MANAGEMENT VARIATIONS FOR U.S. BEEF PRODUCTION SYSTEMS: EFFECTS ON GREENHOUSE GAS EMISSIONS AND PROFITABILITY

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ASTRACT

Resource inputs, live weight outputs, and greenhouse gas (GHG) emissions coupled with economic analyses of five representative US beef production systems were used to evaluate primary source strengths of GHG's (as CO_2 equivalents) and responses to management changes. Beef production simulations were based on state, federal, and industry data and NRC nutrient requirements. The cow-calf, stocker, and feedlot phases produced from 451 to 538 t GHG per 100-cow herd, 13.2 ± 0.42 kg/kg live weight sold (22 kg/kg carcass weight sold), and losses averaging \$1337 ± \$1868. Nitrous oxide (48%), methane (41%), and fuel CO_2 (11%) comprised the GHG emission sources with an average of 8% of these emissions being offset by carbon sequestration. Of five management changes evaluated, intensive grazing with improved pastures use by the mother cows reduces herd GHG and GHG/kg live weight sold by 13% while increasing profit by \$48/t of GHG saved. Intensive grazing also doubled carbon sequestration offsetting 16% of emissions. Moving weaned calves directly into the feedlot, skipping the stocker phase also decreased GHG/kg live weight sold by 4% while increasing profits. Combining intensive grazing of cows with elimination of stocker phase gave approximately additive benefits. Selling fat cattle at a 1% lower fat content decreased herd GHG by 2% but reduced profits costing \$260/t GHG reduction. Although the feedlot phase had relatively high fuel CO_2 and nitrous oxide emissions, the overall GHG/kg live weight sold of 6.7 kg/kg was much lower than other phases of production, thus the sooner they were placed in the feedlot the lower the overall GHG/product. Decreasing herd size linearly decreased GHG's at a cost ratio of \$17/t of lowered emissions. These evaluations illustrate some of the many tradeoffs in gas source and profitability that result from management changes.

INTRODUCTION

Previous summaries (IPCC, 1996b, Phetteplace et al., 2001; Johnson et al., 2003) have characterized the major contributions of livestock production systems to anthropogenic CH_4 and N2O emissions. This report describes simulations of beef cattle operations at locations throughout the U.S using a 'whole farm' approach. These simulations estimate the GHG emissions, soil carbon sequestration, and profitability of the cow-calf through feedlot production systems in representative U.S. areas and under a sampling of varying management, mitigation strategies. The objectives of this project were to evaluate changes in GHG emissions, meat production and profitability and differential response of GHG emissions per unit profit (loss).

MATERIALS AND METHODS

The information to simulate cow-calf and stocker operations in the most productive counties in five states and feedlot operations in two states was obtained from a wide range of government, public and private sources as described previously (Phetteplace et al., 2001). The simulated productions systems were for a 100 mature cowherd, their replacement heifers, breeding bulls, and estimated annual progeny carried through the stockers and feedlot phases. Most (82%) of the weaned calves are grown for an average of 5 months on forage prior to feedlot placement. The feedlot phase averages 128 days to reach market weights at an estimated 28% body fat, choice quality grade.

Five different management scenarios were compared to the 'conventional' beef systems in regard to herd characteristics, net GHG emissions, and GHG emissions per profit. The management scenarios were 1) 'intensive grazing' (IG); 2) 'direct' (100%) placement of calves from the cow-calf system to the feedlot; 3) 'IG + direct' placement, 4) '27% body fat', feeding to one quality grade lower during the feedlot phase, and 5) 'Herd – 20%' or reducing cow herd size by 20%. Intensive grazing was implemented only during the cow-calf phase, while in the 'IG + direct' system calves from the IG feed cows were moved directly to the feedlot.

The dietary ingredient mixtures for each livestock production phase were derived from personal communications with extension agents or published Cooperative Extension Service (CES) materials. The net energy (NE) values of these ingredients and the animal requirements (NRC, 1996) allowed estimation of the amounts of feedstuffs needed for each scenario. The cropping system needs are in turn driven from herd feedstuff needs and the number of ha needed to produce sufficient feedstuff for the simulated herds from crop yield estimates. No correction for harvest, processing or storage losses were made when calculating the total amount of crops required for cattle feed. Any land-use or crop amendments for by-product or supplement feed crops were adjusted according to the fractional dollar ($) value of each crop component. For example, a soybean crop would produce oil, meal and hulls. Approximately 79% of the value is in the soybean meal; therefore only 79% of the ha and their resource inputs required to produce the soybeans are charged to the system.

Pasture was the chief 'crop' required for the cow-calf and stocker systems, while hay or other roughages made-up the majority of remaining feeds consumed. In two beef systems unimproved rangeland comprised a portion (20 or 80%) of the pasture. Rangeland did not receive any crop amendments or irrigation. During the cow-calf and stocker phases, broiler litter plus corn grain was fed during a portion of the year in three of the Southern U.S. systems. Cottonseed cake was the main supplemental feed for cow-calf and stocker systems in one location. Grains, primarily corn, make-up approximately 85% of the ration for the feedlot cattle.

Annual GHG emissions are expressed on a carbon dioxide equivalent (CO_2eq) basis as metric tonne (t) per herd or kg/kg product. Enteric methane (CH_4) emissions are estimated as 6% of GE intake (IPCC, 2001) with the exception of emissions from feedlot cattle where a 3% coefficient is used reflecting recent findings (Jarosz et al., 1999; Hutcheson et al., 1998). The consumption of pre-weaned calves was also estimated and a CH_4 coefficient of 6% applied to the plant-derived fraction of the diet. Manure CH_4 is based on IPCC (2001) with adjustments for climate. However, volatile solids (VS) were calculated using the equation: VS, kg/d = ((Gross Energy Intake, MJ/d – Digestible Energy Intake, MJ/d) + (0.04 x GEI, MJ/d))/20.1 MJ/kg, which estimates the energy added to manure from urinary excretions.

Nitrous oxide emissions were estimated for direct and indirect (volatiles and leached) release from manure management and disposal, crop N-fertilization, and from legume fixed and waste residue-N using IPCC (2001) recommended emission factors. The overall production system N_2O emission factor ranged from approximately 2 to 4% of total excreted plus crop amended N. Nitrogen excretion (N_{EX}) is calculated as dietary N intake – N retained in body growth (NRC, 1996).

Carbon dioxide emissions from fossil fuel combustion for the livestock and cropping operations were estimated from fuel or energy use coefficients obtained from Ward (1980), Pimentel et al. (1980), and Iowa Extension Service (1985). Fuel uses were multiplied by carbon emission factors from IPCC (1996a) and converted to weight equivalents of CO_2. Fuel estimates included use for power equipment, transportation, embodied equipment and facilities energy, fertilizer manufacture, irrigation, feed drying and processing, etc. (e.g. Table 1). The trace amounts of CH_4 and N_2O emissions from fossil fuel combustion and embodied energy were ignored. Ammonium nitrate was taken to be the fertilizer N source at a cost of 61.5 MJ/kg N using natural gas. Methane oxidation by soils has not been included, likely more than trace amounts.

Carbon sequestration was assumed to be 0.12 Mg C/ha/yr for improved pasture (Follett et al., 2001) and 0.4 for IG improved pasture (Conant et al., 2002). Rangeland and cropland was assumed to be at carbon balance with no emissions or sequestration.

Table 1. Example energy coefficients used to estimate fuel consumption.

Crop	**Diesel, L/ha**	**Irrigation, MJ/ha**	**Crop drying, propane, L/t**	**Process, MJ/kg**	**Embodied Machine, kg/ha**
Pasture	3	83			3
Hay	64	998			41
Cottonseed cake	22	189		3.2	18
Corn silage	67	2688			50
Corn	50	2688	25	0.2	55
Soybean meal	40			3.2	11

Economic evaluations used budget information from the National Agricultural Statistics Service (NASS), CES and Economic Research Service (ERS) for the year 1997. In cases where a county or state price was unavailable the regional price was used. Revenues include income from the sale of cull cows, bulls, and fat cattle. Feed was the major expense for all phases. ‘Other’ expenses for these systems include pasture or rangeland rental, transportation, sales commission, veterinary care, custom operations, repairs, hired labor, facilities depreciation, overhead, interest and taxes, replacement bulls, electricity, fuel for livestock use and fertilizer, insecticide and herbicide for the pastures. The expense of land or land-use for crop production was considered to be included in the price of the feedstuff. Profit or (loss) per herd basis equals total revenue minus total expenses.

Simulation of an IG management strategy was estimated to increase 'improved' pasture yield by 50%, harvest fraction by 10 percentage points, Improve grass DE% by 1.0%, and require 20% more fertilization based on information from several sources (Nielson, 1997; Undersander and Paine, 1997; Henning et al., 2000). Any unimproved rangeland pasture was assumed to not respond to IG management. Holechek and coworkers (1999) noted no change in productivity or a possible decrease in productivity due to overgrazing in intensive, rotational grazing of range pasture.

RESULTS AND DISCUSSION

The principle characteristics of the conventional systems (Table 2) indicate the mature cow to weigh 500 kg, calving and replacement rates of 92% and 16%, calf and adult mortality rates of 10 and 1.4%, pasture and hays to supply 75% of diet, and for 37 t of live weight to be produced per 100 cows. Mature weights varied by location, but not production scenario (CES; Cattle-Fax, 1994). Calving and replacement rates are similar to the national averages of 93 and 16% (USDA, 1998). The land required varied from 95 ha in Wisconsin to 751 ha in Utah, reflecting variations in forage and crop yield per ha. Land requirements appear lower than commonly expected (Van Dyne, 1980), perhaps biased by overly optimistic extension agent estimates of forage quality and digestibility as they commonly exceed NRC (1996) requirements, or underestimated pasture, range, or hay forage wastage. These estimates will need further scrutiny but should have only small effects on relative system and strategy comparisons.

The cow-calf phase emits 75% of beef system GHG's, with emissions of 16.5 kg/kg product. This GHG/product is about twice that of the stocker, and nearly three-fold that of the feedlot phases (data not shown). The five state U.S. average is similar to the ratio of 17.1 found in a recent analysis of Colorado beef production (Johnson et al., 2003). Enteric CH_4 in the 'conventional' cow-calf through feedlot scenario accounts for approximately 40% and manure CH_4, 1%, of total GHG emissions (Table 2). Nitrous oxide, primarily from N excreted while grazing, contributes nearly 50% of the CO_2eq emissions. The remaining 11% of total GHG emissions is derived from CO_2, primarily from fossil fuel use and fertilizer synthesis. These proportions changed little during the different production scenarios. The Direct and IG + Direct scenarios showed an increase of 1 to 2 percentage units in the fuel-CO_2 category, primarily due to increased feedlot use.

With the exception of CO_2, individual GHG emissions per unit product were reduced for the IG, Direct, and IG + Direct production scenarios relative to the conventional cow-calf through feedlot system (Table 2). Net GHG emissions per product were reduced from 13 to 11 kg/product with IG resulting from less pasture, other forage, and land requirements with their accompanying emissions. Limited utility of IG, however, is likely in arid or semi-arid environments.

The average cow-calf through feedlot herd lost $1290 annually in these 1997 conventional simulations but ranged from $1922 profit to $8350 loss. Utilizing less productive pasture or rangeland resulted in a greater expenditure for the 'conventional' systems using range pasture. In comparison of the changing management scenarios, the IG systems appeared the most profitable (Table 2), primarily due to reduced feed costs. Marketing of feedlot cattle at lighter body weights with less body fat, or reducing the cowherd size by 20% resulted in the greatest economic loss. The cattle fed to the lighter weight, lower quality grade (27% fat) received a lower price per cwt than the 'conventional' (28% fat) cattle resulting in less revenue. The reduced feed cost did not make up the difference in revenue in this scenario. Reducing the cow-herd also resulted in a reduction of revenue and feed costs, but fixed operating costs remained the same contributing to the overall $ loss.

Expressing profits per unit of GHG emissions ($/t) is meant to compare economic return gained, however, on average the conventional beef production systems lost money (-$2.60/t GHG) during the 1997 year evaluated. Three of the scenarios were indicated to increase returns into the profitable range. Comparisons of the change in $ profitability per unit of change in GHG emissions can, however, allow an evaluation of the economic vs. emission advantage or disadvantage of imposed management strategies. Three of the strategies are indicated to have negative costs while reducing emissions, a win, win situation. Intensive grazing increased profits by $3100, decreased GHG by 66 t, with a differential yield of $48/t of GHG saved (Table 4). The Direct scenario, taking weaned calves directly to the feedlot with no stocker-growing phase, increased profits per herd less than IG but the $/t GHG saved was of approximately equal value. Marketing the feedlot steers at 27% fat was very detrimental to revenue and saved only a few t of GHG ($259/t). Reducing herd sized dropped profits by $17 per t of GHG emissions saved.

Management decisions can impact both GHG emissions and profitability of beef production systems. Simulations of U.S. cow-calf through feedlot beef production systems provide an indication that 'IG' and 'Direct' placement into the feedlot or a combination thereof, decreases GHG emissions/product and improves profitability. Other management options such as decreasing herd size or decreasing the degree of fatness of feedlot cattle reduced GHG emissions but also decreased profitability. These whole-farm simulations are a tool to evaluate various GHG mitigation options, while considering the many tradeoffs, and their impact on profitability.

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Table 2. Characteristics of simulated U.S. beef cow-calf through feedlot production systems, Mean per 100 cow +/- SEM.

Characteristic	**Conventional**	**IG**	**Direct**	**IG + Direct**	**27% Fat**	**Herd – 20%**
Mature cow weight, kg	497 ± 4.6	497 ± 4.6	497 ± 4.6	497 ± 4.6	497 ± 4.6	497 ± 4.6
Total number, head	210 ± 1.7	210 ± 1.7	201 ± 1.2	189 ± 1.2	207 ± 1.6	167 ± 1.2
Replacement, %	16 ± 0.4	16 ± 0.4	16 ± 0.4	16 ± 0.4	16 ± 0.4	16 ± 0.4
Calving rate, %	92 ± 1.2	92 ± 1.2	92 ± 1.2	92 ± 1.2	92 ± 1.2	92 ± 1.2
Calf mortality, to wean, %	10.2 ± 1.1	10.2 ± 1.1	10.2 ± 1.1	10.2 ± 1.1	10.2 ± 1.1	10.2 ± 1.1
Adult mortality, %	1.4 ± 0.4	1.4 ± 0.4	1.4 ± 0.4	1.4 ± 0.4	1.4 ± 0.4	1.4 ± 0.4
Live weight sold, t	37.2 ± 0.6	37.2 ± 0.6	36.0 ± 0.6	36.1 ± 0.6	36.2 ± 0.6	29.7 ± 0.5
Pasture, %	55 ± 2.2	55 ± 2.2	51 ± 2.2	52 ± 2.2	56 ± 2.2	56 ± 2.2
Other roughage, %	20 ± 3.9	20 ± 4.0	18 ± 3.9	19 ± 3.9	20 ± 4.0	19 ± 3.8
Total ha/herd	257 ± 124	186 ± 89	236 ± 114	164 ± 79	256 ± 124	207 ± 100
Nitrogen, syn., 10^3 kg	2.32 ± 0.4	2.28 ± 0.4	2.36 ± 0.4	2.27 ± 0.4	2.22 ± 0.4	1.83 ± 0.3
Fuel, herd, 10^3 l	9.9 ± 0.7	9.8 ± 0.7	9.5 ± 0.6	9.4 ± 0.7	9.5 ± 0.7	7.8 ± 0.6
Manure on pasture, %	89 ± 0.1	89 ± 0.1	84 ± 0.3	85 ± 0.1	90 ± 0.1	89 ± 0.1

Table 3. Beef GHG emissions and GHG emissions per profit for cow-calf through feedlot (annual CO_2eq), Mean ± SEM.

Source of GHG	**Conventional**	**IG**	**Direct**	**IG + Direct**	**27% Fat**	**Herd – 20%**
Enteric CH_4						
t per herd[a]	213 ± 3.5	207 ± 3.7	192 ± 2.4	185 ± 2.5	212 ± 3.5	171 ± 2.9
Kg/kg product[b]	5.7 ± 0.1	5.6 ± 0.1	5.3 ± 0.1	5.1 ± 0.1	5.9 ± 0.1	5.7 ± 0.1
Manure CH_4						
t per herd	5.6 ± 0.6	5.2 ± 0.5	4.9 ± 0.5	4.6 ± 0.4	5.5 ± 0.6	4.5 ± 0.5
Kg/product	0.2 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.2 ± 0.01	0.2 ± 0.01
N_2O						
t per herd	255 ± 12	238 ± 10	237 ± 10	219 ± 8	252 ± 12	203 ± 10
Kg/product	6.9 ± 0.3	6.4 ± 0.3	6.6 ± 0.3	6.1 ± 0.2	7.0 ± 0.3	6.8 ± 0.3
CO_2						
t per herd	60 ± 2.4	59 ± 2.3	60 ± 1.9	58 ± 2.1	58 ± 2.7	48± 1.9
Kg/product	1.6 ± 0.1	1.6 ± 0.1	1.7 ± 0.05	1.6 ± 0.05	1.6 ± 0.1	1.6 ± 0.1
Carbon sequestration						
t per herd	43 ± 4.9	83 ± 12	39 ± 4.4	79 ± 12	43 ± 4.9	35 ± 3.9
Kg/product	1.2 ± 0.1	2.2 ± 0.3	1.1 ± 0.1	2.2 ± 0.3	1.2 ± 0.1	1.2 ± 0.1
Net CO_2 equivalents						
t per herd	491 ± 15	426 ± 14	456 ± 13	387± 14	484 ± 16	392 ± 13
Kg/product	13 ± 0.4	12 ± 0.4	13 ± 0.4	11 ± 0.4	13 ± 0.4	13 ± 0.4
Profit						
\$ per herd, \$1000	(1.29) ± 1.9	1.86 ± 1.2	0.46 ± 1.9	4.07 ± 1.3	(3.17) ± 1.9	(2.95) ± 1.5
\$ change from 'conventional'/t GHG[c]		-48	-50	-52	259	17

[a] Herd is the total mean number of head, cow-calf through feedlot.

[b] Product is live weight sold of culls plus fat cattle.

[c] Negative number indicates more profit per unit reduction of GHG emissions.