DEMYSTIFYING THE ENVIRONMENTAL SUSTAINABILITY OF FOOD PRODUCTION

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INTRODUCTION

Meat, eggs, and dairy products play significant roles in supplying high-quality protein, vitamins, minerals and essential fatty acids as part of a nutritionally balanced diet (Huth et al., 2006; USDA, 2005). According to FAO data for 2007, the U.S. is the leading producer of cow's milk, beef, chicken and poultry and second for pork, eggs and game meat worldwide (United Nations Food and Agriculture Organization, 2009). This is primarily achieved through the adoption of highly efficient agricultural practices that allow for considerable improvements in productivity (Capper et al., 2009).

The global population is predicted to increase to 9.5 billion people in the year 2050 (U.S. Census Bureau, 2008). Total food requirements will increase by 100% (Tilman et al., 2002) as a function of both the 50% increase in population and the additional global demand for animal protein as people in developing countries become more affluent (Keyzer et al., 2005). The resources available for agricultural production are likely to decrease concurrently with population growth due to competition for land and water and depletion of fossil fuel reserves. Livestock industries therefore face the challenge of producing sufficient safe, affordable animal protein to meet consumer demand, using a finite resource base – a challenge which is exacerbated by political and social concerns relating to the environment.

All food production has an environmental impact and livestock production has been singled out as a major contributor to climate change (Koneswaran and Nierenberg, 2008; Steinfeld et al., 2006). However, consumer and governmental perceptions of strategies and production systems used to reduce environmental impact are often simplistic and appear to be based on misconceptions that do not consider potential negative trade-offs. This paper aims to discuss some of the most commonly heard misconceptions relating to the environmental impact of food animal production and transport systems.

THE ROLE OF PRODUCTIVITY IN REDUCING ENVIRONMENTAL IMPACT

The dichotomous challenge of producing more food from a dwindling resource base often leads to the suggestion that adopting low-input production systems is the key to sustainable agriculture. However, this defies a fundamental principle of physics, the First Law of Thermodynamics which states that 'energy can neither be created nor destroyed, it can only change form'. Carbon is the key unit of currency of energy use of living organisms. Just as we balance our checkbook every month, energy (carbon) inputs and outputs must be balanced against each other.

When assessing environmental impact, it is essential to use a standardized assessment tool and to express impact per functional unit of food, e.g. resource use and waste output per liter or kg of product (Schau and Fet, 2008). This ensures that the production system meets total demand for the product. Thus, greenhouse gas (GHG) emissions should not be simply assessed as per animal or per facility but rather based on system productivity using a life-cycle assessment (LCA) approach. This approach is prescribed by the EPA for environmental impact assessment, incorporating all inputs and outputs within the production system boundaries. This is particularly important when making comparisons across differing production systems. For example, Thomassen et al. (2008) reported greater ammonia volatilization per acre from conventional Swedish dairy farms than their organic counterparts. However, ammonia volatilization per unit of milk produced was greatest in organic systems due to reduced stocking rates and the increased number of animals required to produce the same quantity of milk. The purpose of dairy systems is to produce milk, thus the correct functional unit of the LCA analysis in this example is the unit of milk produced, not the acre. The productivity of the system must also be taken into account, to assure that demand is being met and total supply is maintained.

It is worth noting that a recent analysis from the Organic Center (Benbrook, 2009), intended to demonstrate the advantages of moving from conventional to organic dairy production, is based on a flawed premise, namely that productivity (milk yield per cow) does not differ between conventional and organic systems. Productivity is demonstrably lower under organic management with a reduction in milk yield per cow ranging from 15-27% (Nauta et al., 2006; Sato et al., 2005; USDA, 2007; Zwald et al., 2004). When differences in productivity are accounted for, organic dairy production requires considerably more resources (feed, land, water etc) per unit of milk produced and has a greater environmental impact (Capper et al., 2008).

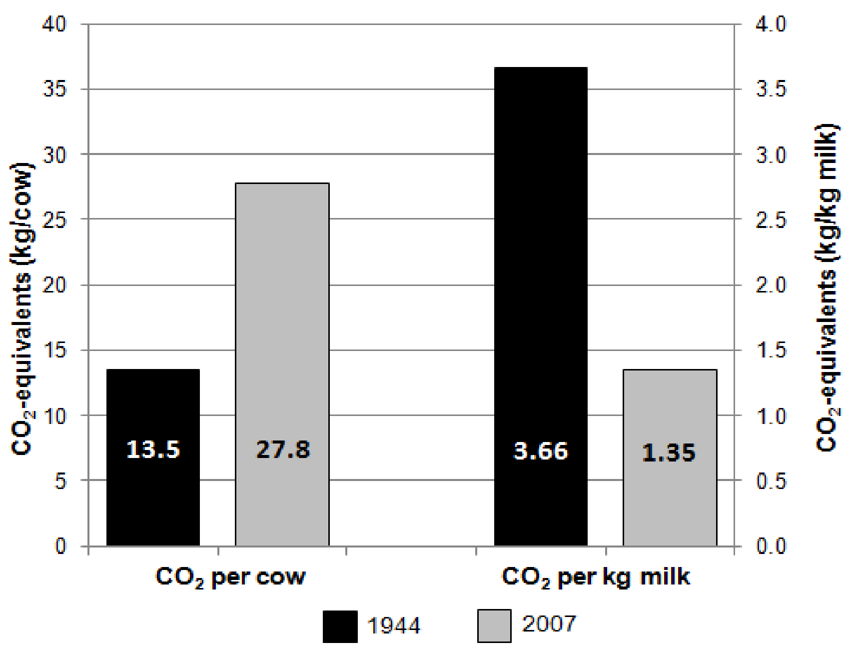

Figure 1. Carbon Footprint per Cow and per Kilogram of Milk for 1944 and 2007 U.S. Dairy Production Systems (Capper et al., 2008)

The 'good old days' of dairy production

The agrarian vision of U.S. dairy farming involves cows grazing on pasture with a gable-roofed red barn in the background – a traditional low-input system. By contrast, the image of modern dairy production propounded by anti-animal agriculture activists is synonymous with "filthy and disease-ridden conditions"[1] and 'industrialized warehouse-like facilities that significantly increase GHG emissions per animal' (Koneswaran and Nierenberg, 2008). The United Nations Food and Agriculture Organization (FAO) report 'Livestock's Long Shadow' (Steinfeld et al., 2006) concluded that intensification of livestock production is essential to mitigate environmental impact. However, this conclusion has often been overlooked in favor of more sensationalized data cited from the study. Despite the demonstrable need for further technological advances to increase future food production (Roberts, 2000; Waggoner, 1995), further intensification of food production is regarded by some as a profane suggestion (Koneswaran and Nierenberg, 2008).

As shown in Figure 1, daily GHG emissions per cow (expressed in CO_2-equivalents) have increased considerably over the past 65 years: the average dairy cow now produces 27.8 kg CO_2-equivalents compared to 13.5 kg CO_2-equivalents back in 1944 (Capper et al., 2009). However, expressing results on a 'per head' basis fails to take the entire system into account. When analyzed using LCA, GHG emissions per kg of milk produced have declined from 3.7 kg in 1944 to 1.4 kg in 2007. This has been achieved through considerable improvements in productivity. Milk yield per cow more than quadrupled between 1944 (2,074 kg) and 2007 (9,193 kg), allowing 59% more milk (84.2 billion kg *vs*. 53.0 billion kg) to be produced using 64% fewer lactating cows (9.2 million *vs*. 25.6 million). As described in Capper et al. (2009), this improvement in productivity facilitates the 'dilution of maintenance' effect, by which the proportion of daily nutrients apportioned to maintenance is reduced. This effect is not confined to the nutrition of lactating cows, but also applies to non-productive animals within the population (dry cows, replacement heifers and bulls) that serve to maintain the dairy herd infrastructure. Increasing productivity therefore reduces both the number of dairy animals required and the resources required to produce a given amount of milk.

The resource use and waste outputs per unit of milk for 1944 and 2007 production systems are shown in Figure 2. The 4.4-fold increase in milk yield per cow drove a 79% decrease in total animals (lactating and dry cows, heifers, mature and adolescent bulls) required to produce a given quantity of milk. Feed and water use were reduced by 77% and 65% respectively, while land requirements for milk production in 2007 were reduced by 90% compared to 1944 due to improved crop yields and the shift from pasture-based to TMR systems. Manure output from the modern system was 76% lower than from the 1944 system, contributing to a 63% decrease in the carbon footprint per unit of milk. To put this into context, the carbon footprint of the entire dairy industry was reduced by 41% by the adoption of technologies and modern management practices that improved productivity between 1944 and 2007.

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[1] Comment from Danielle Nierenberg (Animal Agriculture and Climate Change Specialist, Humane Society of the United States) at the Hudson Institute's Conference on Food for the 21st Century: Challenging the Conventional Wisdom, Washington DC, September 10th, 2008.

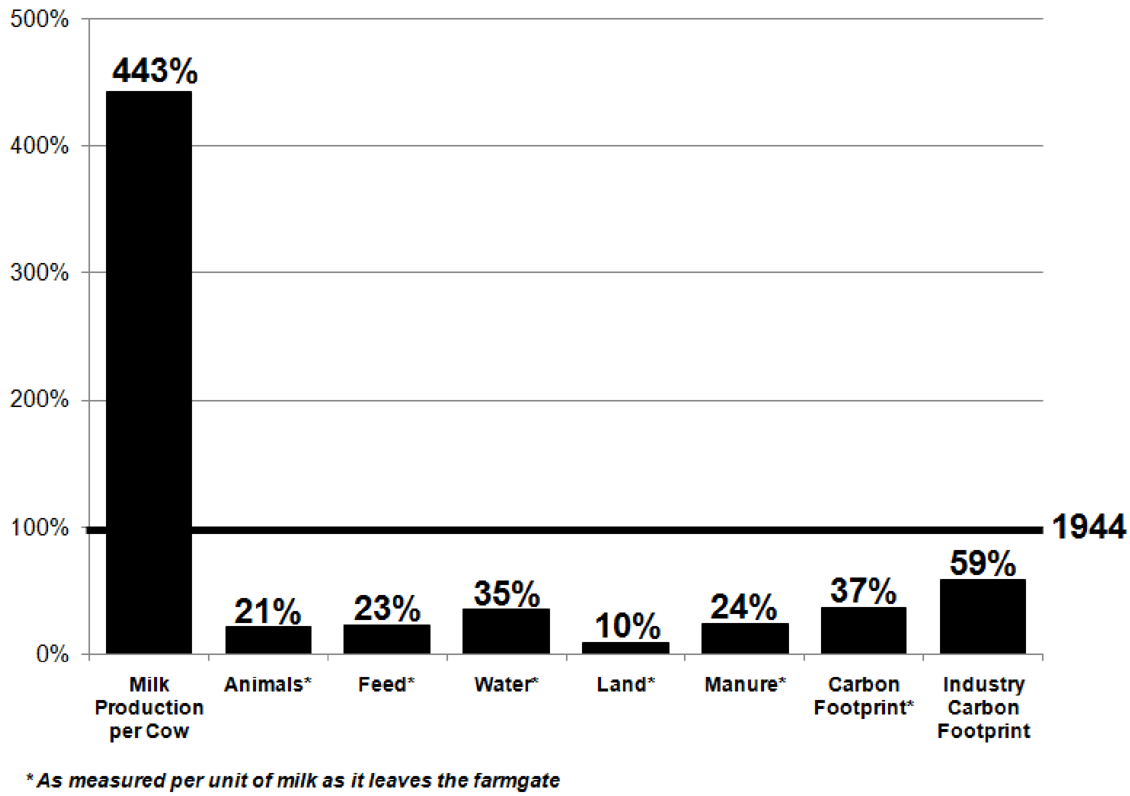


Figure 2. 2007 U.S. Milk Production, Resource Use and Emissions Expressed as a Percentage of the 1944 Production System (Adapted from Capper et al., 2009)

'Grass-fed' beef production

The environmental mitigation effect arising from improved productivity is a function of either output per animal (meat, milk or egg yield) or the time taken to produce the finished product. Average beef-carcass yield per animal has increased over the past 30 years from 266 kg in 1975 compared to 351 kg in 2007 (USDA, 1976; USDA/NASS, 2008), which, in combination with reduced time to slaughter over the same time period (19 mo *vs*. 18 mo), reduces resource use per unit of meat. Time to slaughter is primarily affected by growth rate, thus this is a primary productivity measure by which to mitigate the environmental impact of meat production.

Approximately 50-75% of a conventionally-reared beef animal's life is spent on pasture, however 'grass-fed' or 'grass-finished' beef is often touted as a more environmentally-friendly option for the consumer than conventional (corn-finished) beef. If a superficial view is taken, considering only the comparative energy inputs required to produce and harvest corn in conventional systems, compared to the animals 'harvesting' the pasture through grazing, the suggestion that grass-fed beef has a lower environmental impact appears to be correct (Pimentel and Pimentel, 2007). However, this suggestion relies on three underlying erroneous assumptions that animals within both systems: 1) have equal energy requirements, 2) take the same time to finish and 3) produce the same quantities of GHGs from enteric fermentation. Accounting for the animal's daily maintenance requirement (nutrients needed to maintain the vital functions and minimum activities in a thermo-neutral environment) becomes crucial for accurate analysis.

As shown in Table 1, animals finished on pasture have an additional energy requirement for grazing activity, thus increasing total daily maintenance requirements. The growth rate of beef animals on pasture is also lower than that of animals fed corn. Each day added to the finishing period adds an extra daily maintenance cost, which must be accounted for in the environmental impact of the final product. Finally, pasture-based diets promote greater ruminal acetic acid production (Johnson and Jonhson, 1995), increasing enteric methane production. Both energy use (MJ/kg gain) and methane emissions (kg/kg gain) are thus considerably increased in pasture-based systems.

Table 1. Comparison of energy inputs, methane output and cropland required to finish beef steers in corn-fed or pasture-fed systems

	Corn-fed	**Pasture-fed**
Start weight (kg)	254	254
Finished weight (kg)	635	635
Growth rate (kg/d)[a]	1.61	0.87
Finishing period length (d)	237	438
Daily energy for maintenance (MJ)	26	33
Daily energy for growth (MJ)	30	15
Total energy used during finishing (MJ)[b]	40,934	118,308
Total methane emissions during finishing (kg)[c]	53	149
Energy MJ/kg gain	107	310
Methane kg/kg gain	0.14	0.39
Total land required (ha)[d]	0.21	2.70

[a] Based on corn or pasture diet fed *ad libitum* during the finishing period, calculated according to NRC (2000) by Hereford x Angus steers weaned at 207 days (USDA, 2000)
[b] Includes energy for maintenance and growth (NRC, 2000) plus energy inputs for corn grain and pasture from Pimentel and Pimentel (2007).
[c] Calculated using the model described in Capper et al. (2009) adapted for beef production
[d] Corn yields from USDA (http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/) and pasture yields from Brink et al. (2008)

A significant proportion of land used to graze cattle is not suitable for growing crops for human consumption (Steinfeld et al., 2006). Furthermore, U.S. beef and dairy industries use considerable quantities of by-products from human food, fiber and biofuel production (e.g. citrus pulp, flaxseed oil, corn distiller's grains) that would otherwise be discarded and become a GHG source within landfill. The conversion of indigestible plant material and human food by-products into high-quality milk and meat protein provides an invaluable source of human nutrients, and should be offset against the environmental impact of livestock production.

To make the most efficient use of resource inputs it is essential to match nutrient supply and demand within individual components of the production system. Extensive rangeland systems provide sufficient nutrients to support the cow-calf component of the U.S. beef production system (NRC, 2000) while maintaining biodiversity (Steinfeld et al., 2006). Finishing cattle on intensively-managed pasture offers an opportunity to reduce GHG emissions per unit of beef compared to traditional, extensive grass-finishing systems (DeRamus et al., 2003). However, the resource inputs and greenhouse gas outputs generated by finishing the current U.S. population of 9.8 million fed cattle on intensively-managed pasture would require an extra 24.2 million ha of pastureland and 1.15×10^{12} MJ of energy. The increases in resource use per unit of output associated with 'traditional' dairy and beef production systems demonstrate that the popular perception of low-input sustainable systems does not align with true sustainability when trying to meet a static or increasing demand for food.

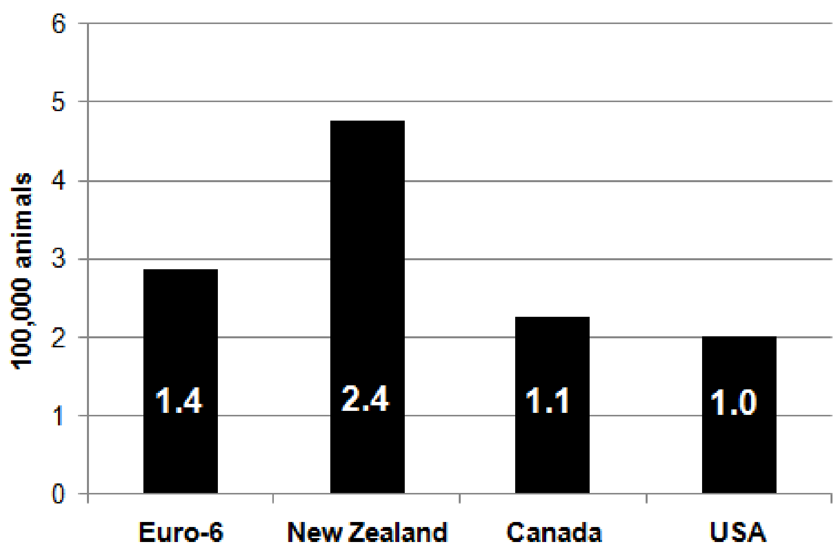
RECONCILING GLOBAL AND NATIONAL EMISSIONS DATA

The FAO (Steinfeld et al., 2006) reported that livestock are responsible for 18% of global anthropogenic GHG emissions. This statistic has been adopted by various groups as evidence that converting to a wholly-vegetarian diet would have a beneficial environmental impact (Walsh, 2009). As previously discussed, one major benefit conferred by livestock systems is the conversion of inedible plant species (e.g. pasture) into high-quality meat protein for human consumption. Indeed, Peters et al (2007) evaluated the ability of New York state agriculture to support a human population consuming one of 42 different diets, each containing 0-381 g/d animal protein (meat and eggs), and concluded that the diet that best optimized resource use contained 63-127 g of animal protein per day. This is further evidence that food production systems must be matched to available resources to improve productive efficiency.

A recent report from the U.S. EPA (2009) quantified the primary anthropogenic GHG sources within the US, concluding that total agriculture (livestock and crops) contributed 5.8% of national GHG emissions. Of this 5.8%, approximately 3.4% can be apportioned to animal agriculture (total emissions from manure and enteric fermentation, plus an estimate of the contribution made by animal feed production) and the remaining 2.4% to food crops consumed directly by humans. To reconcile the considerable difference between the global (18%) and national (3.4%) estimates of livestocks' contribution to GHG emissions it is necessary to explore the data in more detail.

Partitioning out the components of the global FAO figure reveals that almost half (48%) of the total is attributed to changes in land use pattern, specifically the carbon released by clearing forestland (a carbon sink) to grow animal feed. The potential for reduced cropland availability to lead to further deforestation on a global basis is exacerbated by the use of formerly food-producing agricultural land to grow biofuel crops (Sawyer, 2008). Deforestation therefore needs to be taken into account when analyzing the environmental impact of agricultural systems where a considerable portion of animal feed is imported, e.g. imports of soy from Brazil and Argentina into Europe. The majority of U.S. animal feedstuffs are produced domestically; available cropland area has remained stable (USDA, 2002) with increased crop yields compensating for an increase in feed and food crop production required to meet demand. In contrast to the deforestation occurring in South American countries, the U.S. is actively reforesting, with an average increase in forestland area of 0.2%/y over the past 30 years (Smith et al., 2005). Reforestation increases the amount of carbon sequestered from the atmosphere into plant tissue and soil, with an average of 6.4 kg carbon sequestered annually per tree (Sampson and Hair, 1996). The mitigating effect of carbon sequestered by new forest growth is not accounted for in the U.S. EPA (2009) calculations and would further reduce the estimate of agriculture's contribution.

Even after the component of total GHG emissions attributed to deforestation in the FAO report is disregarded, the global estimate remains nearly 3 times higher than the U.S. national estimate (9.4% *vs*. 3.4%). As demonstrated by the historical milk production (Figure 2) and beef production (Table 1) examples, environmental impact is directly affected by the system productivity (food output per unit of resource input). By its very nature, the global average includes a wide range of system efficiencies. For example, U.S. agriculture is characterized by highly-efficient production systems, with the average dairy cow producing 9,219 kg milk per year in 2007. By contrast, the 2007 average annual yield for the top six milk-producing counties in Europe is 6,362 kg milk per year, while annual production in New Zealand and Canada averages 3,801 kg milk/cow and 8,188 kg milk/cow respectively (FAO, 2009).



*Numbers inside bars are a relative ratio to the most efficient country
**Euro-6 represents 2/3 of the cow's milk produced in the EU in 2007

Figure 3. Dairy Animals (Cows, Heifers and Bulls) Required to Produce One Billion kg of Milk in 2007

Differences in productivity between countries means that the dairy population (lactating and dry cows, heifers and bulls) required to produce an equivalent amount of milk is extremely variable (Figure 3). Compared to the U.S. (indexed as 1.0), Canada requires a 1.1x population increase, Europe requires a 1.4x population increase and New Zealand requires a 2.4x population increase. The nutrient requirements and waste output associated with the dietary maintenance requirement for each population therefore varies considerably, with a significant increase in both resource use and GHG emissions per unit of milk in the systems with lower productivity.

When elucidating disparities between global and national GHG emissions, it is essential to understand the effects of differences in system productivity and efficiency. The global average for livestock's contribution to GHG emissions cannot be assumed to be representative of all agricultural systems.

CARBON SEQUESTRATION AS A MITIGATION STRATEGY

As previously discussed within the beef example, pasture-based systems are only sustainable when they are able to provide sufficient nutrients for meat or milk production, without negatively impacting yield or increasing resource use per unit of food. This is a serious consideration when assessing the environmental impact of pasture-based animal production as it is associated with increased maintenance costs (due to activity) and decreased yields, thus more animals or more days to market (and associated resources) are required to produce the same amount of animal protein.

Carbon sequestration (long-term storage of carbon in soil or plant biomass) is often quoted as a major environmental advantage of pasture-based systems. This suggestion is based on the assumption that pasture sequesters carbon indefinitely and at a constant rate. However, carbon sequestration into soil can only be significantly altered with a change in land use, and only occurs over a finite time period (Post and Kwon, 2000; Schlesinger, 2000).

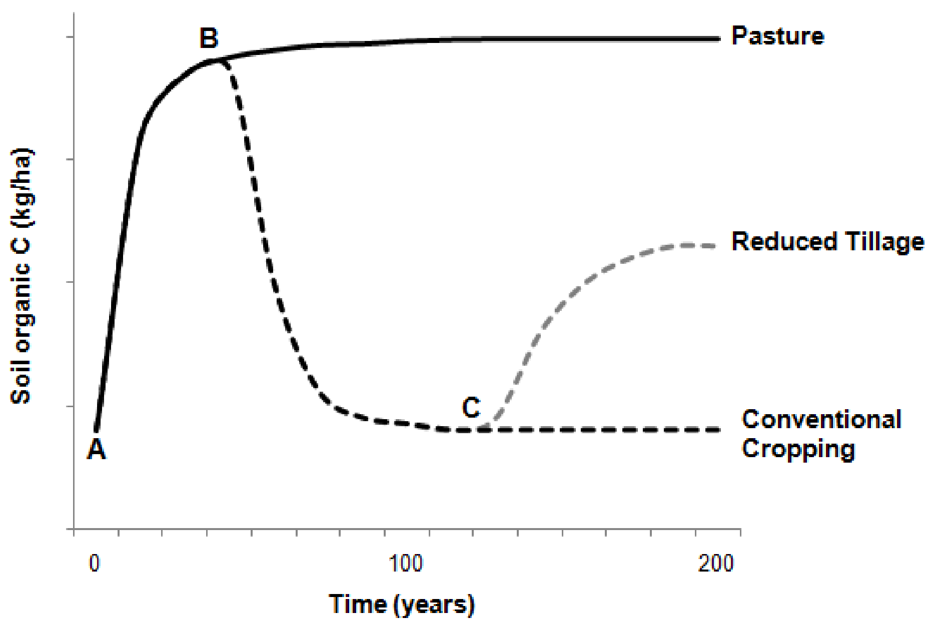


Figure 4. Variation in Soil Organic Carbon Profile According to Changes in Management Practice

The effects of changing from conventional cropping to pasture (point A), pasture to conventional cropping (point B) and conventional cropping to reduced-tillage (point C) on soil carbon reserves are shown in Figure 4. Converting cropland to pasture, or pasture to forestland, leads to increased sequestration and an improvement in soil carbon status. Conversely, changing land use from forest or pasture to cultivated crops increases emissions and reduces soil carbon status. These alterations in carbon sequestration or emissions only continue until an equilibrium point is reached after about 20 years, with the majority of soil sequestration/emissions occurring within the first 10 years following land management change (Smith et al., 2007). Land subjected to the same land use practices over 20+ years is considered to have a net carbon balance of zero, i.e. the amount of carbon sequestered into soil is equal to carbon lost to the atmosphere and the soil is at equilibrium. The environmentally positive effects of sequestration therefore only occur in land recently converted from cropping to pasture – negligible additional carbon is sequestered into permanently-established pasture and if pasture is tilled or converted to cropland, sequestered carbon may be lost to the atmosphere.

At a superficial level, carbon sequestration appears to be a relatively easy strategy for offsetting the environmental impact of livestock production. However, as noted by a recent U.S. Congress report (2007), this is a temporary (and easily reversible) mitigation strategy, capturing a limited amount of carbon. Sequestration potential therefore does not compensate for the comparative inability of pasture-based systems to support intensive livestock production.

‘FOOD MILES’ AND THE TREND TOWARDS CONSUMING ‘LOCAL’ FOOD

The term “Food Miles” is simply defined as the distance that food travels from its place of origin to its place of final consumption. Food miles have become a common topic of discussion in the social media debate over the merits of modern intensive agriculture *vs*. locally grown food. Often, “locally grown” is touted as preferable because consumption of remotely-grown food is responsible for extra atmospheric carbon emissions due to the excessive distance it must travel. As energy prices undoubtedly increase in the future, debate will continue as to the wisdom of transporting food over long distances.

This section demonstrates how to evaluate the most efficient use of fossil fuels to move food to its point of consumption. Many factors must be considered, including supporting the local economy, energy availability, food safety, freshness, and security, cultural preferences and climate. Potentially the most important factor is the agronomic ability of the local land and resources to supply sufficient food in a healthy balanced diet to the indigenous population.

A common but naïve method for evaluating food miles is to measure the linear distance food travels from point-of-origin to point-of-consumption. Intuitively, it seems logical that if a local source of a certain food (e.g. eggs) is available, then purchasing ‘local’ eggs is more energy-efficient and eco-friendly than purchasing eggs that originated from some distance away. However, as discussed by Watkiss (2005) and Saunders et al. (2006) this approach fails to consider the productivity of the transportation system. The following scenario comparisons demonstrate that linear travel miles are not indicative of total energy use and therefore not necessarily a valid measure of the environmental impact of moving food over long distances. Rather this must be evaluated through appropriate measures of fuel efficiency based on cargo capacity and energy use per unit of food moved.

An illustrative example was developed comparing three typical scenarios for a consumer purchasing a dozen eggs: 1) the local chain grocery store supplied by a production facility some distance away; 2) a farmer's market supplied by a source much closer than the grocery store's source; or 3) directly from a local poultry farm. Only the impact of energy use to transport food is examined and eggs at each facility are assumed to be produced with similar egg production practices. As a result, the carbon footprint of a dozen eggs leaving the production facility is similar for all three scenarios. The example illustrates the basic LCA process required to appropriately assess food miles' environmental impact and is not meant to provide the definitive answer as to which food transportation system is consistently superior. To provide some realism to the example, an area of the country known to the authors (Pacific Northwest) was chosen for the farmers' market and farm scenarios in order to develop a plausible example. For the grocery store example, the home is located in the Pacific Northwest but the eggs were transported from California. At least three data inputs are critical to accurately assess the impact of food transportation: distance traveled, fuel use, and cargo capacity of the transport vehicles. Intermediate distances between egg source to store and store to home are shown in Table 2. The total distance traveled by the eggs in scenario 1 (grocery store) is 1,293 km, for scenario 2 (farmer's market) is 150 km, and for scenario 3 (local farm) is 44 km.

Table 2. Linear Road Distances for Transportation Segments

One-way distance (km)	The home	Grocery store	Farmers' market	Local farm	Farmers' market source	Grocery store source
The home		2.4	11	44		
Grocery store	2.4					1,291
Farmers' market	11				138	
Local farm	44					
Farmers' market source			138			
Grocery store source		1,291				

It is not sufficient to simply examine the distance between source and consumption point because in some cases vehicles must make a round-trip. Total miles assigned to each scenario are shown in Figure 5. In all cases, the personal auto must make a round-trip from the home to the place of purchase. In order to simplify the examples we assume that no other business will be conducted during the trip, thus all miles travelled by the auto are assigned to egg transport. The same is true for the pick-up truck used to transport eggs to the farmer's market. Eggs are transported from the source in California to the grocery store using a tractor hauling a refrigerated trailer (reefer). Under these conditions, backhauls are used as much as possible – for example, a load of apples might be backhauled from Washington to California. Situations both with and without backhauls have therefore been included in the analysis. As shown in Figure 5, examining total miles for each scenario seems to reinforce the preliminary conclusion that purchasing local eggs is by far the most eco-friendly option.

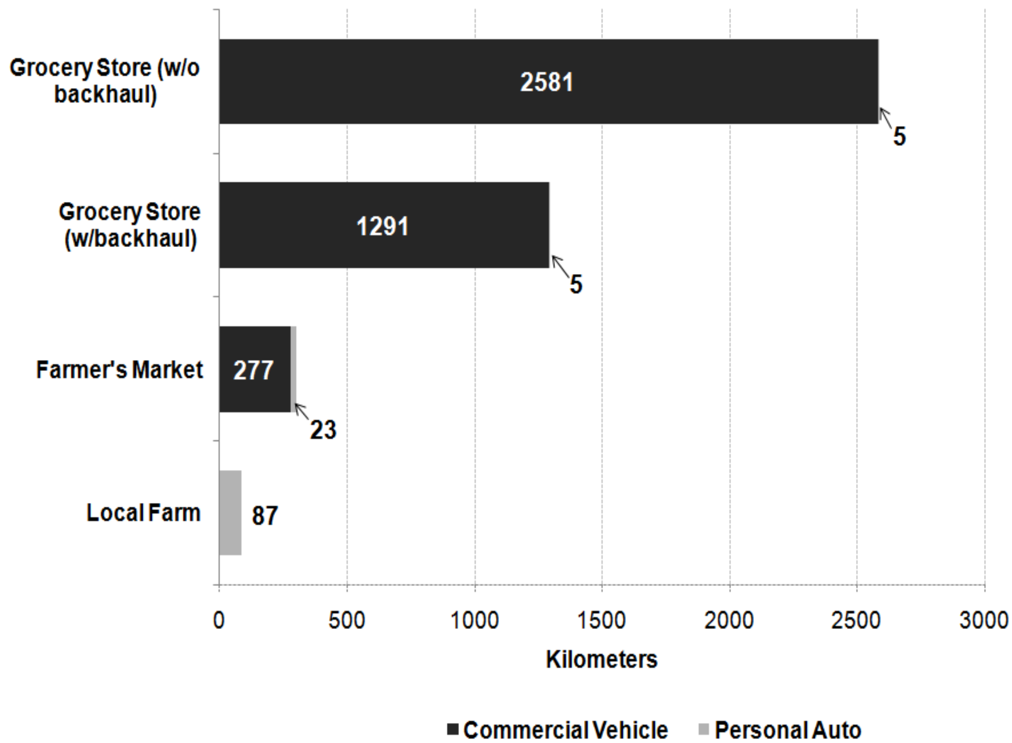


Figure 5. Vehicle Distance Traveled to Move Eggs from Source to Home

Up to this point, the implicit assumption is that each vehicle carries equivalent numbers of eggs and uses equivalent fuel. Data relating to fuel efficiency and vehicle capacity is summarized in Table 3. High fuel efficiency again appears to favor the automobile as the most environmentally-friendly form of egg transport, however, the tractor-trailer moves 23,400 dozen eggs in one trip. Because of the enormous quantity of eggs that can be moved in a single trip by one tractor-trailer (another form of productivity), the fuel use efficiency per dozen eggs is greatly increased over the automobile. Fuel use (total distance divided by fuel efficiency, plus fuel use for egg refrigeration by the tractor-trailer) and egg-carrying capacity were used to estimate total fuel use per dozen eggs for each vehicle within the three scenarios to determine the most fuel efficient method for transporting eggs from the source to the home refrigerator.

Results summarized in Figure 6, provide a very different, perhaps non-intuitive, conclusion as to the most energy-efficient method for moving eggs to the consumer, namely the tractor-trailer from a remote location. Even if a backhaul is not used and therefore the fuel efficiency is halved, fuel expended per egg is still far superior to either the farmer's market or the local farm. This a direct result of the enormous number of eggs moved by the tractor trailer compared to the other two vehicles. Over 90% of fuel consumption is contributed by the automobile in each scenario because the auto only carries one dozen eggs. Using the vehicle fuel efficiency and cargo capacity in these scenarios, eggs could actually be transported across the entire North American continent by the tractor trailer, and the grocery store model would remain the most fuel-efficient, eco-friendly option.

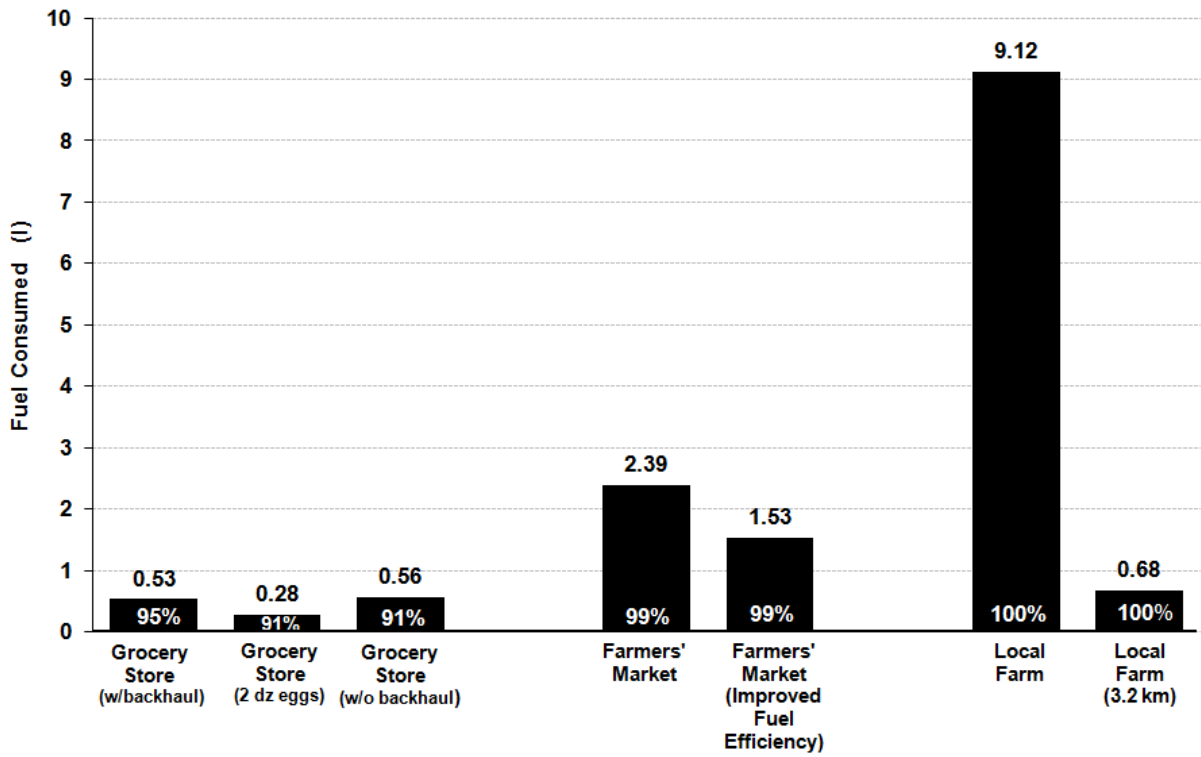
Table 3. Vehicle Fuel Efficiency and Cargo Capacity

	Fuel efficiency (km/l)	Egg capacity (dozen)
Auto	9.5[a]	1
Pick-up truck	7.7[a]	1,740[d]
Refrigerated tractor-trailer	2.3[b]	23,400[e]
Refrigeration unit	1.9[c]	N/A

[a] Bureau of Transportation Statistics (2009)
[b] Langer (2004)
[c] Anon (2006)
[d] Estimated according to egg crate dimensions and pick-up carrying capacity
[e] Personal Communication, Dr. Robert Taylor, Jr., University of New Hampshire, May 2009

To test the robustness of this example, three additional modifications were examined (also depicted in Figure 6): the purchase of two dozen eggs from the grocery store; improving fuel efficiency; and reducing distance traveled from the home to the local farm source. One of the most effective means to reduce fuel consumption per dozen eggs is to purchase two dozen eggs. Because so much of the fuel use is by the auto, purchasing 2 dozen eggs, doubling the carrying capacity of the auto, cuts the fuel consumption per dozen eggs by almost 50%. Using the farmer's market scenario, we examined the impact of improving fuel efficiency for the automobile and pickup truck to 56 km/l and 35 km/l respectively (representative of some of the more fuel-efficient vehicles available on the market today) *vs*. average fuel efficiency used in the baseline scenarios. This improved the overall fuel use per dozen eggs by 36%. Finally, given the fact that the automobile only carries one dozen eggs, distance traveled becomes an extremely important factor in determining how close to home 'local' eggs have to be in order to be more fuel-efficient and eco-friendly to obtain than grocery store eggs. As shown in Figure 6, even when the local eggs are only 0.8 km (3.2 km) further away than the grocery store (2.4 km), the grocery store eggs are still more eco-friendly. Similar results were reported by Coley et al. (2009) in a comparison between large-scale vegetable box delivery *vs*. consumers driving to purchase vegetables from an on-farm store.

This example demonstrates that as a result of high capacity cargo volumes in modern transportation systems, food can be efficiently moved over long distances and remain highly fuel efficient and thus environmentally friendly compared to locally-grown food. This has important consequences when considering how to feed people in high-density population centers (e.g. large cities) where buying locally-produced food is not an option. These results also strongly suggest that food should be grown where the agricultural resources and capacity are most suited to efficient food production rather than converting low-yielding land that is better suited for other purposes such as human occupation or wildlife habitat. It is not sufficient to judge miles travelled to determine the cost, fuel efficiency, and eco-friendliness of food transport. A much more detailed LCA is required. The approach illustrated in this paper only demonstrates the most basic of considerations that must be considered.



Note: Number above bar is fuel use per dozen eggs (l)
% in bar is percentage of fuel used by personal auto

Figure 6. Fuel Consumed per Dozen Eggs to Move Eggs from Source to Home

CONCLUSION

The environmental impact of livestock production is an issue that will remain high on the consumer, producer and political agendas for the foreseeable future. This will be of particular importance as the population continues to increase, leading to a greater dichotomy between the amount of food required to meet the nutritional needs of humans and the resources available for food production. Environmental impact and options must therefore be evaluated using whole-system approaches based on productivity, rather than allowing ideological principles, based either on naïve or incomplete misinformation or a lack of understanding, to direct food production practices. All attempts to mitigate environmental impact are laudable in intent. However, attention should be focused on strategies that make a long-term, positive contribution to enhancing sustainability, rather than focusing on 'quick-win', low impact solutions.

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