ABSTRACT. Before 1940, on-farm beef slaughter made up 3% to 5% of annual beef production. Currently, this statistic is below 0.5%. As part of a larger project to develop strategies to increase prosperity for small farms through sustainable livestock production, processing, and marketing, this study presents data and analyses from five small cattle production operations in the Palouse region of the northwestern U.S. Net greenhouse gas (GHG) emissions were calculated for each of the operations, which each produced 20 to 35 head of cattle annually. Data from the small ranches were analyzed to determine emissions in three main categories: those associated with cattle, feed production, and fuel use. Cattle emissions were calculated according to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. This method provided estimates for emissions from enteric fermentation and manure management. Feed and transportation emissions were estimated using HOLOS whole-farm modeling software and Franklin Associates’ U.S. LCI data, respectively. All emissions were normalized over the mass of live weight cattle output from each ranch. The ranches had average total emissions of 13.78 ±2.08 kg CO₂e kg⁻¹ live weight output. Feed production emissions and fuel use emissions varied more significantly according to ranch practices (having ranges of ±66% and ±4%, respectively) and were considered on a case-by-case basis. Feed production emissions were between 0.42 and 3.98 kg CO₂e kg⁻¹ live weight output. Fuel use emissions were between 0.39 and 1.58 kg CO₂e kg⁻¹ live weight output. Overall emissions were consistent with values for all-sized cattle operations in the literature and slightly less than emissions from production systems utilizing concentrated animal feeding operations (CAFOs).

Keywords. Beef, GHG, Ranches, Small farms.

Local livestock production and marketing has historically been an important part of U.S. agriculture. According to the USDA National Agricultural Statistics Service, on-farm beef slaughter made up 3% to 5% of annual beef production before 1940 (USDA, 2012). In recent years, this figure has fallen to below 0.5%. In today’s competitive environment, raising livestock can be an important supplemental income to small diversified farms. The growing interest in local and regional foods presents an opportunity for small producers to enter higher-profit niche markets. Selling to local markets also provides economic support for rural areas. Foltz et al. (2002) found that small, independent farms that market their products directly to local communities support local businesses and stimulate economic activity. Such activity can increase the quality of life for farmers, their employees, communities, and livestock (Worosz et al., 2008).

Small livestock operations are of particular interest in northern Idaho and eastern Washington, where the majority of cattle sold come from smaller operations (fewer than 199 head). This clearly distinguishes the area from the nation, where the majority of sales come from operations with 500 head of cattle or more (USDA, 2007).

This study compares emissions from small livestock operations raising cattle to the point of slaughter with a system using large confined animal feeding operations (CAFOs). The effects of CAFOs raise ethical, environmental, economic, and human health issues (Hribar, 2010; IPCC, 2001; Lundqvist et al., 2008; Schneider and Garrett, 2009). The environmental burdens associated with CAFOs can be broadly grouped into two categories: those related to the production of animal feed crops, and those related to on-site emissions. Problems linked to production of feed crops include, but are not limited to, deforestation to make space for feed crops, pollution of soil and water by fertilizers and pesticides, and loss of biodiversity due to large-scale monoculture practices. These can be significant when the amount of feed necessary for current levels of meat consumption is taken into account: An estimated nearly 70% of all cereal harvest in developed countries is used as livestock feed (Lundqvist et al., 2008). Some CAFO emissions are attributable to the large amounts of manure produced at the facilities. Storing large quantities of manure has the potential to pollute air, water, and soil through
emissions of greenhouse gasses (GHGs), nitrogen, and phosphorous (Hirbar, 2010).

Due to the negative effects of CAFOs, among other issues, a recent increase in local food production and regulation of industrialized farming has occurred (Eckholm, 2010; Martinez, 2010). Although it is not feasible to replace our current level of beef production with local alternatives, the promotion of local beef as a healthy alternative to conventionally produced beef could perhaps lower overall impacts, benefiting human health in America (Gold, 2004; Erb et al., 2009; Schneider and Garrett, 2009). A shift in beef consumption habits from conventional to local would also act to curb the economic consolidation that the beef industry has seen in the last ten years. The four largest meatpackers in the U.S. (Tyson Foods, Cargill Meat Solutions Corp., JBS USA, and National Beef Packing Co.) currently slaughter four out of every five cattle (GIPSA, 2011). This oligopoly has effectively pushed small slaughterhouses and meat processors out of business in many areas. The total number of slaughterhouses in the U.S. has fallen by 15% in the past decade.

There is some debate about the impact that the shift to industrialized beef production has wrought. The industry, like many industries, is continuously evolving. A study comparing the environmental impact, including GHG emissions, of U.S. beef production in 1977 to that in 2007 found that, due to increases in efficiency, a reduction of GHG emissions in U.S. beef production has occurred over this 30-year period (Capper, 2011).

As part of a larger project to research the feasibility of small-scale livestock processing options, this study presents data and analyses from five small cattle production operations in the Palouse of northern Idaho and eastern Washington. The objective of this study was to estimate the GHG emissions and amount of fossil fuel used per unit of live weight cattle produced up to farm gate for locally produced beef. This analysis is important for determining the environmental tradeoffs of different production and processing strategies, and to determine if small ranches have an advantage over other sizes of operations for marketing low carbon or low fossil fuel use beef products. Emissions in this report were estimated using several tools, including the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) for cattle emissions, HOLOS whole-farm modeling software (AAFC, 2009) for feed emissions, and Franklin Associates’ (Prairie Village, Kansas) U.S. LCI data for transport emissions. Estimated emissions were compared with literature values for beef cattle production emissions from CAFOs and other-sized systems.

**METHODOLOGY**

**RANCH DESCRIPTIONS**

The studied ranches are located in the Palouse region of the northwestern U.S., and each produced 20 to 35 head of cattle annually. Two main types of ranches were present in the sample studied: (1) those that produced cattle mainly for slaughter directly after sale, and (2) those that produced cattle for sale at auction. The first type of ranch generally raised steers and heifers to over 20 months of age before they were directly marketed to customers and slaughtered for beef. These ranches marketed their cattle as specialty beef and typically sold whole, half, or quarter animals to customers or groups of customers. The second type of ranch generally sold cattle at auction at 9 to 14 months of age. Both ranch types sold culled cows at auction. In this study, cattle are defined as calves from birth to weaning. After weaning, they are defined as either heifers or steers (or bull calves if not castrated). Therefore, the main difference between the two ranch types (in terms of ranch emissions) is the amount of time that heifers and steers are retained before sale.

The replacement of heifers is an important part of the process (fig. 1) because not every cow bred will calve in any given season. Each small ranch interviewed had a heifer replacement rate that varied between 10% and 25%. This means that if a small ranch wanted to produce 20 calves each season with a replacement rate of 10%, it would be necessary to maintain a total of 25 animals: 20 cows that calve, two replacement heifers, two culled cows, and one bull. Bull calves can also replace bulls at the small ranches in a similar manner. In our study, however, this occurred at a much lower rate than heifer replacement. Most ranches studied replaced bulls every ten years or more.

**Ranch Operational Time Lines**

The ranches studied utilize very different calving, breeding, and selling regimes. This section provides typical annual timelines and a brief description of the methods employed at each ranch. In this study, one year was defined as February through January because February calving was common to all of the ranches (fig. 2). The period of winter feeding was also similar across the ranches, lasting for roughly four months from December through March in all cases, except at Ranch 5 where cattle were fed for only three months over a typical winter.

Ranch 1 produced cattle for slaughter directly after sale and maintained heifers and steers to 29 months of age before sale. Calving and breeding occurred twice annually, and selling took place three times annually. During the winter months, cattle were fed a mixture of bluegrass stubble and locally cut hay. At all other times of the year, cattle were grazed on pasture. The bluegrass stubble was obtained from a farm approximately 112.7 km (70 mi.) from the ranch. The stubble was transported to the ranch by semi-truck at approximately 22.32 metric tons (25 tons) per load. Historically, stubble not sold to Ranch 1 would have been burned. However, according to Washington Administrative Code (WAC) 173-430, mechanical removal of stubble is now promoted as a viable alternative to field burning for agricultural grasses. Because bluegrass burning is no longer allowed in the state of Washington, where the ranch is located, the avoided emissions due to burning were not included in this study.

Ranch 2 also produced cattle for slaughter directly after sale. Heifers and steers were raised to 25 months of age before sale. Ranch 2 culved and bred only once annually but sold twice annually: once in March for heifers and...
steers, and once in November for culled cows. The winter feed used at Ranch 2 consisted of hay purchased within 80.5 km (50 mi.) of the farm, which was transported to the ranch via semi-truck at approximately 22.32 metric tons (25 tons) per load. During the non-winter months, cattle were grazed on pasture.

Ranch 3 produced cattle for sale at auction at approximately nine months of age. Cattle were grazed on pasture at the ranch in the spring and fall. During the summer months (approximately June through October), cattle were moved to a summer pasture 80.5 km (50 mi.) away from the ranch. The summer pasture is owned and managed by a cattle-
man’s association. The pasture provides Ranch 3 the convenience of not directly managing a herd over the four-month summer period. Cattle were transported in batches of five cow-calf pairs. All winter feed used at Ranch 3 was produced at the ranch.

Ranch 4 produced cattle mainly for sale at auction at 14 months of age. However, five cattle were retained each season and raised to 22 months of age to be sold for slaughter. Ranch 4 also maintained five extra bull calves each season for fertility testing. These were sold at auction at 21 months of age along with culled cows. Thus, cattle were calved and bred once per year but were sold three times annually in April, November, and December. All winter feed used at Ranch 4 was produced at the ranch.

Ranch 5 produced cattle for sale at auction at nine months of age. Cattle were calved, bred, and sold once annually. Through the winter, cattle were fed a mixture of hay produced at the ranch and hay bought and transported no more than 16.1 km (10 mi.) to the ranch. Hay that was bought and transported to the ranch was hauled at 4.46 metric tons (5 tons) per load.

While no two operations in the Palouse are exactly alike, some operations are similar among all studied ranches. For instance, all ranches employ land application of manure for management purposes. This manure management strategy is referred to as the “pasture/range/paddock” system in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

**System Boundary**

The system boundaries for these local beef operations were considered cradle to gate, and GHG emissions were tracked for all farm inputs to their original sources. For example, GHG emissions for hay production and fertilizer used were included even if the rancher purchased hay at the farm gate. Emissions from all inputs were counted to estimate the amount of GHG produced per unit live weight of cattle delivered at the farm gate. The overall system boundary is shown in figure 3.

**DATA COLLECTION**

Direct interviews were the primary means of data collection. A total of five ranchers were interviewed over a period of six months. Interviews were held at each of the farms to facilitate a good understanding of each ranch’s methods of production. The ranches were chosen based on recommendations from a local conservation district and University of Idaho Extension faculty, and response to a survey of livestock producers. The ranches are representative of the size of operations in the Palouse interested in alternatives to selling at auction. The following types of information were collected from each of the participating ranches:

- **Land information**: amount, location, and types of land used for cattle production.
- **Cattle information**: type of cattle, weaning age, heifer replacement rate, calving regime, number of cattle produced annually, and birth, weaning, selling, and mature weights.
- **Feed information**: types of feed, amounts fed annually, sources of feed, and growing information.
- **Fuel use**: amount of fuel used. We used indirect estimation when direct data were not available (i.e., amount of money spent on fuel to estimate fuel use) or had the rancher estimate the amount of fuel used. In these cases, the estimates were treated as the best available data and were used without modification. Estimated values are indicated where applicable. The data collected from the five ranches were compiled under four main sections: land, cattle, feed, and fuel use. Data concerning land, feed, and fuel use were considered input data and are summarized in table 1. Data were generally collected as annual values (e.g., fertilizer use in kg year⁻¹) but are normalized in table 1 over the amount of live weight output from each ranch, with the exception of feed transport distances, which are reported in km. Cattle data were considered to be operational parameters and can

![Figure 3. Cradle-to-gate boundary of local beef production system.](image-url)
be found in table 2. Land used by the ranches was separated by primary use of the land in three categories: pasture, grass hay, and alfalfa hay. The acreage of these land types for each ranch is reported in table 1. This includes land not owned by the ranch and used to support the ranch’s cattle production, but does not include land owned by the ranch and not used for cattle production. Fertilizer use is also reported in table 1.

Feed information was recorded mainly to show transportation distances for winter feed bought and transported to the ranches. This information was used to calculate fuel use for transportation of feed as well as average crop yields associated with land used by each ranch. Feed types were separated into three categories (primary, secondary, and tertiary) according to the percentage of total feed use that they represented. The fuel use in transporting winter feed was calculated using the ratio in equation 4. Average yields were determined by dividing the total amount of each type of winter feed by the amount of land used to produce it.

Irrigation was not used for any feed produced by the ranches in this study and was assumed to be absent from feed purchased from local or nearby locations. Fuel use information also was collected from each ranch. The two main fuels used at all of the ranches were gasoline and diesel, except for Ranch 3, which used diesel fuel as its sole fuel. Cattle-specific electricity use was not recorded for any of the ranches; however, it is expected to be very small and was considered negligible. The main use of electricity at the studied ranches was the intermittent use of lights in barns. One ranch used an electric fence occasionally throughout the year. None of the ranches used electricity from utilities to power motors for pumps.

Table 2 gives general cattle information, static cattle weights, and average numbers of cattle at each ranch. Information from the first two sections of table 2 was used to determine the average numbers and weights of cattle in the third section.

### Data Analysis

Data were analyzed to determine emissions in three main categories: those associated with cattle, feed production, and fuel use. Breaking down the analysis into categories helped to identify the areas emitting higher GHG emissions. Several tools were used in combination to determine the GHG emissions of the selected sources.

### Cattle Emissions

Cattle emissions were calculated according to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). This method provided estimates for carbon dioxide equivalent (CO₂e) emissions from enteric fermentation, as well as CO₂e and nitrous oxide (N₂O) emissions from manure management. The Tier 2 approach was used for CO₂e estimates from both enteric fermentation and manure management. The Tier 1 method was used to estimate N₂O emissions from manure management. Relevant coefficients used in the equations are given in table 3.

The IPCC method was used to determine the emissions from groups of cattle of similar ages. Groups of cattle of similar ages were assumed to have similar weights. Analysis was done on a monthly basis because of the monthly nature of the operations. Monthly weight gains were determined using the difference between birth and weaning weights divided by the weaning age for calves, and the difference between weaning and selling weights divided by the months from weaning to selling for steers and heifers. These calculations are described by equations 1 through 3:

---

### Table 2. Ranch operational parameters related to cattle.

<table>
<thead>
<tr>
<th>General cattle information</th>
<th>Ranch 1</th>
<th>Ranch 2</th>
<th>Ranch 3</th>
<th>Ranch 4</th>
<th>Ranch 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle type</td>
<td>Highland</td>
<td>Black-</td>
<td>Angus</td>
<td>Angus</td>
<td>Herford-</td>
</tr>
<tr>
<td></td>
<td>Lowland</td>
<td>Cross</td>
<td>Cross</td>
<td>Angus</td>
<td>Angus</td>
</tr>
<tr>
<td>Heifer replacement rate (%)</td>
<td>10</td>
<td>10</td>
<td>25</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>Weaning age (days)</td>
<td>210</td>
<td>205</td>
<td>220</td>
<td>205</td>
<td>220</td>
</tr>
<tr>
<td>Number of bulls (head)</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Annual calf production (head)</td>
<td>20</td>
<td>35</td>
<td>25</td>
<td>25</td>
<td>27</td>
</tr>
</tbody>
</table>

### Table 3. Coefficients used for IPCC cattle emissions calculations (Source: IPCC, 2006).

<table>
<thead>
<tr>
<th>IPCC Documentation</th>
<th>Table</th>
<th>Table Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 A-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

[b] During winter months, animals were considered to be fed in stalls.
[c] During non-winter months, animals were considered to be fed in pasture.
[d] A Ym value of 0.00 was suggested for calves prior to weaning.
[e] For all other cattle a Ym of 0.075 was used.
\[
WG_{CA} = \frac{(W_W - W_B)}{A_W} \\
WG_S = \frac{(W_{SS} - W_W)}{(A_{SS} - A_W)} \\
WG_H = \frac{(W_{SH} - W_W)}{(A_{SH} - A_W)}
\]

where

\(WG_{CA} = \) average monthly weight gain of calves (kg month\(^{-1}\))

\(W_W = \) weight at weaning (kg)

\(W_B = \) weight at birth (kg)

\(A_W = \) age at weaning (months)

\(WG_S = \) average monthly weight gain of steers (kg month\(^{-1}\))

\(W_{SS} = \) weight of steers when they are sold (kg)

\(A_{SS} = \) age of steers when they are sold (months)

\(WG_H = \) average monthly weight gain of heifers (kg month\(^{-1}\))

\(W_{SH} = \) weight of heifers when they are sold (kg)

\(A_{SH} = \) age of heifers when they are sold (months).

**Feed Emissions**

Emissions from feed production were analyzed using HOLOS v.1.1.2 whole-farm modeling software (AAFC, 2009). This program, produced by Agriculture and Agri-Food Canada, is an empirical model based primarily on IPCC 2006 methodologies. Ecodistrict 991 in British Columbia was used to model the geographic area in our study, primarily because of its proximity to our study area. Although the model used medium-grained Brown Chernozem soil, which is characteristically different from the Palouse silt-loam in our study area, we did not use the soil carbon sequestration aspects of the model, so this difference was not relevant to our study. Only the cropping and land management areas of the model were utilized, which provided estimates of emissions generated from feed crop production for each ranch, including both nitrous oxide (N\(_2\)O) and carbon dioxide (CO\(_2\)) emissions. Nitrous oxide emissions are based on nitrogen (N) inputs, which include synthetic N fertilizers, crop residue decomposition, and net N mineralization. HOLOS also includes off-farm N\(_2\)O emissions from N lost via runoff, leaching, and volatilization. CO\(_2\) emissions include those from fuel use, including power for tillage, seeding, and harvesting, and the manufacturing of herbicides and fertilizers.

**Transportation Emissions**

Transportation emissions were analyzed using SimaPro 7.1 v.7 LCA software (PRé Consultants, The Netherlands) in combination with Franklin Associates’ (Prairie Village, Kansas) U.S. LCI data to determine emissions from fuel use reported at each ranch. The ratio reported in equation 4 gives the conversion factor used to determine the units of transportation measurement associated with fuel amounts:

\[
\text{Transportation (kg} \cdot \text{km)} = \frac{\text{Fuel use (gal)} \times 55094}{1000 \text{ (kg} \cdot \text{kg/gal)}}
\]

The transportation measurement units were then used to find emissions associated with gasoline and diesel combustion. The fuel use data provided by the ranches includes fuel used in the transportation of cattle and feed to and from the ranches. All emissions were normalized over the amount of live weight output from each ranch annually. Final emissions from each of the three sections (cattle, feed production, and fuel use) were summed to represent the total emissions from each ranch.

**RESULTS AND DISCUSSION**

Cattle emissions were similar among the ranches, while emissions from feed production and fuel use varied considerably according to ranch practices. Table 4 presents estimated emissions for cattle, feed production and, fuel use. Table 5 provides mean emission values from the studied ranches for each category and the standard errors of the means. Little variation occurred in cattle emissions between each ranch despite significant differences in calving, selling, and weaning ages. Ranch 1 had slightly higher than average cattle emissions due to its longer maintenance period before sale (29 months). Figure 4 shows the magnitude of emissions from each category as well as total emissions from each small ranch.

Significant variation was seen in feed production and fuel use emissions, which was expected because of the unique operation at each ranch. Each ranch obtained different types, ratios, and quantities of feed from different locations. The ranches that used fewer resources such as fertilizers and fuels tended to have lower overall emissions. For example, Ranch 3 had lower than average feed production emissions due to the lack of fertilizer used in production of the alfalfa-grass hay feed mixture (table 4). The feed production emissions at Ranch 3 made up only 3.3% of overall emissions. For the other ranches, feed production emissions accounted for up to 24% of total emissions. Similarly, Ranch 5 had lower than average feed production emissions because that ranch fed animals for only three months, as opposed to four, over a typical winter.

Fuel use also was highly variable among the ranches. The most prominent cause of this variability is the proximity of the ranches to pastures and hay production. Most fuel was used for transportation of cattle and feed. Overall emissions in this study fell well within other values in the literature for emissions per live weight output from small ranches (Beauchemin et al., 2010; Casey and Holden, 2006, Cederberg and Stadig, 2003; Nguyen et al., 2010; Ogino et al., 2004; Pelletier et al., 2010; Phetteplace et al., 2001; Veyset et al., 2010; White et al., 2010). Of the cited reports, most utilized either the 2006 or 1996 IPCC guidelines for calculating cattle-specific emissions. Studies that did not utilize IPCC guidelines (Cederberg and Stadig, 2003; Ogino et al., 2004) used single emission factors from other literature sources. Beauchemin et al. (2010) used HOLOS modeling software to estimate whole-farm emissions.

Differences in cattle management, as well as other ranch practices, made it difficult to model and compare the
ranches. Most practices at the ranches were situational, with little uniformity of practices occurring across small ranches in general. Despite these differences, the results obtained for cattle emissions are strikingly similar. Cattle emissions from enteric fermentation and manure management made up the largest portion of overall emissions (80%) and varied least among the farm emission categories. Such a large portion of emissions resulting from natural cattle processes suggests that little opportunity exists for drastic GHG emissions reductions through changes in feed usage or transportation conditions. However, the high variability of the other two emission categories means that a subset of small ranches has lower than average GHG emissions depending on their feed sources and transportation needs, even if small ranches as an overall group did not perform much differently from all-size ranches as a whole.

On the other end of the spectrum, large operations such as CAFOs necessarily operate differently from the ranches discussed in this study. To compare relative emissions from the two approaches to beef production, careful consideration of boundaries must be observed. For example, a CAFO or feedlot operation would need to be analyzed along with a cow-calf operation to produce a cradle-to-gate life cycle assessment. Including the cow-calf portion of the operation, current literature estimations of the emissions from these large-scale beef operations are 15.06 to 15.79 kg CO2e kg⁻¹ live weight output (Pelletier et al., 2010; Phetteplace et al., 2001). These estimates are slightly higher than the average emissions observed from ranches in this study of 13.78 kg CO2e kg⁻¹ live weight output. This could be due to several factors. The EPA found that liquid manure management systems, such as those used at CAFOs, tend to produce greater CH4 emissions compared to manure deposited on fields and pastures, which “produces insignificant amounts of methane” (USEPA, 2011, 2012). In addition, pasture-based systems typically require less fuel and feed than conventional systems (Koneswaran and Nierenberg, 2008; Boody et al., 2005). This was true for the ranches in this study as well. Taking average energy densities of 35 and 35.86 MJ L⁻¹ for gasoline and diesel fuels, respectively (DOE, 2013), the studied ranches had an average fossil fuel usage of 9.78 ± 5.53 MJ kg⁻¹ live weight output. This is low compared to conventional fossil fuel use of approximately 25 MJ kg⁻¹ live weight output (Sainz, 2003).

### Table 4. GHG emissions for each ranch.

<table>
<thead>
<tr>
<th>Ranch 1</th>
<th>Ranch 2</th>
<th>Ranch 3</th>
<th>Ranch 4</th>
<th>Ranch 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enteric fermentation emissions (kg CO2e year⁻¹ head⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bull</td>
<td>2,700.08</td>
<td>2,700.08</td>
<td>2,700.08</td>
<td>2,700.08</td>
</tr>
<tr>
<td>Cow</td>
<td>1,541.11</td>
<td>1,541.42</td>
<td>1,983.56</td>
<td>1,937.47</td>
</tr>
<tr>
<td>Calf</td>
<td>286.12</td>
<td>262.48</td>
<td>489.55</td>
<td>601.00</td>
</tr>
<tr>
<td>Steer</td>
<td>1,148.41</td>
<td>1,271.07</td>
<td>1,592.48</td>
<td>1,717.50</td>
</tr>
<tr>
<td>Heifer</td>
<td>1,457.41</td>
<td>1,440.46</td>
<td>1,551.78</td>
<td>2,355.99</td>
</tr>
<tr>
<td>Direct CO2e emissions from manure management (kg CO2e year⁻¹ head⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bull</td>
<td>49.60</td>
<td>49.60</td>
<td>49.60</td>
<td>49.60</td>
</tr>
<tr>
<td>Cow</td>
<td>28.31</td>
<td>28.32</td>
<td>36.44</td>
<td>35.59</td>
</tr>
<tr>
<td>Calf</td>
<td>10.51</td>
<td>9.64</td>
<td>17.99</td>
<td>22.08</td>
</tr>
<tr>
<td>Steer</td>
<td>21.10</td>
<td>23.35</td>
<td>29.25</td>
<td>31.55</td>
</tr>
<tr>
<td>Heifer</td>
<td>26.77</td>
<td>26.46</td>
<td>43.55</td>
<td>28.51</td>
</tr>
<tr>
<td>N2O emissions from manure management (kg CO2e year⁻¹ head⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bull</td>
<td>554.47</td>
<td>554.47</td>
<td>554.47</td>
<td>554.47</td>
</tr>
<tr>
<td>Cow</td>
<td>277.19</td>
<td>277.25</td>
<td>388.08</td>
<td>375.63</td>
</tr>
<tr>
<td>Calf</td>
<td>50.01</td>
<td>45.93</td>
<td>82.89</td>
<td>92.58</td>
</tr>
<tr>
<td>Steer</td>
<td>144.76</td>
<td>159.99</td>
<td>231.98</td>
<td>179.41</td>
</tr>
<tr>
<td>Heifer</td>
<td>181.19</td>
<td>173.62</td>
<td>218.72</td>
<td>276.07</td>
</tr>
<tr>
<td>Total cattle emissions[b] (kg CO2e year⁻¹)</td>
<td>112,663.40</td>
<td>168,975.10</td>
<td>104,213.70</td>
<td>118,501.80</td>
</tr>
<tr>
<td>Cattle emissions per live weight output (kg CO2e kg⁻¹)</td>
<td>12.36</td>
<td>10.64</td>
<td>11.49</td>
<td>9.84</td>
</tr>
<tr>
<td>Emissions from feed production (kg CO2e year⁻¹)</td>
<td>36,267.00</td>
<td>21,570.00</td>
<td>3,809.00</td>
<td>38,463.00</td>
</tr>
<tr>
<td>Feed production emissions per live weight output (kg CO2e kg⁻¹)</td>
<td>3.98</td>
<td>1.36</td>
<td>0.42</td>
<td>3.19</td>
</tr>
<tr>
<td>Emissions from fuel use (kg CO2e year⁻¹)</td>
<td>14,400.00</td>
<td>14,800.00</td>
<td>6,390.00</td>
<td>4,670.00</td>
</tr>
<tr>
<td>Fuel use emissions per live weight output (kg CO2e kg⁻¹)</td>
<td>1.58</td>
<td>0.93</td>
<td>0.70</td>
<td>0.39</td>
</tr>
</tbody>
</table>

[a] Emissions for steers are lower than average at Ranches 3 and 5 mainly because these ranches sell their cattle at auction and retain them for shorter period than Ranches 1 and 2. Ranch 4 also sells its cattle at auction; however, Ranch 4 is currently in the process of replacing a bull and therefore retains a portion of each season’s bull calves for testing.

[b] Total cattle emissions are given on a whole-ranch basis, while emissions in the preceding rows are given per head of cattle.

### Table 5. Combined emissions for each category from all ranches (standard errors shown in parentheses).

<table>
<thead>
<tr>
<th>Emission Category</th>
<th>Mean Emissions (kg CO2e year⁻¹)</th>
<th>Mean Normalized Emissions (kg CO2e kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>120,059 (12,812)</td>
<td>11.04 (0.42)</td>
</tr>
<tr>
<td>Feed production</td>
<td>21,350 (7,209)</td>
<td>1.94 (0.70)</td>
</tr>
<tr>
<td>Transportation</td>
<td>8,776 (2,419)</td>
<td>0.80 (0.22)</td>
</tr>
<tr>
<td>Total</td>
<td>150,184 (18,112)</td>
<td>13.78 (1.06)</td>
</tr>
</tbody>
</table>
CONCLUSION

This study investigated the practices of five small ranches in the Palouse region of the northwestern U.S., each of which produced between 20 and 35 head of cattle per year. The ranches fell into two main categories: (1) those that produced cattle mainly for slaughter directly after sale, and (2) those that produced cattle for sale at auction. Ranches 1 and 2 fell in the first category, while Ranches 3 and 5 fell in the second. Ranch 4 fell into both categories, mainly selling cattle at auction but also selling a significant portion of its output directly for slaughter. All of the ranches had significantly different cattle management regimes. It was assumed that if cattle were kept at the type 2 ranches for finishing, then emissions would be similar to the studied rearing period when normalized over the amount of live weight leaving the farm gate. This made it possible to compare GHG emission estimates for both ranch types to cattle operations selling cattle directly for slaughter.

The GHG emissions associated with three main areas of operations were estimated and reported. These areas were cattle emissions (enteric fermentation and manure management), feed production, and fuel use. Differences in emissions among the small ranches resulted from differences in feed production practices and fuel use. Ranches that used lower amounts of feed and fuel tended to have lower GHG emissions per live weight output. Combined, the ranches had a mean output of 13.78 kg CO₂e kg⁻¹ live weight output, with a standard error of 1.06 kg CO₂e kg⁻¹. The ranches that used fewer resources such as fertilizers and fuels also tended to have lower overall emissions. Overall emissions fell well within other values in the literature. Additionally, compared to large feedlot operations, such as CAFOs, the ranches in this study had lower overall emissions and used less fuel per live weight output. These results agree with other sources from the literature, which propose that pasture beef operations can have a lower environmental impact than feedlot beef operations (USEPA, 2011, 2012; Koneswaran and Nierenberg, 2008; Boody et al., 2005).

The variation of practices among the small ranches in this study made this system difficult to analyze. However, this variation likely enhances the overall resilience of the system. Additionally, the large variation in fossil fuel and feed-related emissions means that a subset of small ranches has the potential to market their products as low fossil fuel use beef, although not necessarily as low GHG emissions beef. To fully understand the comparative environmental impact of small ranches, more research investigating small-scale ranching methods is needed.

ACKNOWLEDGEMENTS

This research was supported by the Agriculture and Food Research Initiative of the National Institute of Food and Agriculture.

REFERENCES


Foltz, J. D., D. Jackson-Smith, L. Chen. 2002. Do purchasing

![Figure 4. Total emissions from small ranches.](image-url)


