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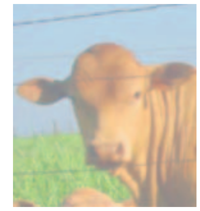
Replacing rose-tinted spectacles with a high-powered microscope: The historical versus modern carbon footprint of animal agriculture



Judith L. Capper

Department of Animal Sciences, Washington State University, Pullman 99164, USA

Implications

- As the global population increases, more animal protein needs to be produced using fewer resources (land, water, and energy) and with a smaller carbon footprint.
- Improved productivity has considerably reduced the carbon footprint of dairy and beef production over the past century.
- Extensive systems intuitively appear to be more environmentally friendly, yet scientific analysis demonstrates that intensive systems reduce resource use, waste output, and greenhouse gas emissions per unit of food.
- As livestock production systems continue to make productivity gains, sustainability should be assessed on the basis of environmental, economic, and social issues.

Key words: beef, dairy, food miles, productivity, sustainability

Introduction

As natural resources dwindle and concern over climate change increases, should the livestock industry continue to intensify and improve productivity to feed the increasing population, or return to less productive traditional methods? In 1800, each US farm could only produce enough food to feed one other family. In the wake of considerable improvements in productivity, each farmer currently produces enough food to feed an average of 125 other people. As the global population increases to a predicted 9.5 billion people in the year 2050, food requirements will rise by 70% compared with the present day (Food and Agriculture Organization of the United Nations; FAO, 2009). Assuming the present competition for energy, land, and water continues, resources available for agricultural production will decrease with increased population growth. The global livestock industries thus face the challenge of producing sufficient animal-source foods to meet consumer demand, using a finite resource base.

The environmental impact of livestock farming is one of the most commonly discussed issues within food production. A lexicon of previously unfamiliar terms including carbon footprint, sustainability, and local food have entered everyday conversation via media articles, blog posts, and restaurant menus. Ethical consumerism, defined by Singer and Mason (2006) as an interest in the way in which food is produced, the practices employed, and a concern for low environmental impact, high animal welfare, and optimal worker conditions, is considered to be increasing. As a consequence, popular perceptions of sustainable agriculture appear to be directed towards traditional systems, organic production, or farms that supply only the local geographical area. Although it is widely understood that improving efficiency reduces expense, resources, and waste, the consumer often considers efficiency to have negative connotations when applied to large-scale contemporary food production. This article will discuss the effects of advances in productivity and efficiency in the livestock industries in the United States on the environmental impact and carbon footprint of modern food production.

The Link Between Efficiency, Productivity, and the Carbon Footprint

Improving productivity (i.e., animal protein output per unit of input) allows the livestock industry to reduce resource use and carbon emissions through the "dilution of maintenance" effect. Every animal has a maintenance nutrient requirement that must be fulfilled each day to support vital functions and minimum activities; this may be considered as the fixed cost of livestock production. Improving productivity such that a greater amount of milk or meat is produced in a set period of time per unit of animal input thus reduces the total maintenance cost per unit of food produced. Maintenance nutrients may be considered a proxy for resource use (e.g., feed, land, water, and fossil fuels) and waste output [e.g., manure and greenhouse gases (**GHG**)]. Improving productivity consequently reduces resource use and waste output per unit of food. From an environmental standpoint, GHG (e.g., CH_4, N_2O, and CO_2) and the carbon footprint [the sum of all GHG expressed as CO_2 equivalents (**CO_2 eq.**; i.e., in terms of their global warming potential compared with CO_2), where CO_2 = 1, CH_4 = 25, and N_2O = 298] may be considered the most important waste outputs.

Improved Dairy Productivity Reduces the Carbon Footprint

Returning to the extensive production systems of yesteryear seems to offer an intrinsically sustainable mechanism for food production, yet sacrificing productivity gains has a negative environmental effect. The phrase "dairy farming in the 1940s" conjures bucolic images of a family

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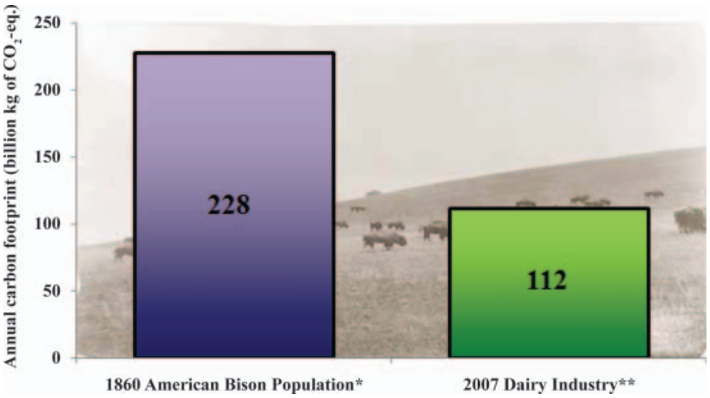

Figure 1. Comparative annual carbon footprints of the 1860 American bison population and 2007 dairy industry in the United States. *CH_4 and N_2O emissions based on forage dry matter intakes for age-appropriate body weights and population dynamics; emission factors from US EPA (2007). **Capper et al. (2009b).

farm with a red barn, green pastures, and a small dairy herd. The farm children did chores each day, and the farmer milked cows by hand while seated on a 3-legged stool. This rural utopia appears to be an untroubled life where neither cows nor manure produced GHG and the small tractor used to plow the fields used small quantities of fuel from an infinite supply. By contrast, the modern dairy farm with streamlined milking equipment, pasteurization processes, and specialized labor appears to some as a futuristic aberration. The fact that cows produce CH_4 through enteric fermentation has been known for many years, yet the link between climate change and livestock production is a relatively recent notion. The perception thus exists that modern livestock production causes climate change, whereas extensive systems akin to historical management are far more environmentally friendly. Indeed, the CH_4 and N_2O emissions from enteric fermentation and manure produced by the 60 million American bison that roamed the US plains until mass slaughter in 1880 (Roe, 1951) are equal to double the carbon produced by the US dairy industry in 2007 (Figure 1).

In 1944, the US dairy population peaked at 25.6 million dairy cattle, producing 53.0 billion kilograms of milk annually (USDA, 2009). The average herd contained 6 cows that were fed a pasture-based diet with occasional supplemental corn or soy (Capper et al., 2009b). Artificial insemination was in its infancy, and neither antibiotics nor supplemental hormones were available for animal use. By contrast, the 2007 US dairy herd contained 9.2 million cows producing 84.2 billion kilograms of milk per year; improvements in management, nutrition, and genetics led to a 4-fold increase in milk yield per cow between 1944 and 2007 (Capper et al., 2009b). This can be considered a proof of concept for the dilution of maintenance effect; increased milk production per cow means that fewer lactating animals are required to produce a set quantity of milk and the size of the supporting herd (i.e., dry cows, bulls, and heifer and bull replacements) is also reduced. Indeed, compared with 1944, the 2007 US dairy industry required only 21% of the dairy population and therefore 23% of the feedstuffs, 10% of the land, and 35% of the water to produce a set quantity of milk. Manure output per unit of milk produced in 2007 was 24% of that in 1944, and the total carbon footprint per unit of milk was reduced by 63%. Despite the increase in total milk production between 1944 and 2007, total carbon footprint of the US dairy industry was reduced by 41%.

Regional Variation in the Carbon Footprint of Dairy Production

If we examine international trends, increased milk production has a mitigating effect on carbon emissions on a global basis. The trend for productivity to improve over the past 50 years is not exclusive to the United States; major milk-producing regions (e.g., United States, Canada, New Zealand, and Europe) have all improved milk yield per cow since the 1960s, the rate of improvement varying from 129 and 117 kg/year for the United States and Canada, respectively, to 77 and 24 kg/year for Europe and New Zealand (Capper et al., 2009a). The environmental effects of regional variations in productivity are exemplified by the results of a recent FAO (2010) report that modeled GHG emissions from dairy production using life cycle analysis. As intensity of production declines and the average milk yield shifts from approximately 9,000 kg/cow for North America to ~250 kg/cow for sub-Saharan Africa, the carbon footprint increases from 1.3 kg of CO_2-eq./kg of milk to 7.6 kg of CO_2-eq./kg of milk (Figure 2). Sustainability is often defined as having 3 interrelated components: environment, economic, and social, with sustainability occurring through a balance of these factors. When assessing the sustainability of dairy systems, the question should not be limited to the environmental impact of dairying within a specific region, but must also consider the economic and social implications. While the FAO data could provoke the conclusion that all regions should adopt North American and Western European-style production systems, or that dairying should be focused in these areas and be discouraged in less productive regions such as sub-Saharan Africa and South Asia, the significant social (both status and nutritional) and economic value of dairying in less developed regions must not be underestimated. The challenge for global dairy production is to optimize sustainability within each region rather than prescribing the best one-size-fits-all global system.

Improving Beef Productivity Reduces Carbon Footprint Per Unit of Beef

Improved productivity in the US beef industry has conferred significant reductions in resource use and GHG emissions. Average beef-carcass yield per animal increased from 274 kg in 1977 to 351 kg in 2007 (USDA, 1978; USDA/NASS, 2008). Management advances including improved genetic selection, ration formulation, and growth-enhancing technology use over this time period also conferred an increase in growth rate, reducing the total days from birth to slaughter from 602 days in 1977 to 482 days in 2007. In combination with increased beef yield per animal reducing the size of the supporting population, producing a set quantity of beef in 2007 required 70% of the animals, 81% of the feed, 88% of the water, and 67% of the land needed by the 1977 system. Along with the changes in resource use, improved productivity meant that manure and GHG emissions were considerably reduced, with a 16% decrease in the carbon footprint per unit of beef (Capper, 2010a).

A positive relationship exists between environmental and economic impact. Survey data indicate that consumers desire food products that are affordable, animal-welfare friendly, and have a low environmental impact (Croney, 2011). Nonetheless, the popular view is that affordability is mutually incompatible with either of the latter factors. This view is fostered by media coverage relating to "cheap" food, suggesting that grass-finished systems are superior to conventional feedlot beef production in

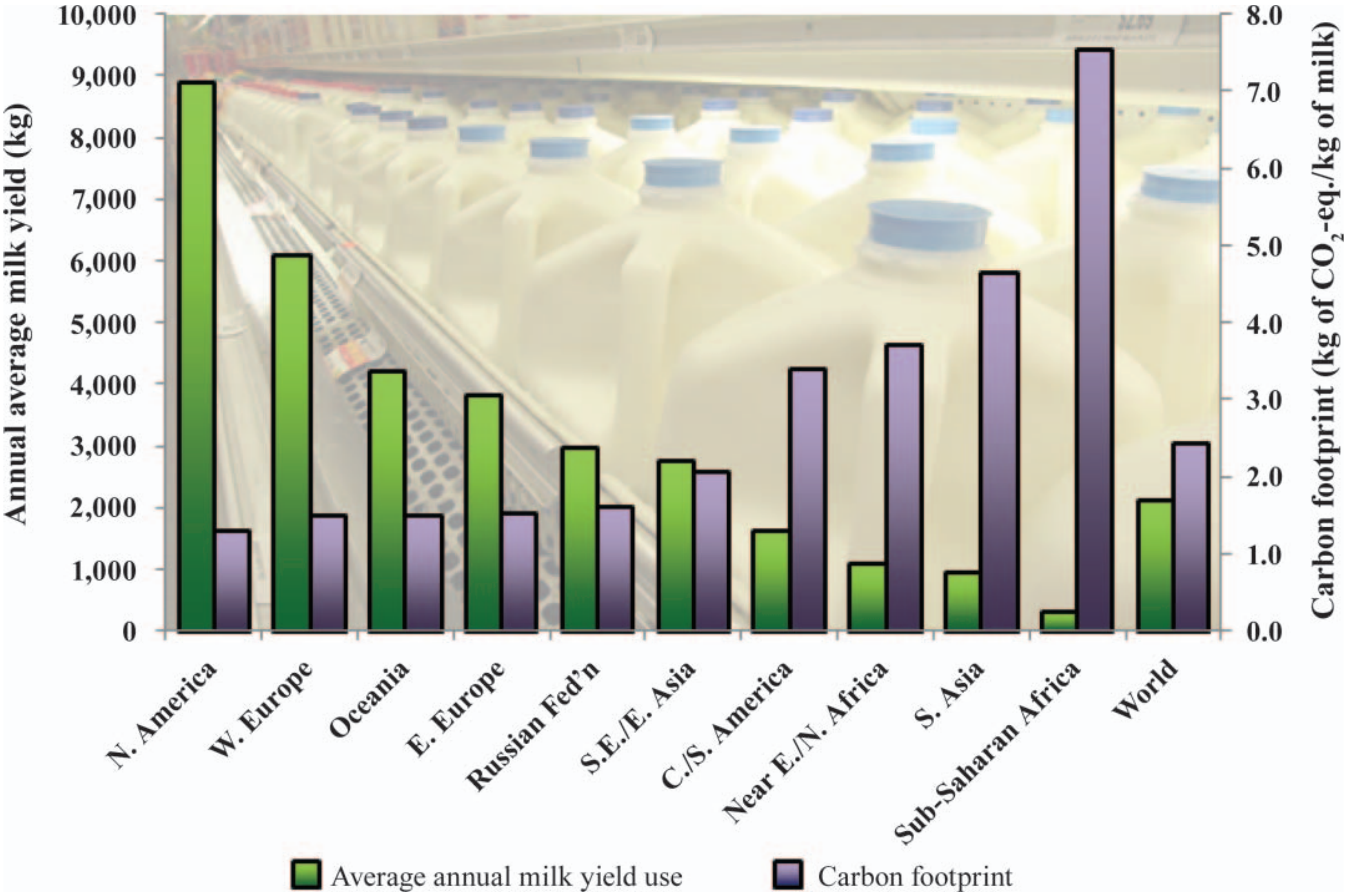

Figure 2. Average annual milk yield and carbon footprint per kilogram of milk for selected global regions. FAO (2010). CO_2 eq. = CO_2 equivalents.

terms of nutritional quality, GHG emissions, and animal welfare (Walsh, 2009). The increased economic cost of products labeled organic, natural, or hormone-free (Yiridoe et al., 2005) further supports the subliminal impression that conventional production must occur at the expense of environmental, animal, or human health. The FAO (2006) concludes that it is essential to continue to intensify livestock production to maintain the efficiency gains that improve environmental and economic sustainability. By contrast, consumers often assume that extensive, pasture-based beef systems where cattle are finished on grass have a smaller carbon footprint than conventional feedlot systems.

Pelletier et al. (2010) reported that GHG emissions per unit of beef were greater in pasture-finished systems than in feedlot systems. This result seems intuitively incorrect; a conventional system that finishes animals on corn-based diets grown with significant fertilizer inputs, transports both feed and animals across the country, and houses animals in confinement seems to have an intrinsically greater environmental impact than a grass-finishing system. Nonetheless, from a biological viewpoint, the results are easy to explain. Growth rates are considerably less in animals finished on grass, and it is difficult to achieve heavier slaughter weights; therefore, grass-finished cattle are usually slaughtered at around 486 kg at 679 days of age, compared with 569 kg at 453 days of age in a conventional system. Capper (2010b) demonstrated that as a consequence of the reduced slaughter weight, 4.5 total animals (slaughtered animals plus the supporting population required to produce calves for rearing) are required to produce 363 kg of hot carcass weight beef in a grass-finished system compared with 2.6 total animals in a conventional system. When combined with the increased time required for animals to grow to slaughter weight, this increases the carbon footprint per unit of grass-finished beef by 74% (Figure 3). The increased land required for grass-finished production renders whole-scale conversion of the US beef production system to grass-finished production practically impossible. However, if we assume it would somehow be achievable and that beef production was maintained at 11.8 billion kilograms as in 2009 (USDA/NASS, 2010), the increase in carbon emissions would be equal to adding 26,465,074 cars to the road on an annual basis.

Proponents of pasture finishing may counter-argue that although decreases in productivity increase GHG emissions from animal sources, the quantity of carbon sequestered by pasture-based systems compensates for reduced efficiencies [International Trade Centre UNCTAD/WTO Research Institute of Organic Agriculture (FiBL), 2007]. Sound data on carbon sequestration is notably lacking from environmental literature, and this is one area where future research would pay dividends in terms of improving knowledge and understanding. It is important to understand that pasture and forage-based diets are fed to conventional growing beef animals for one-half to two-thirds of their life, and that diets for the supporting beef herd (cows, heifers, and bulls) are based on forage and pasture over the entire lifespan. Differences attributed to carbon sequestration between systems could hence only be attributed to the

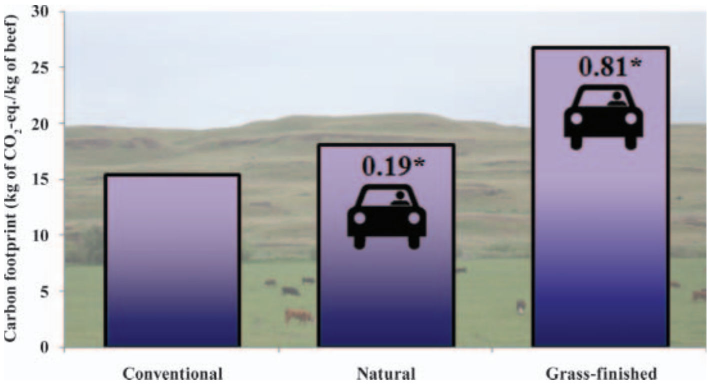

Figure 3. Carbon footprint per kilogram of beef produced in 3 different systems. CO_2 eq. = CO_2 equivalents. *Difference from conventional expressed as annual emissions from an average US passenger car (US EPA, 2009). Capper et al. (2010b). Carbon footprints based on full-system analyses with full productivity-enhancing technology use and feedlot finishing (conventional); no productivity-enhancing technology use plus feedlot finishing (natural), or no productivity-enhancing technology use plus grass finishing (grass-finished).

finishing period. Considerable carbon sequestration into pastureland would have to occur to outweigh the total GHG emissions resulting from the combination of a greater population size, extra days required to finish animals on pasture, and increased CH_4 emissions emitted from animals fed predominantly forage diets, particularly given that each kilogram of CH_4 or N_2O emitted has a 25- or 298-fold, respectively, greater global warming potential when compared with CO_2 indexed as 1 (IPCC, 2007)

Advances in Monogastric Animal Productivity

Compared with ruminant production, swine and poultry industries are generally considered to be less environmentally threatening with regard to climate change. Estimates of the carbon footprint of monogastric animal protein production range from 2.8 to 4.5 kg of CO_2/kg of pork (Strid Eriksson et al., 2005; Vergé et al., 2009; de Vries and de Boer, 2010) and 1.9 to 2.9 kg of CO_2/kg of chicken (Katajajuuri, 2008; Pelletier, 2008; Cederberg et al., 2009). Nonetheless, given the increase in poultry and swine consumption predicted to occur over the next 40 years (Rischkowsky and Pilling, 2007), further efficiency improvements are necessary within these industries to reduce overall environmental impact over time. Vertical integration and consolidation within both industries considerably improved productivity over the past 50 years. According to historical USDA data, between 1963 and 2009, average US swine carcass weight increased by 27 kg, from 65 to 92 kg (USDA, 2009). This allowed total carcass weight (slaughtered animals × average carcass weight) to increase from 5.4 billion kilograms to 10.5 billion kilograms (a 92% increase) while slaughter numbers only increased by 44% (35 million animals). Despite the increase in slaughter numbers, the US swine breeding population decreased from approximately 9.1 million head to approximately 5.9 million head, as a function of both increased litter size and a greater number of farrowings per year. As demonstrated by the historical beef comparison, the increase in average carcass weight combined with the smaller supporting population would be expected to mitigate the carbon footprint per unit of pork.

Average chicken slaughter weight also increased from 1.61 to 2.54 kg over the same time period (1963 to 2009), facilitating an 594% increase in chicken production (3.17 to 29.4 billion kilograms) with only a 3.41-fold increase in slaughter numbers (1.96 billion head to 8.66 billion head; USDA, 2009). Growth rates and feed efficiency also improved considerably over the past 60 years, reducing the time period from hatching to slaughter from 90 days to less than 40 days (Konarzewski et al., 2000). Evidence from feeding studies involving heritage-style chicken breeds suggests that although nutrition and management have played a significant role, the majority of this improvement has occurred through genetic gain (Havenstein et al., 2003; Schmidt et al., 2009).

The question as to how efficient livestock production can become is often posed. Given the already increased feed efficiencies and growth rates seen in the pork and poultry industries, there may be less opportunity to improve these metrics than in the beef industry, yet the use of by-products from the human feed and fiber industries is relatively low in monogastric diets. The beef and dairy industries play an invaluable role in converting inedible forages and by-products from human food and fiber production into high-quality animal protein. Because concern already exists as to the extent of human-edible food used for animal production (Gill et al., 2009), increased use of by-product feeds, which by their nature have a considerably smaller carbon footprint and effect upon human food stocks, may be a potential avenue to further mitigate carbon emissions from monogastric animals.

The Value of the "Exact" Number Versus a Proportional Difference Between Systems

The carbon footprint of livestock production is difficult to define; considerable discussion exists as to the ideal methodology and metric for its quantification (for more details, see Bertrand and Barnett, 2011). Within academia, this is understandable due to the intent to validate models and methodologies and the search for improved knowledge. Personal communications between the author and producers within the beef and dairy industry suggest that producers desire accuracy when calculating the carbon footprint for their particular product, yet are concerned that it may provide ammunition for those opposed to animal agriculture on an environmental basis. The need to quantify the carbon footprint of animal production is generally recognized; however, comparative studies that provide insight into the relative impact of systems or production practices and thus the possibilities to improve the delta (i.e., the difference between the systems) may be far more valuable. This is especially pertinent to carbon footprints quantified via life cycle analysis, which is specific to particular time points and regions, and governed by system boundaries. The carbon footprint of beef production has been quantified using life cycle analysis in the United States, Canada, Brazil, Sweden, Australia, and Japan (Figure 4), and a global analysis is currently being undertaken by the FAO. However, variation in methodology, boundaries, and time-points for each system render direct comparisons unreliable. The need for a coordinated international methodology has been noted by many industry groups and nongovernmental organizations (Bertrand and Barnett, 2011), yet life cycle analysis and other methods are still in developmental infancy, with significant data gaps. The urgency of current consumer, retailer, and policy-maker concerns relating to the carbon footprint of animal production suggests that rather than waiting for the science to evolve further, systems and management practices that mitigate carbon emissions based on credible science and biology should be implemented immediately.

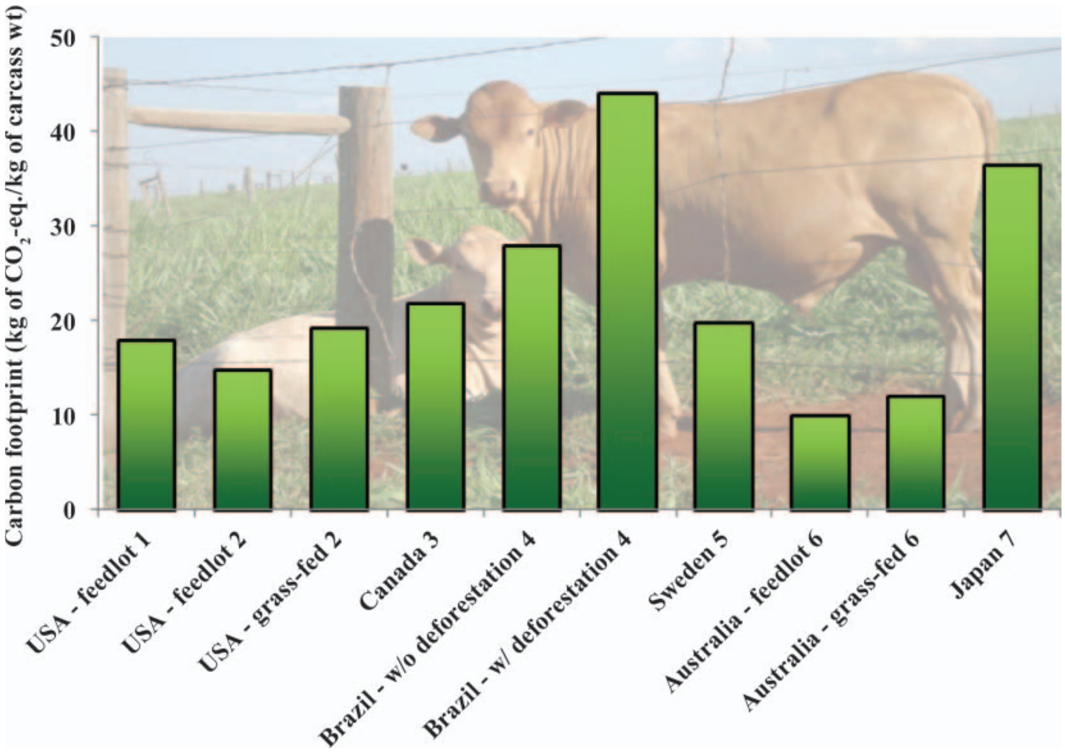

Figure 4. Variation in the carbon footprint per kilogram of beef according to region and system. CO_2 eq. = CO_2 equivalents. 1 = Capper et al. (2010a); 2 = Pelletier et al. (2010); 3 = Beauchemin et al. (2010); 4 = Cederberg et al. (2011); 5 = Cederberg et al. (2009); 6 = Peters et al. (2010); 7 = Ogino et al. (2004).

Food Transport: The Unicorn of the Locavore Movement

The view that food should be produced locally often appears in tandem with the historical ideal of traditional farming, yet local food production may not be the ideal strategy by which to reduce environmental impact. In bygone days, a significant amount of time was spent shopping for food at the butcher, baker, fishmonger, and grocer within the local town. The same voices crying out against modern agriculture often lament the loss of this lifestyle and argue against large-scale grocery stores that carry food from national and international sources. There is no doubt that lifestyles have changed considerably in the past 60 years; the suggestion by Pollan (2008) that "To grow sufficient amounts of food using sunlight will require more people growing food—millions more" is entirely laudable if the current 9% of the US population who are unemployed decide to work in agriculture. Realistically, however, moving to an extensive "sun-food" system where fossil fuels are replaced by human labor negates the improvements in efficiency made over time and neglects to consider the energy inputs and carbon output associated with human labor, let alone the negative trade-offs occurring from shifts in labor patterns from, for example, healthcare, education, or construction to agriculture. The perception that transport composes a significant proportion of the total carbon footprint of animal products is simply untrue. Recent analyses demonstrate that 7.7% of the GHG emissions of a unit of milk (Innovation Center for US Dairy, 2010) and 0.75% of a unit of beef (adapted from Capper, 2010a) can be attributed to transport. Niche extensive markets often seek to differentiate from conventional production on the basis of reduced fossil fuel use for transport and therefore implicit reductions in carbon emissions. For example, one farm website (Polyface Inc., 2011) proudly states that "We do not ship anything anywhere. We encourage folks to find their local producers and patronize them." However, the same website describes a buyers' club where food is mass-transported to locations an average of 239 km from the farm for consumers to collect and also includes the following quotation: "I drive to [a farm] 150 miles (241 km) one way to get clean meat for my family." Using details of vehicle carrying capacity and fuel efficiency derived from Capper et al. (2009a),

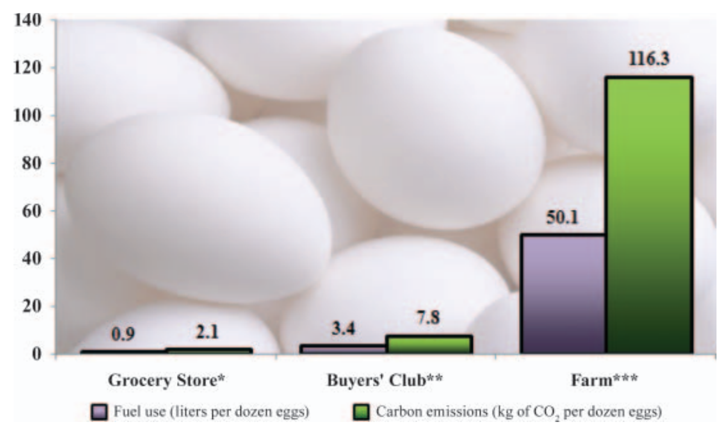

Figure 5. Fuel use and carbon emissions associated with purchasing 1 dozen eggs from 3 different sources. *3,862 km tractor-trailer round-trip (23,400 dozen egg capacity) plus 8 km consumer's car round-trip (1 dozen egg capacity). **477 km pickup truck round-trip (1,740 dozen egg capacity) plus 16 km consumer's round-trip (1 dozen egg capacity). ***482 km consumer's car round-trip (1 dozen egg capacity). Methodology and all fuel efficiencies as described in Capper et al. (2009a).

the fuel use and consequent carbon emissions associated with buying 1 dozen eggs were assessed using 3 points of purchase: the local grocery store, the buyers' club, or the farm. Figure 5 shows that productivity is again the key factor; improved carrying capacity of the tractor-trailer outweighed both the low fuel efficiency and the distance that eggs were transported across the country to the grocery store, with 0.9 liters of fuel used per dozen eggs. Intermediate productivity and carrying capacity in the buyers' club example increased fuel use to 3.4 liters per dozen eggs and the decreased productivity (one dozen eggs per car) involved with buying the eggs directly from the farm increased fuel use 56-fold (50.1 liters). When emissions from gasoline and diesel were considered (US EPA, 2011), carbon emissions per dozen eggs were greatest for the farm example (116.3 kg of CO_2/dozen eggs), intermediate for the buyers' club, and smallest in the grocery store example (2.1 kg of CO_2/dozen eggs). The "feel-good" factor involved with traveling a round-trip of 482 km to purchase eggs that are perceived to be of greater quality directly from a farm certainly contributes to the social sustainability of this choice. Nonetheless, the choice carries huge economic and environmental consequences. Consumer choice appears to be one of the paramount issues for retailers, marketers, and policy makers; nonetheless, the choice should be an educated one based on science and logic rather than philosophical assumptions.

Important Unresolved Questions

The livestock industry faces a clear challenge in producing sufficient animal protein to supply the needs of the growing global population, while reducing environmental impact. Possibly the most significant question relating to this issue is how contemporary agriculture can overcome the popular perception of being environmentally unfavorable. Scientific studies show that advances in productivity garnered through improved management and technology use reduce the carbon footprint per unit of food, yet the animal science industry needs to find ways to share these data and educate consumers, retailers, and mainstream media. Demonization of specific sectors (e.g., feedlot beef or eggs purchased from the grocery store) in favor of niche markets that intuitively seem to have a smaller carbon footprint further propagate the idea that conventional production and mass food transport are undesirable. In a region where food is readily available, consumers are afforded the luxury of making choices according to production system or technology use, yet many developing regions exist where the simple need for food negates such concerns. Ideally, improved education in combination with observations of the continuing food crisis and associated rise in food and fuel prices will shift consumers toward a science basis for food choices in the future.

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About the Author

Judith L. Capper is an assistant professor of dairy science in the Department of Animal Sciences at Washington State University. She completed her undergraduate and graduate degrees at Harper Adams University College (Shropshire, UK) before doing postdoctoral research with Dale Bauman at Cornell. Her current position is split between teaching and extension, and her research focuses on modeling the environmental impact of beef and dairy production systems. Current research includes the environmental impact of corn-fed versus grass-fed beef systems, comparing historical and modern production practices in dairy and beef industries, and the effect of technology use in livestock production.
Correspondence: capper@wsu.edu