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Animal Feed vs. Human Food: Challenges and Opportunities in Sustaining Animal Agriculture Toward 2050

Maintaining and improving sustainability of animal agriculture is a key component of feeding the growing global population. (Photo on left from iStock; photo on right from Shutterstock.)

Abstract

The perception exists that feed produced for livestock competes for human food supplies and represents an inefficient or wasteful use of resources. This perception can create confusion in communicating with retailers and other supply chain partners, policymakers, and consumers. In this CAST publication, scientific experts examine the facts and provide science-based information on which reasoned choices can be made in determining appropriate resource allocations regarding livestock production.

The global livestock industry faces a considerable challenge because a presumed dichotomy exists between the increasing demand for animal-source foods conferred by population growth and consumer concerns regarding livestock production sustainability. Many consumers are unaware of the advantages of livestock productivity gains conferred by modern practices, by-product feeds, and use of technology. The members of this Task Force note the following:

- Global animal agriculture provides safe, affordable, nutrient-dense foodstuffs that support human health and well-being as part of a balanced diet in addition to manifold by-products that have significant contributions to society. These include but are not limited to edible and inedible components, medicines, lubricants, manufactured goods, and other industrial uses. By-product utilization also enhances sustainable practices while lowering the industry's environmental footprint.
- Livestock production is important in the economic and social sustainability of developed and developing countries, and it supplies considerable draft power within smallholder operations that make up the majority of global food production.

CAST Issue Paper 53 Task Force Members

Authors

Jude L. Capper (Chair), Department of Animal and Range Sciences, Montana State University, Bozeman/ Department of Animal Sciences, Washington State University, Pullman/Livestock Sustainability Consultant, Bozeman, Montana

Larry Berger, Department of Animal Science, University of Nebraska, Lincoln

Mindy M. Brashears, Department of Animal and Food Sciences, Texas Tech University, Lubbock

Helen H. Jensen, Department of Economics, Iowa State University, Ames

Reviewers

Thomas G. Field, Engler Agribusiness Entrepreneurship Program, University of Nebraska, Lincoln

James Pettigrew, Department of Animal Sciences, University of Illinois, Urbana

J. Michael Wilkinson, School of Biosciences, University of Nottingham, United Kingdom

CAST Liaison

A. David Scarfe, Scientific Activities Division, American Veterinary Medical Association, Schaumburg, Illinois

- Large areas of land are incapable of supporting the production of human food crops. Terrain, soil type, and climate render the majority of land currently used for grazing unsuitable for cultivation for the production of vegetable-based foods for human consumption, yet forages can be sustainably converted by ruminant animals into meat and milk products.
- The gains made by "recycling" safe, yet otherwise valueless, by-products from human food and fiber production lessen competition between humans and animals for crops that can equally be used for feed or food, maximize land use efficiency, and decrease the environmental impact of food production.
- Improved communication is required between livestock production stakeholders and the consumer to further a better understanding of the economic, environmental, nutritional, and social advantages conferred by animal agriculture on a regional and global basis.

Introduction

In November 2011, the global human population passed a significant milestone, reaching seven billion people. By the year 2050, the Population Division of the United Nations (2011) predicts that the planet will support more than nine billion people and that the population will exceed ten billion by the year 2100. According to the Food and Agriculture Organization of the United Nations (FAO) (2013a), demand for food, fuel, and fiber will thus increase 60% by the year 2050. The seeming discrepancy between the increase in food demand and the extent of population growth is due to projected region-specific changes in population growth and affluence over time. The current 48 least-developed countries are predicted to have the highest rate of population growth (2.5% per year), and the population of the entire developing world is expected to grow to 8.0 billion in 2050—nearly 90% of the total population (United Nations 2011).

Concurrently, per capita incomes in presently impoverished regions such as China and India are predicted to increase until they reach levels similar to those enjoyed by residents of developed regions by 2050 (Tilman et al. 2002). A positive correlation exists between per capita income and demand for animal-source foods (milk, meat, and eggs). Thus, unless major changes in diet preferences occur, livestock production will have to substantially increase over the next 40 years to supply global demand.

Sustainability of all economic and human activity is an area of growing worldwide attention. The Brundtland Report provides what is arguably the most widely used definition of sustainable development, which is that it "meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations World Commission on Environment and Development 1987). The concept of sustainability is partitioned into three components: environmental stewardship, economic viability, and social responsibility (United Nations 2005). For a system or industry to be sustainable, all three components must be considered—if one factor is misaligned, ignored, or the sole focal point, then the system cannot achieve long-term sustainability. Addressing global sustainability presents substantial challenges because issues, opportunities, and resources vary considerably within and between regions. Sustainability is not an absolute state, thus no single system can be designated as sustainable or nonsustainable, because it is influenced by a myriad of external factors and impacts. Rather, sustainability can be thought of as a process within which systems are more or less sustainable, changing over time and only moving forward through continuous improvement.

Principal concerns relating to food sustainability in developing regions currently focus on limited food availability due, at the farm-level, to low agricultural yields, lack of producer education, and inadequacies of transport and sanitary infrastructure (Godfray et al. 2010). Broader issues of concern that impact food supply in developing regions include political instability, lack of wide-scale education (particularly for women, who are often the main agricultural workers), and military conflict (Pinstrup-Andersen 2000). The importance of animal-source foods (e.g., milk, meat, and eggs) in maintaining health and nutrient supply is well recognized (Murphy and Allen 2003; Neumann, Harris, and Rogers 2002; Randolph et al. 2007). Livestock play an invaluable role in maintaining the health and nutritional status of inhabitants of developing countries, for whom the supply of high-quality protein is often limited (Smith et al. 2012). Indeed, the prevention of protein-energy malnutrition, iron-deficiency anemia, and vitamin A deficiency through consumption of animal-source foods improves global longevity by a total of 33.6 million disability-adjusted life years (World Health Organization 2009).

Nutrient-dense animal-source foods represent the predominant, most affordable source for many essential dietary nutrients (Drewnowski 2011; Fulgoni et al. 2011; Huth et al. 2008; Zanovec et al. 2010) and have been noted in dietary recommendations by global human health organizations. Aside from dietary benefits, the social and economic importance of livestock ownership in developing countries cannot be underestimated, because animals primarily supply a source of fertilizer and draft power; have significant benefits in terms of improved income, wealth storage, and providing risk management through agricultural diversification; and deliver cultural wealth and improved nutrition to owners (Godfray et al. 2010; McDermott et al. 2010; Randolph et al. 2007; Smith et al. 2012). Indeed, almost one billion households worldwide rely on livestock for their livelihood (FAO 2012a).

By contrast, the environmental impact of animal agriculture is arguably the greatest sustainability concern for food system stakeholders within the developed world. Resource use, waste output, and *greenhouse gas*[1] (GHG) emissions from animal agriculture are currently under scrutiny by both impartial scientific associations (FAO 2006) and agenda-driven activist groups (Environmental Working Group 2011; Nierenberg 2005). The consensus opinion is that animal agriculture uses a considerable amount of resources (both renewable and nonrenewable) and makes a significant contribution to global carbon emissions (FAO 2006; Pelletier and Tyedmers 2010). For example, Metz and colleagues (2007) cited all agriculture as contributing 14% of global GHG emissions (Figure 1); the FAO (2006) estimated that animal agriculture accounts for 18% of global GHG emissions, which is cited as being a greater proportion of total emissions than transport (13%); and the World Watch Institute (2009) claims that 51% of global GHG emissions result from animal agriculture. Nonetheless, it is important to appreciate that all foods have an associated environmental cost and that this is not restricted to foods of animal origin (see "Food's Environmental Impact").

The biggest challenge facing animal agriculture within the next fifty years is to maintain and improve all three facets of sustainability. This challenge is exacerbated by assertions that animal agriculture directly competes with production of other human foods for renewable and nonrenewable resources and that animal agriculture is an inherently inefficient method of food production. These assertions do not consider either the quantity of land used by the global animal agriculture industry that cannot be used for other purposes or the volumes of by-products from the human food, fiber, and fuel industries that are currently fed to livestock. This paper outlines the background and principles relating to the perception that livestock compete with humans for food and the challenges and opportunities faced by the animal agriculture industry in addressing this issue.

The Conflict between Animal Feed and Human Food

The global population is predicted to face a growing food crisis during the next century. Worldwide, one in seven people have insufficient energy and protein within their diet to maintain health and well-being (Godfray et al. 2010) and undernutrition accounts for 12% of deaths (FAO 2012b). Food crises classically result from a combination of factors, primarily rapid population growth, a shortfall in food supply, and poverty (Yotopoulos 1985a). The reasons underlying the current food crisis are not intuitive because it has occurred during a period of considerable agricultural innovation over the past century and many regions have a greater per capita income than ever before. Indeed, gross food prices have generally fallen during the past century, thus food is more available to those with wages above subsistence levels (Godfray et al. 2010).

The shortfall in food availability is often attributed to shortcomings in food distribution in combination with significant food waste. Global grain production has more than doubled during the past 50 years, yet developing regions often lack the facilities and infrastructure to store and transport cereal crops.

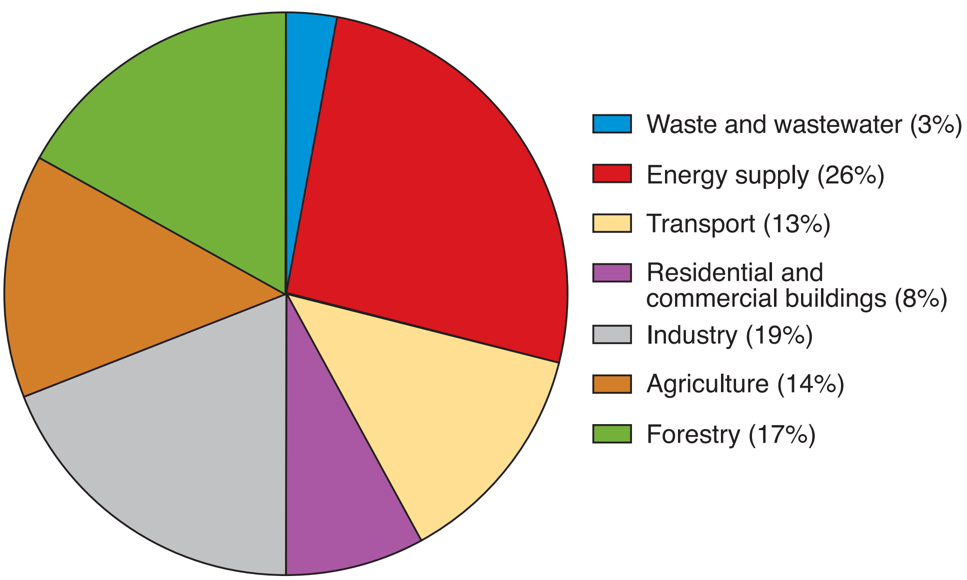

Figure 1. Global greenhouse gas emissions from various sources (expressed as CO_2-equivalents as percentage of the total). Data from Metz et al. (2007).

[1] Italicized terms (except genus/species names and published material titles) are defined in the Glossary.

Postharvest losses from spoilage, pests, and lack of cold storage in combination with the need to sell crops immediately after harvest for economic gain lead to preretail losses of up to 40% (Godfray et al. 2010). Greater investment in transport infrastructure, adoption of best management practices, and development of better-functioning markets within the developing world would mitigate this issue to a certain extent, yet they would not affect what is considered to be one of the major underlying issues behind food shortages—the so-called "feed vs. food" competition between animals and humans.

Difference between Human-inedible and Human-edible Foodstuffs

Evolution has allowed both animals and humans to develop specialized digestive and metabolism systems to process foods and absorb nutrients, often with considerable variation between and among species. Thus, a herbivorous mammal has a definitively different dental structure than a carnivore, and a ruminant has the capacity to digest plant materials (e.g., cellulose) through bacterial fermentation that is less efficient or nonexistent in a monogastric. For the purposes of this report, animal feed consists of those plant or animal materials that are either indigestible by humans or are unfit for human consumption because of sanitary or cultural characteristics, whereas human-edible foods are those that can be digested and metabolized by humans to provide nutrients (and that are part of the conventional human diet). Although many foods that are suitable for human consumption may also be used as animal feed, it should be noted that animal feed and human food are not always interchangeable, as even a single species (e.g., corn) may have varieties that vary considerably in digestibility (e.g., less-human-digestible *Zea mays indenata*; compared to *Zea mays rugosa*, sweet corn, eaten by humans). The perception commonly arises, however, that animals compete with humans for feed/food.

Competition between animals and humans for land or crops is not a new issue; indeed, it must have been more intense at earlier points in history when animals were the predominant source of agronomical power. The rapid rate of population growth and the presence of a worldwide transport network, however, turn what would formerly have been a contest for local land use into a global competition for the final fate of a cereal crop. Cereal crops are the staple energy source for low-income communities within the developing world, thus cereal consumption can be considered a proxy for nutritional adequacy (Yotopoulos 1985a). Cereal crops also remain the nutritional foundation within the developed world, yet in this instance cereals are an indirect nutrient source because they are converted to animal protein before human consumption. Total global cereal demand is therefore a combination of direct and indirect cereal consumption—a shortfall in the quantity of cereals available for human food is not simply a consequence of decreased yields or increased waste, but in some circumstances may occur from the diversion of cereal crops away from human consumption toward animal feed, where animal feed commands a premium (e.g., as an export) over the price that can be paid by the human consumer in that region.

The "feed vs. food" nomenclature is somewhat of a misnomer because true competition results not between animals and humans, but between human populations. As reported by Popkin (2003) using China as an example, an increase in population wealth leads to a dietary shift away from coarse grains (millet, sorghum, corn) toward refined cereals, from carbohydrates as the major energy source toward vegetable and animal fats, and from vegetable-based proteins to animal proteins. The extent of the shift is more pronounced in urban vs. rural populations and increases proportionally with per capita income. Cereal prices in the near future are predicted to rise and exhibit considerable volatility as a consequence of increased demand from developing countries and the growing market for biofuels (Godfray et al. 2010), thus the most significant contributor to food shortages in developing regions may be income distribution.

In the quest to alleviate world hunger, the oft-quoted statistic that one-third of cereals are fed to livestock (FAO 2002) leads to the seemingly logical suggestion that animal protein consumption should be curtailed (Foley 2011; Koneswaran and Nierenberg 2008; Lewis 1994). Stehfest and colleagues (2009) report that significant climate benefits, including a considerable decrease in land use (assuming that pasturelands could be used for human food crop production), would be achieved through limiting *ruminant* production. Increasing animal feed prices has been proposed as a mechanism to decrease global meat consumption, yet this would also confer a rise in the cost of cereal crops to low-income populations (Yotopoulos 1985b).

The assumption that reducing ruminant production will increase the availability of cereals for human food, however, only holds true if the same cereal crops are interchangeable between animal feed and human food. On a regional basis, this may be true of certain livestock systems; nonetheless, when assessing the extent of global "feed vs. food" competition, one major factor must be accounted for—livestock diets include a considerable quantity of crops and by-products from human food, fiber, and fuel production that are not suitable as human food use because of safety, quality, cultural, or digestibility considerations.

Examples of commonly used feeds within North American livestock systems are detailed in Table 1. This list is not intended to be exhaustive and many feeds exist within other regions worldwide, the detailing of which is beyond the scope of this paper. Yet it is clear from the variety of feeds listed that the oft-heard supposition that livestock diets are primarily composed of human-edible cereals is invalid. Indeed, it is estimated that 37 kilograms (kg) of by-product feeds suitable for livestock are produced from every 100 kg of plants grown for human food (Gill 1999). A wide range of by-products is used, which varies considerably depending on region, system, and animal species; yet there is a paucity of data available on the absolute quantities of by-product feeds fed to livestock either on a regional or national basis (Sapkota et al. 2007). It should be noted, however, that pastures used for livestock grazing, which remain the foundation for many global livestock systems ranging from subsistence dairying in Sub-Saharan Africa to the North American beef industry, are based on plants indigestible

Table 1. Examples of feeds commonly used within U.S. livestock production systems (adapted from Mowrey and Spain 1999; Sapkota et al. 2007; and Wilkinson 2011)

Feed Source	Examples	Human Edible?
Forage crops	Pasture grasses, alfalfa, clovers, hays, silages (grass or crop based)	No
Cereals	Corn, wheat, barley, millet, sorghum, triticale, oats	Yes
Plant proteins	Soybean (meal and hulls), cottonseed (whole and meal), safflower meal, canola meal, peanut meal	Partially
Grain by-products	*Distillers grains* (wet and dry), corn gluten, wheat bran, straw, crop residues	No
Vegetable by-products	Apple pomace, citrus pulp, almond hulls, pea silages	No
	Waste fruit/vegetables	Partially
Food industry by-products	Bakery waste, cannery waste, restaurant waste, candy, potato chips	Partially
Sugar industry by-products	Molasses (cane, beet, and citrus), beet pulp	Partially
Animal by-products	Meat and bone meal, tallow, feather meal, bloodmeal, poultry litter	Partially
Dairy by-products	Milk, whey products, *casein*	Partially
Marine by-products	Fish and seafood meal and oils, algae	Partially
Miscellaneous	Vitamins, minerals, probiotics, antibiotics, yeasts, flavors, enzymes, preservatives	Partially

by humans.

In contrast to ruminant systems, which have a significant foundation in pasture-based systems, monogastric animals are fed considerable quantities of human-edible grains in order to support productivity. Although by-product feeds are used in both ruminant and monogastric systems, when assessing the conflict between animal feed and human food, a dichotomy exists between the improved feed efficiency of the monogastric animal and the quantity of human-edible grains used for monogastric feed. This is discussed in more detail in the "Feed Efficiency" section.

Use of human-indigestible forages and by-product feeds allows opportunities for significant resource efficiency within livestock production (Fadel 1999); indeed, feeding human food waste to livestock was the basis of the small-scale "backyard" farming operations that founded modern swine and poultry systems. Nonetheless, within the developed world there is increasing consumer concern as to the potential human health risks of by-product feeds used within livestock diets (Sapkota et al. 2007) and a growing perception that animal proteins produced using "natural" feeds (e.g., pastures and forages vs. cereals or by-products) have greater environmental benefits (Grannis, Hooker, and Thilmany 2000). These perceptions are discussed in more detail later in both the "Food Safety" and "Food's Environmental Impact" sections.

Pasture vs. Productive Cropland

The FAO estimates that 26% of the world land area and 70% of the world agricultural area is covered by grasslands (FAO 2012c). To feed the nine-plus billion people projected to inhabit the earth by 2050, some are proposing that this land would be best used through systems producing food consumed directly by humans. There are only two approaches by which this could be accomplished. The first is to harvest the forages currently produced and to feed them directly to humans. The second is to cultivate the grazing land to produce other crops that could be consumed directly by humans. As discussed later, both of these approaches are impractical on a large scale and have great ecological risks.

Currently, food production from these grasslands most often occurs through the grazing of cattle, sheep, goats, water buffalo, and wildlife. Ruminant animals are best equipped to harvest the solar energy stored in the fibrous feeds growing on these grasslands and convert it into meat, milk, wool, or power from draft animals (Van Soest 1994). The majority of energy stored in these plants is in cellulose or hemicelluloses, which are inefficiently digested by monogastrics and are not digestible by man.

Ruminants are unique because of the symbiotic relationship the animal has with the microflora in the rumen. The rumen is the largest of the four compartments in the stomach, and a single cow's rumen is home to a quantity of bacteria, protozoa, and fungi that exceeds the size of the global human population (Yokoyama and Johnson 1988). The microbial population in the rumen produces a complex of enzymes that breaks down the plant cellulose and hemicelluloses into simple sugars. Because of the anaerobic environment within the rumen, the sugars are fermented into *volatile fatty acids*, primarily acetic, propionic, and butyric acids. These volatile fatty acids typically supply approximately 70% of the energy needed by ruminant animals.

Ruminants have another advantage over humans and other monogastric animals in that they can use *nonprotein nitrogen* as a protein source. In many types of forage, as much as 70% of the nitrogen is bound to fiber or found in nonprotein forms (Beever 1993). Rumen bacteria can convert nitrogen to microbial protein in the rumen. The microbial protein then passes out of the rumen and is broken down to amino acids in the small intestine where they are absorbed. Consequently, the two major requirements for growth and milk production—energy and protein—can be harvested from grasslands much more efficiently by ruminants than any other species.

The second approach of converting grassland into cultivated cropland is equally problematic. The majority of global grasslands is located in areas where it is impractical to cultivate the land for a variety of reasons. Figure 2 shows an FAO (2007) map illustrating where land is most suitable for cereal production. This should not be interpreted to indicate that it is impossible to grow the various cereal crops outside of the indicated region, nor that the indicated crops are the only ones grown in that area. For example, although the U.S. "corn belt" is suitable for growing

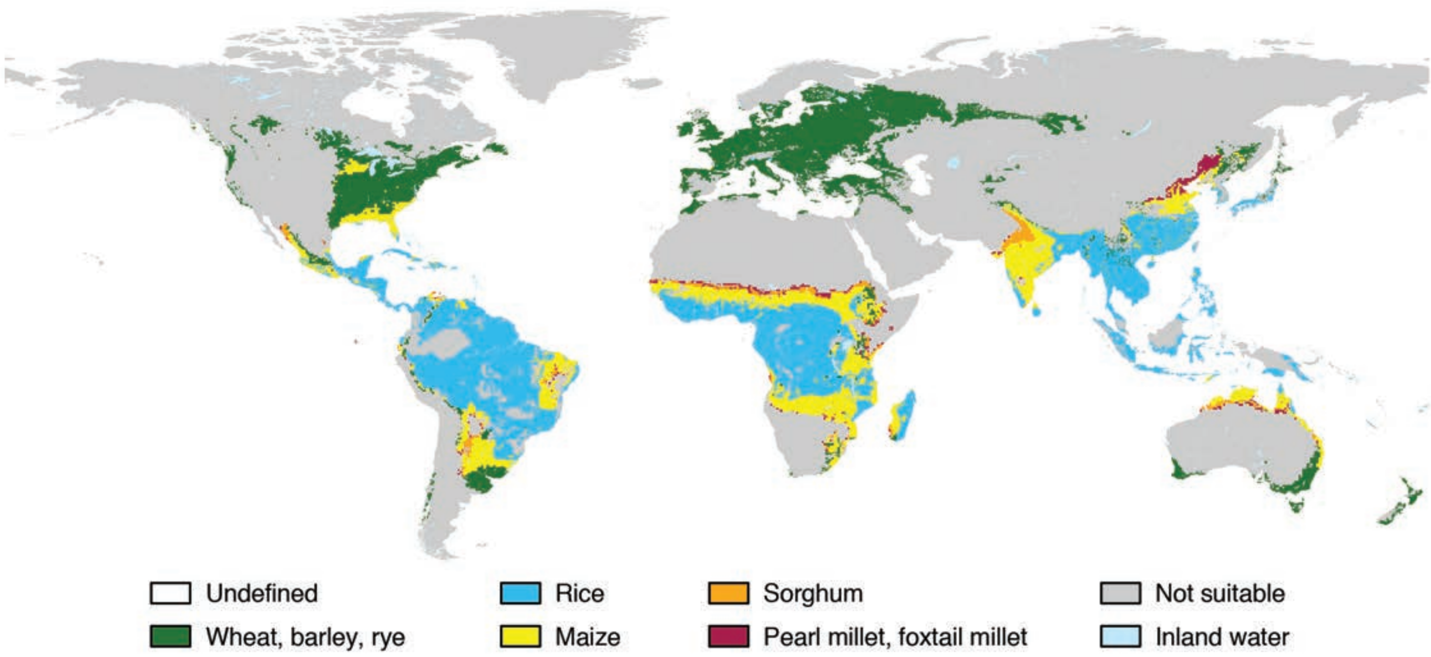

Figure 2. Land most suitable for cereal production. (Reprinted courtesy of the FAO 2007.)

wheat, barley, and rye, the majority of this land is devoted to corn (maize) production. Much of the gray portion is too dry, wet, steep, or infertile—or has too short a growing season—to raise cereals continuously without special management. The additional work required to raise cereals includes irrigation, summer fallowing, terracing, drainage, leaching of salts, and soil amendments.

In much of the gray-shaded lands, grass is the *climax species*. To convert these lands to cultivation would destroy the ecosystem, eliminate a major feed resource for grazing ungulates (including livestock), ruin the habitat for wildlife and other species, increase the risk of soil and wind erosion, increase nutrient runoff, and decrease soil carbon storage (Claassen, Carriazo, and Ueda 2010). In short, the environmental risks are much too severe to convert a significant amount of grassland into cultivated cereals. The U.S. Department of Agriculture (USDA) Economic Research Service showed that in 2007 less than 9% of the U.S. pastureland was sufficiently productive to be considered suitable for growing other crops (USDA–ERS 2011).

The efficiency of cropping production for feed and food use could be considerably improved by making more efficient use of the crop residues that result from current grain production. The USDA estimated that more than 500 million tons of crop residues are produced each year (USDA–NRCS 2006), with the proportion of residue to harvested crop varying widely according to species, nutritional value, and rate of decomposition (Lal 2005). Corn is the most common grain crop produced in the United States, and yields continue to increase. Recent research has shown that under the right conditions, a proportion of corn stalks can be grazed or harvested and fed to livestock without decreasing the health of the soil or subsequent grain yields (Wilhelm et al. 2004). Andrews (2006) described the conditions that need to be considered in determining appropriate residue removal rates. These factors include, but are not limited to, susceptibility to water and wind erosion, soil organic matter level, slope and soil type, water retention, chemical runoff, and wildlife habitat. Edgerton and colleagues (2010) used this information to guide the harvest of 3,200 tons of corn stover (corn stalks plus leaves) near Cedar Rapids, Iowa, in 2008 and 2009. This study demonstrated that field-specific stover retention rates can be estimated on a large scale and the current harvest equipment can be used to harvest corn stover at rates based on these estimates.

Recent research (Russell et al. 2011; Sewell et al. 2009; Shreck et al. 2013) has shown that calcium oxide treatment of crop residues can dramatically improve fiber digestion and animal performance. These studies show that in diets containing 35% or more distillers grains, 15% calcium oxide-treated stover can replace an equal amount of corn grain with no reduction in rate of gain or feed efficiency of finishing cattle. With many other examples of human-edible foodstuffs being replaced by by-product feeds, the aforementioned data demonstrate that a combination of by-product feeds (distillers grains) and treated corn stover can replace approximately two-thirds of the corn typically fed to finishing cattle while maintaining equal performance. Data derived from Capper (2011) show that corn only accounts for approximately 7% of the total feed consumed per unit of beef produced, thus the replacement of corn with by-product feeds would decrease human-edible grain use per unit of beef to less than 2.5%. This represents a significant opportunity for sustaining future animal agriculture while maintaining productivity.

Conflict between Land Used to Produce Animal Feed for Work Energy and Human Food

Draft power provided by livestock is an integral component of many extensive, small-scale agricultural systems (Gill 1999; Smith et al. 2012). Ramaswamy (1994) reported that livestock are used on more than 50% of cultivated lands globally, and de Haan, Steinfeld, and Blackburn (1997) estimated that they provide sufficient power to cultivate more than 320 x 10^6 hectares (ha). This enables the adoption of improved soil practices, timeliness of farming operations, and increased cropping yields (FAO 2011), thus enhancing productivity. On an annual basis, the total energy required by draft livestock is similar to that of a small tractor (Capper, Cady, and Bauman 2009), yet the energy inputs (i.e., feed crops) are renewable compared to the non-renewable fossil fuels used to power machinery (Sansoucy 1995). Draft power may therefore be considered to be a more environmentally favorable mechanism to complete agronomical operations (Wilson 2003), yet the question of whether or not livestock are again competing with humans for food resources still remains. The majority of feed supplied to draft livestock is composed of crop residues that are indigestible by humans (Kaasschieter et al. 1992; Ramaswamy 1994), yet more research is required to elucidate potential trade-offs between consumption of crop residues by draft livestock and use of resulting animal manures to improve soil quality versus using crop residues as green manures (Smith et al. 2012).

Effects of Human-inedible vs. Human-edible Food/Fiber By-products

Food Safety

Food safety is a principal consumer concern and thus has become a significant factor in the preharvest/production environment of livestock. Livestock naturally harbor small quantities of foodborne pathogens in the digestive tract, although many do not cause symptomatic responses in the animal because they are pathogenic only to humans. An increasing quantity of research thus focuses on controlling pathogens at the source through examining the prevalence of pathogens in live animals with regard to a variety of diets. To date, most research has focused on cattle and the shedding of Shiga toxin-producing *Escherichia coli* (STEC).

One of the issues that has come into question with regard to food safety and animal feeding is the impact of grain feeding and forage feeding on the prevalence of foodborne pathogens in cattle before slaughter. Media controversy currently exists as to whether or not grain feeding is “unnatural” or “unhealthy” for livestock; it is often suggested that ruminants “prefer” to graze on grass or other forage crops and that feeding forage-based diets results in fewer foodborne pathogens (specifically STECs and other *E. coli*). An early study (Diez-Gonzalez et al. 1998) reported that acid-resistant *E. coli* was more prevalent in cattle fed grain-based diets than those fed forage-based diets. The study did not, however, evaluate any specific pathogens.

Evidentially, several studies have proved that grass-fed beef has STEC prevalence rates similar to grain-fed animals. In a recent review article that examined all studies comparing pathogen shedding in grain- and grass-fed cattle, Jacob, Callaway, and Nagaraja (2009) reported that studies chronicling variations in pathogen shedding in cattle as it related to forage-based and/or grain-based feeding are “not repeatable” and that the “complexity of the hindgut ecosystem” is driven by many factors and not only the primary dietary components. Thus, there is little evidence to indicate that diets composed primarily of grains or forage result in significant changes in pathogen presence in cattle.

Another recent debate is related to supplementing cattle with distillers grains—by-products of the distilling industry. Several studies have indicated that diets supplemented with distillers grains result in higher pathogen (STEC) prevalence in cattle. Jacob and colleagues (2008a) reported that supplementing diets with wet distillers grain (WDG) decreased the need for antimicrobial supplementation for growth promotion. On day 122 of the study, the prevalence of *E. coli* O157:H7 was higher in cattle supplemented with 25% WDG compared to those not fed WDG; however, no significant differences in pathogen prevalence were seen at day 136 (Jacob et al. 2008a).

Varel and colleagues (2008) also noted that cattle fed 20% or 40% WDG in the diet had higher concentrations of generic *E. coli*, and Jacob and colleagues (2008b) evaluated dry distillers grain (DDG) supplementation in the diet and reported that cattle supplemented with 25% DDG had a higher prevalence of *E. coli* O157:H7 over the duration of the study. By contrast, Wells and colleagues (2009) reported that the supplementation with 13.9% WDG increased the prevalence but not concentration of *E. coli* O157:H7 in cattle and, in a follow-up study, showed that excluding WDG from the diet at the end of the feeding period would decrease the pathogen prevalence to that of control cohorts at slaughter (Wells et al. 2011).

Finally, Chaney and colleagues (2011) demonstrated that cattle fed high-WDG (>15%) diets averaged an *E. coli* O157 prevalence in the manure of 23.91%, compared to cattle fed low-WDG (<8%) diets, which averaged 9.43% prevalence. Although there is evidence that WDG can impact the pathogen prevalence, it seems that the prevalence is related to the quantity of WDG included in the diet and can be managed to mitigate the negative impacts by removing it from the diet at the end of the feeding period.

All livestock feeds have potential safety concerns for animal or human health with risks ranging from the minuscule to the significant. The solution, however, is to use appropriate mitigation strategies and management to ensure that health hazards are eliminated or minimized below the level at which animal welfare or human health are compromised. The challenge currently facing the animal industry is to demonstrate the safety of by-product feeds as a viable ingredient in animal diets.

Food Security

Food security is often considered in the same arena as food safety, although in reality they are separate (but linked) issues. It is essential to use animal feeds and by-products with due regard for potential safety concerns, yet in addition, all components of the animal that have a potential consumer benefit as food, fiber, or industrial ingredients should be used to decrease waste and improve our ability to meet global food needs.

The need to make the most efficient use of resources in order to maximize the sustainability of animal agriculture is not confined to the preharvest component of the production system (e.g., cropping and animal yields); it also extends to the postharvest processing stage. If every component of a livestock carcass can be used for human consumption or other purposes, waste is minimized. In 2012, the global media created consumer mistrust by labeling a staple product in the U.S. beef industry "pink slime." This product, correctly named lean finely textured ground beef (LFTB), efficiently uses each portion of edible protein from a beef animal by removing small pieces of meat from the bones that cannot be removed during normal fabrication processes, grinding the meat, and treating it with ammonia to decrease pathogen load. Media misrepresentations of the manufacturing process and the safety of LFTB led to the closure of four major LFTB-producing plants in the United States, leaving hundreds of workers without jobs. Although LFTB has been used within human food for more than 30 years, is safe, and contains 100% pure beef, it was represented by the media as unsafe and unwholesome. Loss of this significant source of protein in the human diet resulted in an increased need to produce more beef cattle to fulfill consumer demand for ground beef, with a concurrent increase in environmental impact from beef production. This is but one example of the media's influence on consumer perceptions of food production, which, in this case, resulted in a significant loss of economic, environmental, and social sustainability for the beef industry.

Food Affordability

Economic factors are strong predictors of food consumption and the dietary intake of food components. Across global regions, increased income is positively correlated with calorie consumption and, as shown in Figure 3, a shift from grains to animal protein sources. In the United States and other advanced economies, more than 60% of protein comes from animal sources, whereas the contribution of animal sources in Africa, India, and other food-deficit countries is 20–25% of total protein.

In addition to satisfying preferences for taste and meeting cultural norms, animal-source foods are an important nutrient source. Studies from developing countries have shown that schoolchildren consuming diets with little or no animal-source foods have an inadequate intake of essential micronutrients that results in negative health outcomes including poor growth, suboptimal cognitive performance, neuromuscular deficits, psychiatric disorders, and increased rates of mortality (Murphy and Allen 2003; Neumann, Harris, and Rogers 2002). Countries with lower shares or different mixes of animal-sourced foods obtain nutrients from other dietary sources and tend to have less saturated fat in their diets, though they may face some deficiencies in other nutrients. In the United States, animal-source foods contribute nearly one-quarter of calories consumed (Table 2) and more than 60% of total protein, and they are important sources of vitamin A, B vitamins, and zinc (USDA–ERS 2012a). Shifts within the U.S. diet to more vegetable-based protein sources would require increased consumption of beans and peas, processed soy products, and nuts and seeds to replace the recommended nutrient levels based on the *Dietary Guidelines for Americans, 2010* (USDA/DHHS 2010). Although these vegetable-based proteins often have a lower economic cost (per serving) than many animal-based sources, the higher energy of animal-based proteins means that they are relatively less expensive on a per-calorie basis (Carlson and Frazao 2012).

In aggregate, Americans spend less than 10% of their disposable income on food (USDA–ERS 2012b). As incomes increase, consumers spend more on food (though a smaller share of income), purchase higher "quality" foods, and buy more food away from home. Recent U.S. estimates by Okrent and Alston (2012) are that the income/expenditure elasticity of meat is approximately 0.64—i.e., if incomes increased by 10%, expenditures on meat would increase by 6.4%. This implies that although the consumers increase purchases (consumption) of most meat and animal products with increases to their income, the relative share of their budget going to food (and specifically meats) will fall.

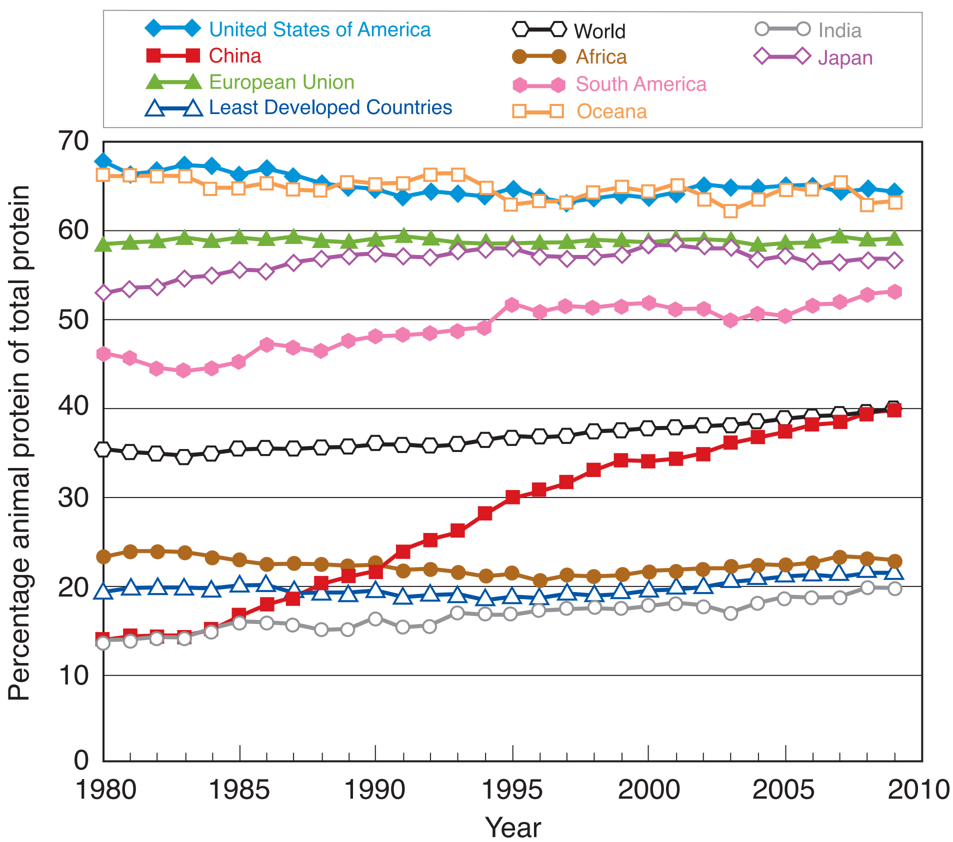

Figure 3. Percentage of total dietary protein supplied by animal-source foods in selected countries and regions from 1980 to 2009 (FAO 2013b [authors' calculations based on FAO data]).

Table 2. Contribution of major animal-source food groups to selected nutrients in the U.S. food supply (2006) (USDA–ERS 2012a)

Nutrient	Meat, Poultry, and Fish (%)	Dairy Products (%)	Eggs (%)	Total (%)
Energy (calories)	13.4	8.6	1.4	23.4
Protein	40.3	19.0	4.0	63.3
Saturated fat	22.5	20.8	2.0	45.3
Vitamin A	32.0	17.5	6.4	55.9
Vitamin B_6	36.1	7.2	1.9	45.2
Vitamin B_{12}	75.5	19.9	4.5	99.9
Thiamin	18.2	4.7	0.7	23.6
Riboflavin	17.5	25.7	6.3	49.5
Niacin	36.6	1.1	0.1	37.8
Zinc	37.2	16.3	2.6	56.1

Consumers respond to changes in price of meat, but the response is relatively smaller than the change in price itself. The Okrent and Alston (2012) estimate of the price elasticity for meat is -0.4% (i.e., an increase in the price of meat by 10% would lead to a decrease in consumer demand by 4%). Of course, price changes for specific types of meat would have a stronger response as consumers shift from one type to another. As meat prices change, consumers may shift to other foods, but these changes are smaller for most food groups. In the United States, as is the case in most advanced economies, price changes in meats are unlikely to confer whole-scale shifts away from meat and toward other sources of energy and protein.

Market prices and quantity are affected by both consumers (demand) and producers (supply), and these market effects have important implications for changes in consumption patterns. If a consumer were to change traditional patterns and shift to less meat consumption, the change does not necessarily lead to an equivalent reduction in the amount of meat produced and offered to the market. As some consumers decrease meat intake, producers may not be immediately able to fully adjust and cut back on the quantity supplied to the market. Market prices would therefore fall, encouraging a section of the population to purchase more meat in tandem with producers offering less.

Although these market adjustments vary by meat type (with adjustments in supply taking longer for beef than poultry, for example), recent estimates show the order of magnitude. Giving up one unit of beef leads to a decrease of 0.68 units of production (available for consumption); whereas giving up one unit of chicken leads to a decrease of 0.76 units of chicken (Norwood and Lusk 2011). Multiplying these amounts by a million consumers means that giving up 1 million pounds of beef would result in 680,000 pounds less beef consumed; giving up 1 million pounds of chicken would result in 760,000 pounds less chicken on the market—the magnitude of the chicken response being greater because poultry producers are relatively more responsive to changes in price than are beef producers.

In addition to economics, other market and social factors affect the types of food products on the market and result in changes in the affordability and mix of animal- and plant-based foods on the market. Among other social factors, consumers express concerns about animal welfare and argue for reduced animal-sourced foods in the diet. Although this is an important consideration for some consumers, most Americans rank other food concerns above animal welfare. Norwood and Lusk (2011) conducted a national survey of U.S. consumers and showed that most of the issues were related to human welfare (human poverty [24%], health care [23%], and food safety [22%]), the environment ranked fourth (14%), and least of the seven concerns surveyed was the well-being of animals (4%). Although this does not mean that Americans do not care about animal welfare, it does suggest that animal welfare ranks lower than other social issues as a primary area of concern.

Concurrently, the U.S. market has increased availability of animal-source food products raised under differing systems, allowing consumers to choose between animals raised traditionally and those produced within organic, "natural," "free-range," or cage-free practices. Some consumers are willing to pay a higher price for these products, although the share of the market is relatively small. For example, cage-free and organic eggs represent less than 4% of the U.S. fresh egg market and command a price that is double or more than traditionally produced eggs (Norwood and Lusk 2011).

Consumer choice is a paramount concern for all food supply chain stakeholders, and consumer willingness to pay for foods with desirable environmental attributes (e.g., lower GHG emissions) is generally lower than that for organic products or those that confer perceived health benefits (e.g., foods produced without GMO ingredients) (McCluskey and Loureiro 2003). Yet consumer perceptions often have a significant impact on both agricultural systems and management practices, regardless of the scientific basis (or lack thereof) for these philosophies. Growth-promoting technologies (hormones, in-feed antibiotics, and beta-agonists) may be considered by the consumer to be undesirable within animal production, and this is used as justification by various retail agencies to remove such products from their supply chain. Yet the productivity gains allowed by such technologies often decrease the economic production cost of animal-source foods through improved efficiency—a shift that keeps foods affordable to the consumer (Capper and Hayes 2012). Examples of the contrast between consumer perceptions and environmental impact of animal-source foods will be discussed in the following section.

Food's Environmental Impact

The suggestion that animal agriculture should be abolished and that the global population could subsist on a vegetarian or vegan diet (Berners-Lee et al. 2012; Environmental Working Group 2011; Pimentel and Pimentel 2003) is a narrow view and fails to consider the myriad of consequences of such an action. Most comparisons are based on substituting plants for animal-source foods on the basis of mass or energy (calories), and these results are extrapolated to estimates of impact on GHG emissions without regard for supply of protein, vitamins, or minerals from animal-source foods. Although GHG emissions are important from a climate change perspective, they are a single metric of environmental impact that is ranked lower than water and land use in terms of limits to future livestock production. Nonetheless, campaigns aimed at encouraging the consumer to decrease consumption of animal-source foods often quote a reduction in GHG emissions as the principal rationale. The "Meatless Mondays" program, which encourages consumers to forgo meat for one day per week, is claimed to decrease U.S. GHG emissions by the equivalent of removing 20 million mid-size sedan cars from the road (The Monday Campaigns Inc. 2012).

By contrast, the U.S. Environmental Protection Agency (2012) cites meat-producing animal agriculture (i.e., beef, swine, sheep, goats, and poultry) as contributing 2.1% of total national GHG emissions. Taking the simplistic view that a one-day-per-week decrease in meat consumption would cut animal production by one-seventh, if every one of the current U.S. population's 313 million people adopted this dietary change, the projected reduction in national GHG emissions would be equal to 0.29%. A change that decreases GHG emissions by less than one-third of one percent is likely to have only a very small environmental impact within the United States, yet it should not be forgotten that the small magnitude of this number is partly a consequence of the impact of other industrial sectors on total GHG emissions. Focusing on reducing GHG emissions from livestock in a region where the majority of GHG results from agriculture (e.g., Australia) would have more significant results when expressed on a percentage basis.

A large-scale reduction in meat consumption not only would result in the replacement of animal products with plant-based foods, but additional sources would be required for the diverse by-products from animal agriculture, including hides, fertilizer, tallow, and pharmaceuticals. For example, replacing leather with hydrocarbon-based synthetics and manure with inorganic fertilizers would be expected to have a considerable global environmental impact because manufacture of the replacements uses large amounts of primary energy.

Increasing interest in the systems in which livestock are raised seems to have led some consumers to believe that animal-source foods produced in pasture-finished systems are more nutritious, safer, or of higher quality than those of feedlot-finished systems (Grannis, Hooker, and Thilmany 2000; Raab and Grobe 2005). As previously discussed, a major advantage of livestock production is the ability to convert human-indigestible by-products into high-quality animal proteins for human diets. Nonetheless, the previously discussed perception that feeding diets based on grains and by-product feeds are "unnatural" (Pollan 2007; Salatin 2007), and that modern livestock systems have a far greater environmental impact due to the production and transportation of concentrate feeds, seems to be gaining momentum.

Until the 1950s, the majority of beef consumed in the United States was produced in pasture-based systems. The advent of finishing rations formulated to meet cattle requirements and containing a significant proportion of corn and by-product feeds (with consequent improvements in growth rate and carcass quality) encouraged producers to move toward a more intensive system (Corah 2008).

Since 1977, the average carcass weight per animal has increased from 274 kg to 351 kg, thus decreasing the number of animals within the national herd required to meet the demand for beef products (Capper 2011). Average growth rate increased from 0.71 kg/day to 1.16 kg/day between 1977 and 2007, which decreased the average number of days required to reach slaughter weight from 609 to 485. Improving productivity per unit of time is vital to the magnitude of livestock's environmental impact because every animal within a herd or population has a daily nutrient requirement for *maintenance*, pregnancy, lactation, or growth and thus associated resources (including feed, land, and water) and GHG emissions. The combination of the decreased number of animals in the national beef herd and the lesser number of days for animals to reach slaughter weight decreased total feed use by 19%, land use by 33%, water use by 12%, fossil fuel use by 9%, and the carbon footprint per kg of beef by 16% (Capper 2011).

The U.S. pork industry also has decreased both resource use and GHG emissions per unit of pork over the past 50 years through similar mechanisms to those exhibited by the U.S. beef industry—i.e., increasing the number of hogs marketed from 87.6 million in 1959 to 112.6 million in 2009, from a breeding herd that has decreased in size by 39% over the same time period (Boyd and Cady 2012).

Environmental gains were also exhibited by the U.S. dairy industry during the transformation of the extensive, pasture-based systems of the mid-1940s to the intensive systems of the modern day. Advances in genetics, management, and nutrition, including the adoption of nutrient-dense by-product feeds such as soybean meal, cottonseed meal, and DDGs, facilitated an increase in milk yield per cow from 2,074 kg/year in 1944 (Capper, Cady, and Bauman 2009) to 9,682 kg/year in 2011 (USDA–NASS 2012). As with increased productivity in the beef industry, improved milk yields decreased feed, land, and water use per unit of milk by 77%, 90%, and 65%, respectively, and GHG emissions by 63%.

It is interesting to note that despite a significant increase in the transport of feed, fertilizers, and animals over the past century, the proportion of carbon emissions attributed to transportation comprises less than 1% of beef production systems (Capper 2011, 2012). Nonetheless, the reliance of intensive beef and dairy systems on fossil fuels and fertilizer inputs for feed production and transportation may lead to the suggestion that they have an intrinsically greater environmental impact than pasture-based extensive systems (Environmental Working Group 2011; Pollan 2007; Salatin 2007). This supposition, however, does not account for the lower slaughter weights and growth rates in extensive systems.

Capper (2012) and Pelletier, Pirog, and Rasmussen (2010) reported that GHG emissions per unit of beef were greater in pasture-finished systems than in feedlot systems. Pelletier, Pirog, and Rasmussen (2010) cited GHG emissions of 19.2 kg CO_2-equivalent (CO_2-eq)/kg liveweight for pasture-finished beef compared with 16.2 kg CO_2-eq/kg liveweight for feedlot-finished yearling-fed beef, whereas Capper (2012) reported 26.8 kg CO_2-eq/kg hot carcass weight beef for pasture-finished beef and 16.0 kg CO_2-eq/kg hot carcass weight beef for feedlot beef. Furthermore, organic dairy production confers a 13% increase in carbon emissions per unit of milk in U.S. systems (Capper et al. 2008) and an increase of approximately 15% in Swedish systems (Cederberg and Mattsson 2000). By contrast, Boggia, Paolotti, and Castellini (2010) reported that organic poultry systems had better environmental performance (assessed using life cycle assessment) than conventional systems.

Some advocate for a return to the pasture-based production systems that predominated in the first half of the twentieth century within the United States (Environmental Working Group 2011; Pollan 2007; Salatin 2007), yet the increased land required (52 million ha) to supply the current domestic and international beef market would render whole-scale conversion of the U.S. beef production system to pasture-fed production practically impossible. If conversion did occur and annual beef production was maintained at 11.8 billion kg (USDA–NASS 2011), the increase in carbon emissions would be equal to adding 25.2 million cars to the road on an annual basis (Capper 2012).

Furthermore, supplying the future U.S. population in the year 2040 with sufficient milk to fulfill USDA consumption recommendations from organic production systems would require 3.5 million more dairy cattle and 3.1 million more ha of land as well as emit 15.7 million additional metric tonnes of GHG than conventional production (Capper et al. 2008). Although the tendency to idealize historical production systems and feeding systems that mimic "natural" (i.e., unmodified by human interaction) livestock systems is understandable, this should not be used as an indicator of environmental impact or a recommendation for future livestock systems without scientific foundation.

Ruminant livestock are often considered to have the greatest impact on the environment when compared to their monogastric cohorts, due to a combination of the decreased feed efficiency exhibited by ruminants (discussed later in the "Feed Efficiency" section) and the production of GHG from ruminant digestion. The majority of research concentrating on decreasing major resource use (land, water, energy) or GHG emissions has therefore focused on ruminant systems to date, yet monogastric animals also make a significant contribution, especially in terms of manure management and point-source pollution. Indeed, modifications to feed and manure aimed at decreasing phosphate excretion from both poultry and swine systems have become a major focus in recent years. In contrast to ruminant systems, however, where the animals contribute the majority of resource use and emissions, Pelletier (2008) reported that feed production accounted for the major contributions to energy use, GHG emissions, acidification, and *eutrophication* within the U.S. broiler poultry industry.

Feed Efficiency

At first glance, feed efficiency seems to be a fairly simple concept, defined as the amount of feed required to produce a unit of weight gain, milk production, or dozen eggs. When comparisons are made across species fed widely different diets, however, it becomes much more complex.

In ruminants, feed conversion (defined as the amount of dry feed required per unit of weight gain) has been the most common estimate of feed efficiency, because this was the information needed to determine the economic cost of production. From a scientific perspective, one of the major problems with feed conversion is that as gains approach zero, feed:gain ratio approaches infinity. By contrast, gross efficiency (usually expressed as the amount of gain per unit of feed) can be equal to zero, or even negative, and is easier to work with statistically. It has long been recognized that animals require a certain amount of feed nutrients each day to fulfill the maintenance requirement. Only after the animal meets its maintenance requirement can additional dietary nutrients be used for weight gain, pregnancy, lactation, or egg production. The efficiency of feed utilization above maintenance is often referred to as partial efficiency.

From a genetic improvement perspective, the feed:gain ratio has serious problems. For example, feed:gain has been shown to have antagonistic genetic correlations with mature size and maintenance requirements. Selecting for a decreased feed:gain ratio (i.e., more efficient animals) will result in larger later-maturing animals. To avoid these problems, Koch and colleagues (1963) described the concept of residual feed intakes (RFIs) as the observed feed intake minus the predicted feed intake (as calculated from a regression equation that includes animal weight and gain) (Archer et al. 1999). Animals with a negative RFI are efficiently superior because they eat less than predicted based on their average weight and daily gain. The potential advantages of negative RFI animals are multifaceted. Not only is more animal protein produced per unit of feed consumed, but consumed feed is digested and used more efficiently. For example, Nkrumah and colleagues (2006) reported that low-RFI animals produced 16,100 liters less methane per year than high-RFI animals at the same level of daily gain. Selection for improved feed conversion through the use of RFI is also occurring in poultry, pigs, and lactating dairy cattle and offers a significant opportunity to increase food production from the same resources while simultaneously decreasing GHG emissions/unit of product produced.

The public is often confused about the efficiency of food production because of the way activists describe the conversion of animal feedstuffs to human-edible products. For example, it is common to assume that all feedstuffs are composed of grains or soybean meal that could be consumed by humans (World Watch Institute 2013). In reality, many livestock diets contain high levels of by-products that are not consumed by humans—e.g., distillers grains, cottonseed meal, feather meal, or almond hulls (Table 1). Secondly, some feed conversions are expressed on an "as-fed basis," in which case the final diet may contain between 10 and 70% moisture. To avoid these problems, all diets should be converted to an equal dry-matter basis. Similarly, some authors condemn the feeding of grain to cattle when there are feed conversion ratios of 6:1, but they do not mention that 75% of that animal's life was spent grazing pasture, hay, or crop residues that are not edible by humans (PETA 2013).

When grains or other vegetable ingredients are processed for human consumption, a significant portion is residue. For example, 1,000 kg of sugar beets are processed to produce 140 kg of sugar, 58 kg of dried beet pulp, 40 kg of molasses, 15 kg of beet residue, and 60 kg of *Betcal*. Water accounts for the rest of the original weight. In countries containing large food-processing industries, food-residue disposal is a significant issue. It is estimated that more than half of the industrial waste in the Netherlands originates from the food-processing industry, yet livestock can often convert this residue into meat, milk, and wool. Elferink, Nonhebel, and Moll (2008) report that 70% of the feedstuffs used in the Dutch livestock feed industry originates from the food-processing industry and that the human-inedible residues generated from the consumption of vegetable oil, sugar, and potato products by the Dutch would produce 87 grams of pork/capita/day when fed to pigs. Production of these food residues will continue to increase as the human population grows.

Given the perceived competition between animals and humans for feed and food, the most meaningful measure of feed efficiency in the future may be the ratio of human-edible protein input relative to the human-edible protein output. Wilkinson (2011) used this approach to compare different food production systems in the United Kingdom. When expressed as the ratio of human-edible protein input per unit to edible animal protein output, milk was 0.71, various beef production systems were 0.92 to 3.00, pork was 2.6, poultry meat was 2.1, and eggs were 2.3. The edible protein conversion ratios reported by CAST (1999) were 0.48, 0.84, 3.4, and 1.6 for the U.S. milk, beef, pigs, and poultry systems, respectively. These results show good agreement between two totally independent sets of data and calculations, demonstrating the need to revolutionize the methods by which feed efficiency has conventionally been assessed in favor of a system that accounts for alternative uses for crops that can be used either for animal feed or human food.

Research is continuing to optimize utilization of pasture, crop residues, and by-product feeds in all aspects of livestock and poultry production. As the world population continues to grow, livestock and poultry will be essential to convert feedstuffs that are inedible by humans to high-quality protein sources. Ruminant animals will be most valuable because they can convert the energy and protein in fibrous feedstuffs to milk, meat, wool, and other products.

Conclusions

Populations of developed countries have transitioned through the past century from predominantly agrarian societies to urban communities in which the majority of consumers has little understanding of animal agriculture and the management practices contained within. Because citizens of currently developing countries enjoy a higher standard of income and a greater proportion of the future population lives within urban rather than rural areas, this chasm between food producers and consumers is likely to increase.

There can be no doubt that the global livestock industry faces a considerable challenge in the next 50 years. The need to provide more food to fulfill the demands of the growing global population while countering the myriad claims relating to the environmental, economic, and social sustainability of animal production will require continued scientific development and an unprecedented level of collaboration among livestock producers, animal health and feed industry professionals, researchers, and policymakers. Developing an effective, proactive communication strategy that conveys in a compelling manner the benefits of the livestock industry should be an important focus of the various livestock supply chains and their trade/professional associations and organizations.

All foods have an environmental cost, and that cost is not restricted to foods of animal origin. Animal agriculture uses resources (both renewable and nonrenewable) and has a measurable environmental footprint (FAO 2006; Pelletier and Tyedmers 2010). At the same time, the benefits accrued to society by the livestock industry are substantial in terms of economic profitability, the supply of high-quality proteins in conjunction with macro- and micronutrients, and the provision of cultural and societal standing within developing regions.

The significant savings in environmental footprint and economic cost conferred by improved productivity within livestock systems must be communicated to the consumer in order to demonstrate the gains made by advances in animal nutrition, genetics, and management over time, as well as to enhance consumer confidence in modern agriculture.

By-product feeds are often described as "waste," a term that confers an obvious negative message to the consumer. In the United States, the value of food scraps as feed for backyard and smallholder livestock was celebrated in the 1940s and '50s when food comprised slightly more than 20% of personal income (USDA–ERS 2012b). The proportion of income spent on food has since declined to less than 10% and has occurred in tandem with both an apparent desire for companion animals and livestock to be fed "natural" diets that do not contain by-products from human food or fiber manufacture and a societal guilt relating to animal protein consumption for environmental or health reasons. In fact, the current market system allows for both types of production—traditional and "natural"—to occur, albeit with one having significantly higher costs (and potential for higher rewards). The most critical messages that need to be communicated by food production stakeholders to the consumer are as follows:

- Global animal agriculture provides safe, affordable, nutrient-dense foodstuffs that support human health and well-being as part of a balanced diet in addition to manifold by-products that play roles in human life.
- Livestock production plays a significant role in the economic and social sustainability of developed and developing countries alike, and it supplies considerable draft power within smallholder operations that make up the majority of global food production.
- A significant proportion of land is incapable of supporting the production of human food crops—terrain,

soil type, and climate render the majority of land currently used for grazing unsuitable for production of vegetable-based foods for human consumption, yet forages can be efficiently converted by ruminant animals into meat and milk products.

- The gains made by "recycling" safe, yet otherwise valueless, by-products from human food and fiber production decrease competition between animals and humans for crops that can equally be used for feed or food, maximize land use efficiency, and lessen the environmental impact of food production.

It is the responsibility of every livestock production stakeholder, from the producer to the policymaker, to help educate consumers with regard to the sustainability of animal agriculture. Consumers enjoy a wider variety of animal proteins than ever before—from a myriad of production systems—yet are sometimes misinformed as to the differences or perceived advantages and disadvantages of divergent systems. Ultimately, consumer choice is the final determinant, yet often that choice is determined, at least in the short run, by the decisions made by retail and restaurant buyers in stocking meat/dairy cases and menus. Historically, there has been little interaction between producers and stakeholders further down the production chain. In the future, a greater degree of collaboration will be required as the desire grows for retailers and restaurants to demonstrate sustainability. Designated certification programs, audits, and prescribed best management practices could conceivably lead to the prohibition of specific management practices, by-product feeds, or technology use in the absence of appropriate outreach or education.

Food price, taste, and convenience are major determinants of consumer food choice at present (Simmons 2009), and this trend is likely to continue into the future. Globally, 94% of consumers seem to be neutral toward or favor the use of technology within livestock production; however, 1.8% of consumers actively campaign against technology use (Simmons 2009). This latter group is often seen to have an unbiased outlook (as opposed to the perceived vested interests of those actively involved in livestock production or the wider animal feed/health industry) and therefore potentially has a significant influence on the majority of consumers who wish to be reassured that their food choices are safe, environmentally responsible, and socially acceptable.

Few would deny the advantages of modern ready and immediate access to information through the Internet, social media, and blog sites; yet the credibility and scientific veracity of information provided is seldom obvious. This is exemplified by the speed at which purported negative issues relating to livestock production—such as the health impacts of "pink slime" or meat production's environmental impact—spread within the global community. In an ideal world, critical thinking would be an integral component of every educational program. In many cases, however, the "follow the money" ideology seems to be the instinctive reaction to studies that promote conventional agriculture, with the net result that studies funded by the livestock industry are automatically distrusted. The rise of social media provides one avenue by which consumer education may be advanced—people tend to trust messages promoted by friends and family far more quickly and easily than those seen as being purported by companies or industries. Use of social media websites (e.g., Facebook, Twitter) is, as yet, a somewhat untapped mechanism to improve the information available to the consumer, and those sites could be used to overcome or at least provide a forum for discussion of common consumer perceptions that are at odds with the realities of animal agriculture.

Finally, the question remains—at what point will demand for foods overcome inherent consumer concerns relating to the safety of management practices, technologies, or by-product feeds used in animal production? Effective consumer information is vital within all sectors of agriculture, but particularly within animal agriculture. For example, data from consumer willingness-to-pay studies indicate that a market exists for beef fed forage-based diets, natural diets, or diets free of genetically modified corn (Corsi and Novelli 2002; Huffman et al. 2003; Umberger, Boxall, and Lacy 2009; Umberger, McFadden, and Smith 2009). By contrast, the considerable marketing advantages of productivity gains conferred by modern practices, by-product feeds, and technology use in improving both environmental impact and food affordability are not currently being exploited by conventional livestock producers. In a world where one in seven people do not have sufficient food, the fact that conventional animal management practices incorporating a diverse array of protocols, technologies, and production enhancements allow the average U.S. cow-calf producer (35 cows) to provide enough extra beef to supply 19 families with their average beef demand (Capper 2013) is an example of the type of message that may be needed in order to resonate with future consumers and demonstrate the value of animal agriculture.

In a world where the global population is continually increasing, the argument that producing feed for livestock conflicts with feeding hungry people is likely to continue for some years. It is clear that the use of by-product feeds in combination with management strategies that improve efficiency will mitigate the environmental and economic impact of animal agriculture. The challenge thus remains to foster social acceptability and understanding of the industry's contributions, thus advancing the industry to fulfilling the three pillars of sustainability.

Glossary

Betcal. By-product of the conversion of sugar beets into sugar.

Casein. One of the two main protein fractions of milk.

Climax species. Plant species that remains unchanged as long as the site is undisturbed.

Distillers grain. A cereal by-product of the distillation process.

Eutrophication. The process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of aquatic plant life; usually results in the depletion of dissolved oxygen.

Greenhouse gas. A gas that traps heat in the atmosphere.

Maintenance. Support of metabolism and health in an animal kept within its thermoneutral zone.

Nonprotein nitrogen. Nitrogen-containing feed components, such as urea, that are not proteins but can be converted to proteins by microbes in the ruminant stomach.

Ruminant. Having a stomach divided into four compartments.

Volatile fatty acids. Created by fermenting carbohydrates, they are the main energy source for ruminants, used primarily for reproduction and growth.

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4420 West Lincoln Way
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(515) 292-2125, Fax: (515) 292-4512
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