Protein Supplementation of Beef Cattle to Meet Human Protein Requirements

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Introduction

Utilization of ruminants as a source of protein, calories, and other essential nutrients predates civilization. Domestication of ruminants allowed societies to more effectively harness the ruminant's capacity to transform calories (energy) and amino acids (protein) locked in biomass (plants) inaccessible to the human gastrointestinal tract. This process transforms solar energy, carbon dioxide, nitrogen, and water into high-quality nutrients for human growth and development. Upcycling of nutrients from unavailable biomass results in some energy losses, most notably methane emissions. Recently, consumers (especially in developed economies) have begun to question whether the cost of ruminant production systems, primarily beef production, as sources of human consumable nutrients outweighs their value or benefit. In other words, does beef production bring more to the table than it removes?

Are we as a society deriving value from beef production? Beef producers, when asked; respond with a resounding "YES!" Often, this response is delivered defensively and lacks quantitative support. Developing methods of accurately accounting for beef's contribution to human nutrient supplies and for the costs associated with beef production are essential for addressing societal concerns. Additionally, thoughtfully developed methods of accounting can be used to assess the net benefit of alternate production systems, evaluate existing and emerging technologies, and improve the efficiency of beef production, all of which benefit both beef producers and consumers. Ultimately, the goal is to accurately describe the benefits and costs associated with beef production, and to use that knowledge to improve the sustainability of beef production systems while providing rational and defensible, rather than defensive, answers to concerned consumers.

Protein's Value

Beef production systems primarily bring value to society by providing a source of high-quality nutrients in a form that people have a strong desire to consume. Cattle do this by consuming diets (forages and byproducts) whose nutritional value is largely unavailable to humans. Cattle are upcyclers of protein, transforming low-quality or human-inedible proteins and converting them into beef, a high-quality protein source. When human-consumable nutrients are fed to beef cattle, it is usually to improve utilization of other nutrients and to significantly improve system efficiency. Some of the largest gains in sustainability of beef cattle production have been made by delivering energy dense rations for a short period of time (e.g., during finishing).

For humans, one the primary benefits of consuming beef is its high-quality protein component; a characteristic shared with all animal derived proteins (meat, milk, and eggs). Therefore, understanding protein and the value of different sources of protein in human diets becomes essential to understanding the benefits of beef. A protein is similar to a chain, where each link in the chain is an amino acid. Nutritionists tend to focus on 20 amino acids, and of those, especially the 10 that are considered to be indispensable. "Indispensable" indicates that these 10 amino acids must be consumed in sufficient quantities to meet the body's requirements. Different sources of protein contain different ratios of these amino acids, with some proteins containing more of the indispensable amino acids than others. Plant-based proteins generally have fewer digestible indispensable amino acids than animal-derived proteins; so generally, animal-derived proteins are a higher-quality source of protein (supplying more of what is required).

Human nutritionists quantify differences in protein quality using the digestible indispensable amino acid score (DIAAS; Table 1). A larger DIAAS score indicates a protein is of higher-quality; it does a better job of providing indispensable amino acids. Animal proteins have a DIAAS that is 2.75 times greater than cereal grains (wheat and corn). Soy-based products have DIAAS that are much closer to animal-derived proteins than the cereal grains. The key take-home message is that animal-sourced proteins are the highest quality sources of protein because of their ability to provide indispensable amino acids to humans.

Table 1. Digestible indispensable amino acids score (DIAAS) for common protein sources

Protein Source	DIAAS	Protein Source	DIAAS
Wheat	40.2	Beef	111.6
Corn Grain	42.4	Pork	113.9
Soybeans	99.6	Chicken	108.2
Soybean cake	97.0	Lamb	116.8
Soybean expeller	100.3	Milk	115.9
Corn Silage	42.4	Eggs	116.4

Adapted from Ertl et al. 2016

Protein cost

Protein sources in livestock diets can be broken into two categories: 1) sources that cannot be consumed by humans (grass, cottonseed meal, distillers' grains, etc.) and 2) sources that can be consumed by humans (wheat, corn, soybeans, etc.). Protein that can be consumed by humans is referred to as human-edible protein; the consumption of this protein by livestock represents a cost. Protein is being taken from potential human consumption and placed into a feed bunk when human-edible protein is consumed by livestock.

Protein Quality

At first glance, redirecting human-edible protein to livestock feed may appear to be a completely negative action; however, in some cases (e.g., wheat, corn) ruminant transformation of the protein significantly improves the DIAAS of the protein delivered to the table. If soybean meal is fed to animals, the potential for improvement is low, because it already provides a relatively high-quality protein (high DIAAS). It is also important to note that for most humans, the desire to consume meat protein is greater than the desire to consume soy protein. When human-edible protein is fed to livestock, minimizing the DIAAS score of the feedstuffs used provides the animal production system with a greater opportunity to improve protein quality. Improvement in protein quality is quantified as a protein quality ratio (Equation 1). The output DIAAS, in this case the protein quality score for beef, is fixed by biology; there is very little producers can do to change the amino acid profile of beef. The input DIAAS or the DIAAS of the feed used to produce beef is determined by taking a weighted average of the DIAAS score for the human-edible proteins fed to beef cattle. Sources of protein that are inedible by humans are not included in this calculation, instead, the weighted average DIAAS score of only the human edible portion is considered. If we fed a diet where the only source of human-edible protein (HeP) was corn, the protein quality ratio would be 2.63 (Equation 1.1) indicating a more than doubling of protein quality. This would be the calculated result if corn were 50% of the diet or 100% of the diet, as it represents the only HeP. In contrast, if the human-edible portion of the steer's diet contained 25% soybean meal and 75% corn the protein quality ratio would be decreased (1.96; Equation 1.2) as a result of adding the high-quality soybean protein to the diet.

Equation 1: $$protein\ quality\ ratio = \frac{\text{output DIAAS}}{\text{input DIAAS}} = \frac{\text{beef DIAAS}}{\text{cattle feed DIAAS}}$$

Equation 1.1: $$protein\ quality\ ratio = \frac{111.6}{42.4} = 2.63$$

Equation 1.2: $$protein\ quality\ ratio = \frac{111.6}{(42.4 \times 75\%) + (100.3 \times 25\%)} = 1.96$$

Human-edible Protein Conversion

Feed conversion is a concept familiar to most livestock producers and represents how effectively the animal converted the diet into gain. A similar concept in the discussion of protein is human-edible protein conversion efficiency (HePCE; Equation 2); a descriptor of how effectively the HeP in the animal's diet was converted into HeP in the product. There are two values required for this comparison: the amount of human-edible protein found in the product (197 g of protein/kg of meat; Wilkinson, 2011) and the amount of human-edible protein required to produce the kg of meat. Similar to the DIAAS value, the amount of protein in a kg of meat is relatively fixed; but increasing the amount of fat in proportion to lean decreases this number. In contrast, the amount of human-edible protein fed to produce that beef begins at zero and increases depending on the diet offered. For example, feeding 439 g of dietary human-edible protein to produce 1 kg of meat (197 g HeP/kg of meat) results in a conversion efficiency of 0.45 (Equation 2.1). Which means for every pound of human edible protein put into the system 0.45 pounds of human edible protein is produced. This conversion is simply the ratio of inputs to outputs and does not account for any improvement in protein-quality.

Equation 2: $$HePCE = \frac{\text{HeP Output}}{\text{HeP Input}}$$

Equation 2.1: $$HePCE = \frac{\text{197g HeP in 1 kg of meat}}{\text{439 g HeP to produce 1 kg of meat}} = 0.45$$

Net Protein Contribution

Multiplying the human-edible protein conversion by the protein quality ratio adjusts both the input and the output for DIAAS content, and this is termed net protein contribution (Equation 3). Net protein contribution provides a complete picture of how much a specified livestock production system contributes to our ability to meet human protein demand. Feeding diets that allow the animal to make greater improvements to protein quality (i.e. a high protein quality ratio) or feeding diets that contain less human-edible protein (lower HeP, increased HePCE) creates a livestock production system that makes a greater contribution to addressing human protein requirements (Equations 3.1 and 3.2). In fact, NPC values above 1 suggest that the system yields more indispensable protein than it consumed; it is a net creator of beneficial nutrients.

Equation 3: $$Net\ Protein\ Contribution = \text{Protein Quality Ratio} \times \text{HePCE}$$

Equation 3.1: $$Net\ Protein\ Contribution = 2.63 \times 0.45 = 1.18$$

Equation 3.2: $$Net\ Protein\ Contribution = 1.82 \times 0.30 = 0.55$$

Scenario Evaluation

Using the three equations above livestock production systems can be evaluated and compared. When comparing alternate production systems, those with greater net protein contributions are of greater value.

In the United States, the primary meat producing livestock systems are swine, broilers, and cattle. In 2014, Peters, et al. published a paper evaluating the rations and feed conversion of these three systems. Their paper provided estimates of feed usage per unit of output which we have used to calculate human-edible protein (Table 2). Their work provides a great starting point; however, it was limited to the data available and like most modeling exercises, included assumptions that need to be refined. Two assumptions that are most problematic are:

1) the limited number of feedstuffs considered: alfalfa, corn silage, corn grain, grass hay, soybean meal, and pasture; and

2) deficiencies in energy and protein for beef cattle were addressed solely by feeding corn grain and soybean meal .

Both of these assumptions are punitive to beef cattle production systems, where a wide variety of feedstuffs are available and many of those feedstuffs contain little or zero human-edible protein. The assumptions made by Peters et al. (2014) result in a diet that contains approximately 14% corn during the backgrounding period and 85% corn and 6% soybean meal during the finishing period. For the purposes of the current discussion, only the beef cattle assumptions have been modified, to create five scenarios for beef production:

1) 100% of the corn and soybean meal estimated by Peters et al. (100% + SBM),
2) 45% of the corn and 0% of soybean meal (45%),
3) 70% of the corn and 0% of the soybean meal (70%),
4) 100% of the corn and 0% of the soybean meal (100%), and
5) 120% of the corn and 0% of the soybean meal (120%).

The 120% scenario is designed to evaluate a scenario in which the entire production system used 20% more corn than the baseline system, and how increasing corn usage might impact net protein contribution. These scenarios act as a starting point to begin to evaluate beef cattle production systems and in no way represent the breadth of technologies applied to commercial beef production or commonly fed diets.

Table 2. Net Protein Contribution of Livestock

Species	HeP	Diet DIAAS	PQR	HePCE	NPC
Swine	1057	79.9	1.43	0.19	0.28
Broilers	1273	87.5	1.23	0.15	0.19
Cattle					
100%+SBM	651	61.0	1.82	0.30	0.55
45%	198	42.4	2.63	1.00	2.62
70%	306	42.4	2.63	0.64	1.69
100%	439	42.4	2.63	0.45	1.18
120%	526	42.4	2.63	0.37	0.98

HeP = Human-edible protein required g/kg of meat (adapted from Peters et al., 2014)

DIAAS = Digestible indispensable amino acid score

PQR = Protein quality ratio

HePCE = Human edible protein conversion efficiency

NPC = Net protein contribution

In the base scenarios (Swine, broilers, Cattle – 100%+SBM) the inclusion of soybean meal as a source of protein results in greater levels of human-edible protein required for production, and the greatest digestible indispensable amino acid score for the animals' diets. This results in the lowest protein quality ratio of all the evaluated scenarios, and also results in the lowest human-edible protein conversion efficiency and the lowest net protein contribution. It is important to note that this effect is driven by only a 6% inclusion of SBM in the finishing phase for cattle.

The remaining scenarios compare the impact of changing the level of corn in the systems (compared to the baseline). As expected, including less corn in the production system decreases the amount of human-edible protein utilized, while the digestible indispensable amino acid score of the animal's diet remains constant. The DIAAS is constant because the only HeP contributor in the diet is corn, so the protein quality ratio remains the same for all of these scenarios. Human-edible protein conversion efficiency increases as the amount of corn is decreased, driven by decreased human-edible protein consumption. The result of decreasing the amount of corn in beef production is an increase in the net protein contribution. Even when corn is fed at 120% of the level reported by Peters et al. (2014) beef still represents a break-even proposition on a net protein contribution basis. Importantly, reducing corn by 30 percentage units in the diet (e.g., comparing 100% scenario to 70% scenario) results in a 43% improvement in the NPC; removing only 6 percentage units of SBM increases NPC by almost 115% (100%+SBM vs. 100%).

Upcycling: Beef cattle systems have two distinct advantages compared to the other primary sources of meat in the United States:

1) ruminal microbes can transform low-quality sources of protein (it doesn't even have to be protein, urea will do!) into a much more valuable source of indispensable amino acids; and

2) these systems can utilize sources of biomass (e.g., forages and byproducts) that other meat producing animals cannot. Upcycling of low-value or inaccessible sources of protein into a high-quality source of human edible protein is truly remarkable, and an essential component of meeting the increasing demand for high-quality sources of human-edible protein.

Conclusion

Net protein contribution is a useful tool for describing the value of beef production systems and for evaluating the utility of changes to protein production systems and the introduction/removal of production technologies and dietary ingredients. Calculation of net protein contribution can serve as a key performance indicator of both social (ability of the system to provide protein) and environmental (efficiency of energy and nutrient utilization) sustainability. Additionally, describing the beef industry's ability to increase the net supply of human-edible protein has value in communicating with consumers who are equally interested in the beef "story" as they are the eating experience. As with any key performance indicator, net protein contribution must be interpreted in concert with other key performance indicators in some balanced scorecard or indexed approach. For example, development of extensive, grass-based beef production systems would very likely maximize net protein contribution, but might simultaneously increase land use and methane production, decrease the beef supply, and compromise system sustainability. The role of the U.S. Beef Industry as a positive contributor to the protein supply is a story that has largely gone untold. ***It is up to producers to begin to tell this story.***

Literature Cited

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