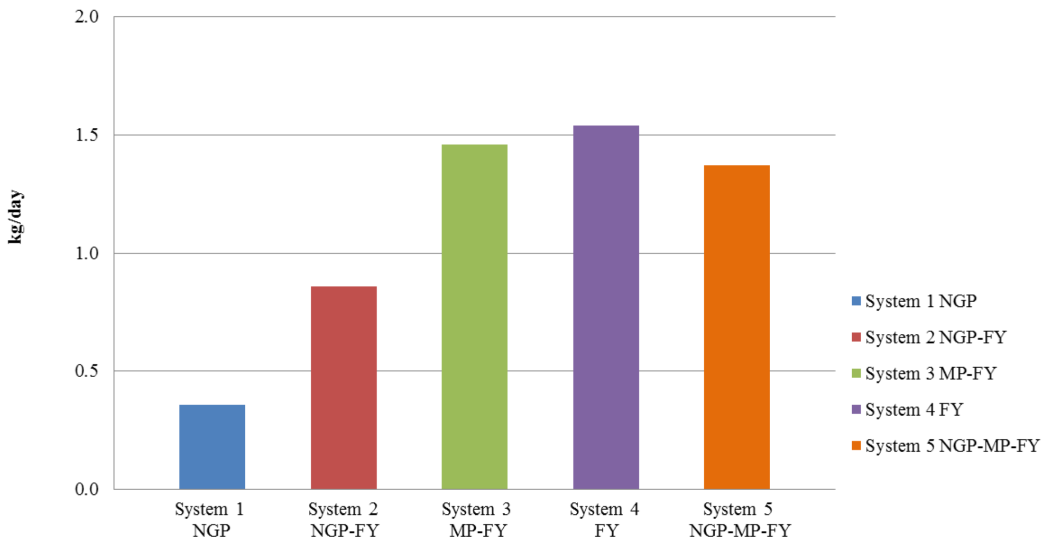

Figure 12. Beef cattle average daily gain by production system.

Increased amounts of manure are produced by the systems as the efficiency of feed conversion decreases (Figure 13). This increase in manure has a direct environmental consequence to the total CO_2e emissions produced by the different feeding systems. Feeding low quality forage for long periods of time, as in System One, increases the total amount of manure excreted for a given FSBW. The increased manure directly increases N_2O in the manure management and managed soils calculations, thus increasing total CO_2e emissions (Tables 12-14; Figure 3).

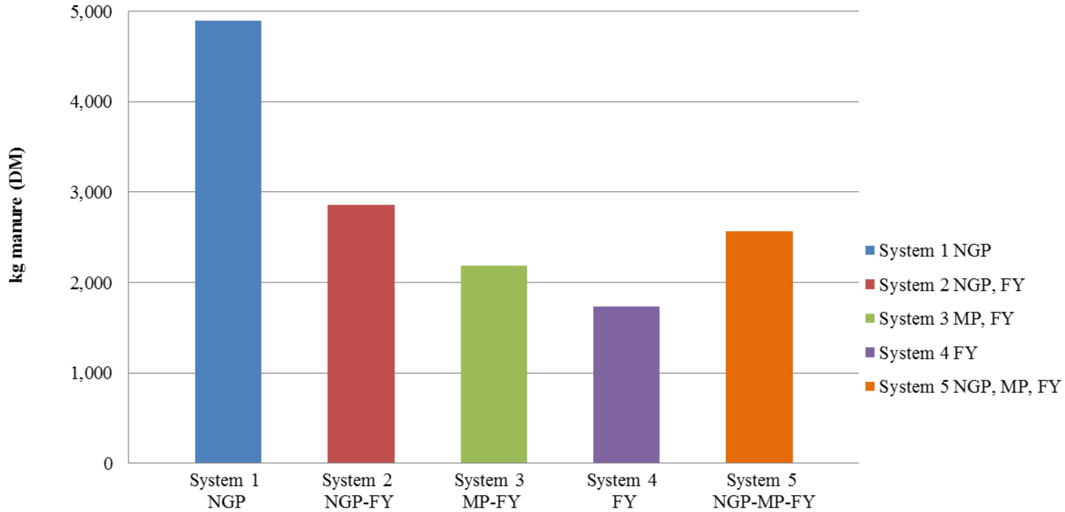

Figure 13. Total manure excreted to produce a marketable steer from the five modeled beef production systems.

Water consumption was assumed to be the same average daily value irrespective of the feeding system. Published results from Parker et al. (2000) reported daily water consumption averaged 40.9 L/head/day. Days on feed to achieve market size steers affect the amount of water used in each system and the longer feeding periods affect the liters of water per kilogram of gain (Figure 14-15).

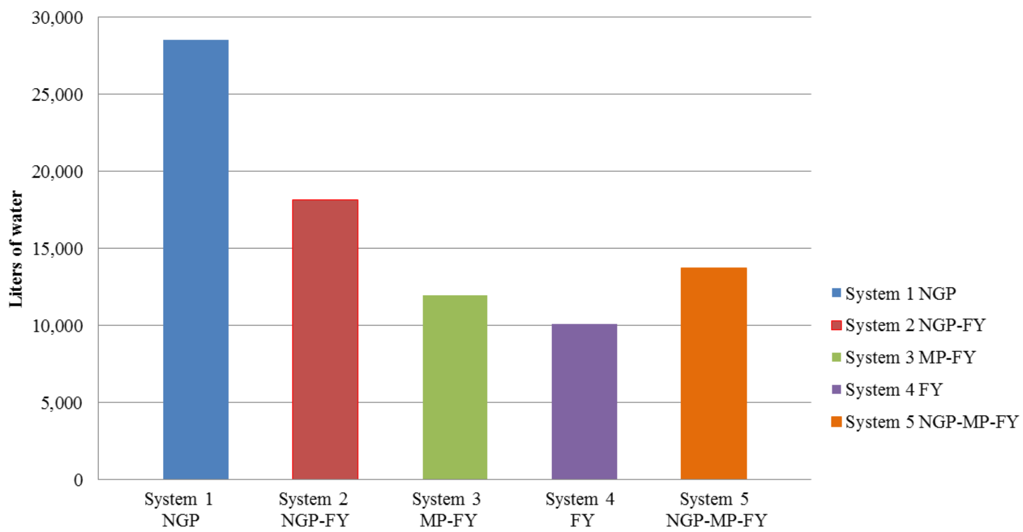

Figure 14. Cumulative water consumption to produce a marketable steer from the five modeled beef production systems.

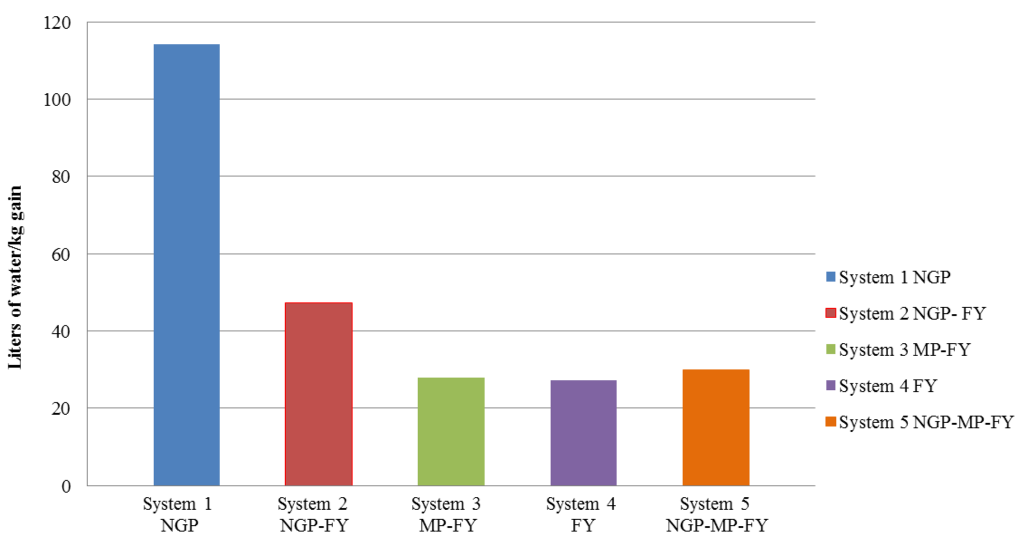

Figure 15. Water consumption per kilogram of gain to produce a marketable steer from the five modeled beef production systems.

MODEL COMPARISONS TO PREVIOUSLY PUBLISHED WORK

This modeling effort generated life-cycle carbon-footprint estimates for beef-production systems that are comparable to other published model results and direct measurements of GHG emissions associated with cattle production (Table 15). Direct comparisons with common functional units (FU) can be made with several published LCAs including Capper and Cady (2010), Peters et al. (2009), Rotz et al. (2013), and Beauchemin and McGinn (2005).

Table 15. Model Comparisons to Previously Published LCAs.

Model Comparisons to Published LCAs	kg CO_2e/kg Gain	kg CO_2e/day	Total CO_2e	*Adjusted Total CO_2e	**kg CO_2e/kg HCW	Enteric Emissions (kg CO_2e/d)	Enteric Emissions (kg CO_2e)
System 1 (NGP)	26.5	9.5	6,632	8,580	27.5	3.9	2,703
System 2 (NGP, FY)	7.6	6.6	2,918	4,866	12.28	2.7	1,212
System 3 (MP, FY)	7.6	11.15	3,255	5,203	12.31	3.4	992
System 4 (FY)	4.8	7.3	1,799	3,747	9.6	2.1	529
System 5 (NGP, MP, FY)	8.1	11.12	3,737	5,685	12.8	3.6	1,209
Capper and Cady (2009) Corn Fed	-	-	-		-	-	1,425
Capper and Cady (2009) Grass Fed	-	-	-		-	-	3,125
Peters et al. (2010) Corn Fed	-	-	-		9.9	-	3,602
Peters et al. (2010) Grass Fed	-	-	-		12.0	-	3,365
Ogino et al. (2007)	32.3	-	5,959		-	-	2,851
Subak (1999)	-	8.0	-		-	-	-
Harper et al. (2011) Pasture Fed	-	-	-		-	5.75	-
Harper et al. (2011) FY	-	-	-		-	1.75	-
Beauchemin and McGinn (2005) FY	4.87	-	-		-	-	-
Rotz et al. (2013)	10.9 ±0.6	-	-		-	-	-
Stackhouse et al. (2014)	-	-	-		21.1 - 24.2	-	-
Andreini et al. (2014) Stocker to FY	-	-	-		21.2 ±2.0	-	-
Andreini et al. (2014) Wean to FY	-	-	-		22.6 ±2.0	-	-
Basarab et al. (2012)	-	-	2,958 - 3,345		19.9 - 22.5	-	-
Rotz et al. (2015)	-	-	-		18.3 ±1.7	-	-
FAO (2013)	-	-	-		46.2	-	-

*Adjusted total CO_2e refers to the additional CO_2e emissions if emissions for the first 205 days of the steers life were estimated for Systems 1-5

**kg CO_2e/HCW was estimated based on adjusted total CO2e emissions and 62.5% dressing percentage of the FSBW for Systems 1-5

Adjustments to the CO_2e emissions generated by each system were calculated for comparisons with LCAs that used different FUs as model endpoints. Hot carcass weight (HCW) was a common endpoint in seven peer reviewed articles, and the five beef production systems modeled were adjusted accordingly. To adjust the FU endpoint from kg CO_2e/kg gain to kgCO_2e/ kg HCW two assumptions must be made; 1) the calf is in a grass-based system for the first 205 days of its life, and a daily emission rate can be estimated based on daily CO_2e emissions from System One NGP at 9.5 kg of CO_2e/day, and 2) converting FSBW to HCW by multiplying FSBW by the USDA average of 62.5% dressing percentage. The estimated CO_2e emissions per HCW and total emissions for the five modeled beef production systems are detailed in Table 16. The adjusted CO_2e emissions were compared to Peters et al. (2010), Andreini et al. (2014), Basarab et al. (2012), Rotz et al. (2015), and FAO (2013).

Table 16. Adjusted CO_2e Emissions for Functional Unit Comparisons to Previously Published Beef Cattle LCAs.

Adjusted CO_2e emissions	System 1 (NGP)	System 2 (NGP-FY)	System 3 (MP-FY)	System 4 (FY)	System 5 (NGP-MP-FY)
FSBW (kg)	500	634	676	622	709
HCW (kg)	313	396	423	389	443
kg CO_2e/Day (NGP)	9.5	9.5	9.5	9.5	9.5
Additional Model Days	205	205	205	205	205
Additional CO_2e Emitted	1947.5	1947.5	1947.5	1947.5	1947.5
Adjusted Total CO_2e Emitted	8,580	4,866	5,203	3,747	5,685
kg CO_2e/kg HCW	27.5	12.28	12.31	9.6	12.8

The additional model days added 1,947.5 kg CO_2e to each of the five productions systems and the kg CO_2e /kg HCW was 27.5, 12.28, 12.31, 9.6, and 12.8 for Systems One through Five respectively.

Capper and Cady (2009) reported that grain-finished cattle emitted a total of 1,425 kg/CO_2e enteric methane, and that is comparable to System Two (1,212 kg CO_2e), System Three (992 kg CO_2e) and System Five (1,209 kg CO_2e). Capper and Cady (2009) also reported enteric methane emissions of 3,125 kg CO_2e for grass-finished beef, and that is comparable to System One (2,703 kg CO_2e). Rotz et al. (2015) reported 10.9 ±0.6 kg CO_2e/kg gain for grain finished beef cattle and that is comparable to System Two (7.61 kg CO_2e/kg gain), System Three (7.64 kg CO_2e/kg gain), and System Five (8.15 kg CO_2e/kg gain). Beauchemin and McGinn (2005) reported emissions from steers placed directly into a feedlot upon weaning to be 4.87 kg CO_2e/kg gain and that is comparable to the modeled System Four (4.84 kg CO_2e/kg gain).

Comparisons based on kg CO_2e/kg HCW are higher for all published LCAs, with the exception of Peters et al. (2010), who reported an emission rate of 9.9 kg CO_2e/kg HCW. This value is comparable to Systems Two through Five and nearly identical to System Four (FY). The FAO (2013) emission rate of 46.2 kg CO_2e/HCW is a global estimate and primarily focuses on subsistence beef production systems using low quality forage over long periods of time. The FAO (2013) estimate is not comparable to the five modeled Southern High Plains beef production systems or any of the beef systems reported in peer-reviewed, published literature.

ECONOMIC IMPLICATIONS

It is unclear how the regulation of GHG emissions will impact beef cattle production systems in the Southern High Plains region. However, any governmental imposed caps, via market forces (cap and trade) or environmental regulations, on the amount of GHGs emitted from livestock, would likely increase the overall price of production. Assuming inelastic demand, the price of beef products would likely increase proportionally to the amount of emissions emitted by a particular production system if a carbon trading market, such as the European Union Emission Trading System (EU ETS), were implemented in the United States. At the height of carbon trading, the price of CO_2e in the EU ETS (2011) was $30 /tonne (Swartz, 2013). If this rate were applied to GHGs emitted from livestock production in the Southern High Plains region, the additional cost of producing beef would increase (Table 17). System Four (FY) would have the lowest additional cost in a “cap and trade” system, while System One (NGP) would be the highest. Interestingly, those market forces would create a profitability gradient toward intensive production systems and away from grass-fed production.

Table 17. Additional Cost of GHG Emissions at $30/tonne CO_2e for the Five Modeled Production Systems.

System Emisions and CO_2e Costs	System 1 (NGP)	System 2 (NGP-FY)	System 3 (MP-FY)	System 4 (FY)	System 5 (NGP-MP-FY)
Total CO_2e Emissions (kg)	6,632	2,918	3,255	1,799	3,737
$30/tonne CO_2e	$198.96	$87.54	$97.65	$53.97	$112.11

It has been shown in this LCA and livestock growth model, and in other peer reviewed manuscripts, that the least intensive production system (NGP) emits the greatest amount of GHGs as a result of low-quality diets, and longer production times. The increased time of production, lower rates of gain, lower FSBW, and greater GHG emissions make grass-only systems less desirable from an efficiency and emissions standpoint. Total production time to achieve the desired FSBW and % body fat content is the most important variable affecting total CO_2e emissions. The FAO reports (2006, 2013) emphasize the importance of high quality cattle diets to reduce overall GHG emissions in beef cattle production systems. The simplest way to increase the quality of the diet is to feed cattle a concentrated, grain-based diet. This reduces total CO_2e emissions and decreases total days on feed per desired FSBW and body fat content.

CHAPTER 5

CONCLUSIONS

The environmental burdens of GHG emissions and resource use per functional unit (kg CO_2e/kg gain) increased as the level of system productivity decreased. System productivity was measured by total days on feed, dietary gross energy consumed, average daily gain, water consumption, dry matter intake, and total manure excreted. Cattle fed in grass-based systems having lower quality forage coinciding with seasonal cold temperatures typical of Southern High Plains region had lower average daily gain, FSBW, increased resource consumption, and GHG emissions as compared to systems with high quality forages (wheat pasture) and grain-based diets. Total CO_2e emissions from the grass-only system were 73% greater than the most efficient system (System Four), which produced a larger (+122 kg) FSBW grade "Choice" steer in 451 fewer days.

The "footprint" of the cattle feeding industry per functional unit decreased when cattle were fed high-quality diets and intensively managed to produce a grade "Choice" steer (28% body fat) in the shortest time possible. The weaned calf to feedlot system was the most efficient in terms of producing an animal in the shortest amount of time. The system also had the smallest emission footprint, highest average daily gain, and consumed the least amount of water and dry matter, minimizing manure production. Water consumption and dry matter intake were decreased by 65% and 60%, respectively, while increasing the total amount of gain by 33% as compared to the least efficient system. The efficiency of the feedlot system can reduce overall CO_2e emissions attributed to livestock production while reducing resource demands per unit of marketable product.

FUTURE RESEARCH

Further discussion is needed to determine which industry is assigned the GHG emissions generated for each of the processes involved with beef cattle production. Industries that supply the feedstocks to feedyards could take full or partial credit for GHG emissions related to, transportation, fertilizer, electricity, and crop production. Double accounting must also be avoided when looking at the LCA for a given industry that provides raw materials that are further refined by other industries. A thorough economic analysis should also be performed to determine the effects of a carbon tax or a carbon market on producers, and ultimately the consumers, that will pay for the additional costs associated with GHG policies.

The seventh revised edition of the National Research Council handbook *Nutrient Requirements of Beef Cattle* (1996) presents the equations for animal growth and energy requirements in a way that is difficult to follow without an animal science background. Retained energy (RE) equations are not subscripted to distinguish the differences between feed RE and animal required RE for weight gain. The mathematical example in chapter three, *Growth and Body Reserves*, has errors in the calculations, and those errors make it impossible to validate/compare model estimates for animal growth based on the examples given within the text.

Additional research is needed to determine the complete “carbon footprint” for the cattle feeding industry in the Southern High Plains as well as the economic impacts of GHG regulations. Furthermore, additional research is needed to determine GHG contributions from ancillary systems such as feed crop production, cow/calf systems, transportation, and fossil fuel use that contribute to the overall CO_2e emissions of the cattle feeding industry. A LCA for a cow/calf system with an emission and livestock growth model from birth to weaning would help complete the LCA for beef production from the five typical feeding systems in this region. A detailed LCA for each of the model inputs could also improve the model robustness and the overall accuracy of GHG estimates attributed to beef cattle production. Future model development will need to address the impacts to other environmental systems related to air quality, water quality and waste management. These additions to this LCA model would improve the accuracy of GHG emissions attributed to beef cattle production systems.

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Appendix

Tier Two CO_2e emission values for Wheat (MSU, 2015)

Tier 2 Calculation CO_2e	Dallham County TX	Hartley County TX	Beaver County, Ok	Weld County, CO	Greley County, KS	Lipscomb County, TX
Wheat						
Yield (MT/ha)	2.6	2.9	1.5	2.7	2.15	1.9
Soil CO_2e (MT/ha/yr)	-0.5	-0.05	0.13	-0.15	0.7	0.13
N2O (CO_2e MT/ha/yr)	1.5	1.52	1.4	1.52	1.47	1.45
Fuel (CO_2e MT/ha/yr)	0.13	0.13	0.13	0.13	0.13	0.13
Fert (CO_2e MT/ha/yr)	0.03	0.03	0.03	0.03	0.03	0.03
CO_2e (MT ha/year)	1.63	1.65	1.7	1.52	2.32	1.72

Tier Two CO_2e Emissions Calculations for Corn and Soybeans (MSU, 2015)

Tier 2 Calculation CO_2e	Dallham County TX	Hartley County TX	Hancock County IL	Webster County IA	Lincoln County NE	Blue Earth County MN	Rock County WI
Corn							
Yield (MT/ha)	11.7	13.2	11.9	10.5	10.4	11.1	9.2
Soil CO_2e (MT/ha/yr)	-0.7	-0.8	0.07	0	0.03	-0.25	0.13
N2O (CO_2e MT/ha/yr)	3.17	3.28	3.2	3.13	3.13	3.15	3.05
Fuel (CO_2e MT/ha/yr)	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Fert (CO_2e MT/ha/yr)	0.07	0.07	0.07	0.07	0.07	0.07	0.07
CO_2e (MT ha/year)	2.68	2.65	3.47	3.33	3.33	3.1	3.38
Soybean							
Yield (MT/ha)	3.4	3.7	3.4	3.2	3.4	3	2.5
Soil CO_2e (MT/ha/yr)	-0.13	-0.13	0.72	0.58	0.5	0.43	0.65
N2O (CO_2e MT/ha/yr)	1	1.05	1	0.98	1.02	0.98	0.93
Fuel (CO_2e MT/ha/yr)	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Fert (CO_2e MT/ha/yr)	0	0	0	0	0	0	0
CO_2e (MT ha/year)	1.02	1.05	1.88	1.7	1.65	1.52	1.7

Transportation Center Point Distance (km), State to State (TX)

Distance (km) From State to Texas			
Texas	0	Alabama	1,224
Nebraska	1,059	Illinois	1,345
Kansas	794	Michigan	1,851
California	1,865	Washington	2,203
Oklahoma	427	Georgia	1,600
Missouri	992	Mississippi	989
Iowa	1,256	Arizona	1,068
South Dakota	1,334	Indiana	1,595
Wisconsin	1,633	North Carolina	1,970
Montana	1,882	Utah	1,299
Colorado	995	Louisiana	739
Minnesota	1,700	Nevada	1,676
Idaho	1,865	West Virginia	1,908
Kentucky	1,565	South Carolina	1,759
North Dakota	1,735	Vermont	2,746
Tennessee	1,292	Maryland	2,240
Arkansas	829	Hawaii	26,212
Florida	1,835	Maine	3,005
Pennsylvania	2,263	Connecticut	2,603
Virginia	2,030	Massachusetts	1,717
New York	2,503	New Hampshire	2,772
New Mexico	581	New Jersey	2,452
Oregon	2,229	Delaware	2,330
Wyoming	1,395	Alaska	14,879
Ohio	1,786	Rhode Island	2,732

*Distance calculated from the center of the Texas High Plains to the center of each state