Dairy Production: 1940's through Today

Jude L. Capper[1], *PhD;* Roger A. Cady[2], *PhD;* Dale E. Bauman[3], *PhD*
[1]*Department of Animal Sciences, Washington State University, PO Box 646310, Pullman, WA 99164*
[2]*Elanco Animal Health, 2500 Innovation Way, Greenfield, IN 46140*
[3]*Department of Animal Science, Cornell University, Ithaca, NY 14853*

Abstract

The sustainability of the US dairy industry is an increasingly significant issue. Producers are challenged with increasing the supply of dairy products to meet the demands of the growing population, whilst maintaining the tradition of environmental stewardship. Advances in nutrition, management, and genetics resulted in a four-fold improvement in dairy cow milk yield between 1944 and 2007. This allowed the US dairy industry to produce 59% more milk using 64% fewer cows and conferred considerable reductions in feed (77%), land (90%), and water (65%) use per gallon of milk. The carbon footprint of the entire US dairy industry was reduced by 41% over the same time period. The global livestock industry is thought to contribute 18% of greenhouse gases worldwide. However, this global average does not address the variability between systems. Instead, differences in system productivity demonstrate the considerable variation in potential environmental impact between dairy regions. Improving productivity arguably has the greatest potential to reduce the environmental impact of dairy production, regardless of system characteristics. As dairy industries worldwide pledge to reduce total greenhouse gas emissions, attention should be focused on a whole-system life cycle assessment approach rather than racing to find a 'magic bullet' solution focused at a specific process that may confer negative trade-offs.

Key words: dairy, environment, greenhouse gas, productive efficiency

Résumé

La durabilité de l'industrie laitière américaine est un enjeu de plus en plus important. Les producteurs sont mis à l'épreuve car ils doivent d'une part augmenter l'offre de produits laitiers pour faire face à la demande d'une population toujours grandissante tout en maintenant d'autre part une tradition de responsabilité de gérance environnementale. Des percées au niveau de l'alimentation, de la régie et de la génétique ont permis de quadrupler la production de lait par vache entre les années 1944 et 2007. Ceci a permis à l'industrie laitière américaine de produire 59% plus de lait en utilisant 64% moins de vaches entraînant par le fait même des réductions considérables au niveau des aliments (77%), de la terre (90%) et de l'eau (65%) requis pour produire un gallon de lait. L'empreinte carbone de l'industrie laitière américaine a été réduite de 41% sur la même période. On pense que l'industrie laitière à l'échelle globale produit 18% des gaz à effet de serre dans le monde. Toutefois, cette moyenne globale ne prend pas en considération la variabilité entre les systèmes. Au contraire, les différences dans la productivité des différents systèmes démontrent une variabilité considérable au niveau de l'impact environnemental potentiel des différentes régions productrices de lait. L'amélioration de la productivité a certainement un rôle à jouer afin de réduire l'impact environnemental de la production laitière peu importe les caractéristiques du système. Dans l'optique d'une réduction des émissions totales des gaz à effet de serre par les industries laitières à travers le monde, il est important de mettre l'accent sur une approche d'évaluation globale plutôt que de foncer pour trouver une solution magique ciblée sur un processus spécifique qui pourrait engendrer un compromis négatif.

Introduction

Sustainability is often defined as "meeting society's present needs without compromising the ability of future generations to meet their own needs".[38] This often leads to conflict as to the role of sustainability within the context of the modern dairy system. The popular perception of sustainable agriculture is often directed towards low input: low output systems, 'traditional' (historical) agricultural systems or farms that produce food to supply only the local geographic area. Under such myopic constraints, highly-efficient systems such as those seen in modern agriculture may therefore be deemed as environmentally unfriendly.[14]

The global population is predicted to increase to 9.5 billion people in the year 2050,[36] thus increasing total food requirements by 100%,[35] both as a function of population size and the augmented global demand for milk and meat protein resulting from more widespread global affluence.[12] If the present competition for energy, land, and water supplies continues, resources available for agricultural production are likely to decrease concurrently with increased population growth. The global dairy industry therefore faces the challenge of producing sufficient safe, affordable milk to meet consumer demand, using a finite resource base. All food production has an environmental impact, and livestock production has been singled out as a major contributor to climate change.[14,30] When evaluating the sustainability of dairy production systems it is therefore necessary to adopt a science-based approach, rather than relying upon intuitively-correct solutions that do not consider potential negative trade-offs. This paper will discuss the role of productivity in producing sufficient milk to supply the human population, whilst reducing environmental impact.

Low-input Systems are also Low-output Systems

In 1611, European dairy cattle were imported into Jamestown, Virginia and the fledgling US dairy industry was formed. Since those first cattle arrived, the industry has made huge productivity gains; the earliest recorded US milk production data relates to a Jersey cow (Flora 13) that produced 511 lb (232 kg) of milk over 350 days in 1854.[40] By contrast, the average milk yield per cow in 2007 was 20,203 lb/year (9,164 kg). Changes in total US milk production, cow numbers, and individual cow milk yield between 1944 and 2007 are shown in Figure 1. It is clear that as milk production per cow increases, the size of the national herd has decreased. This can be attributed to advances in nutrition, management, and genetics that have allowed us to move from a pasture-based system with an average herd size of six cows in 1944, to today's total-mixed-ration (TMR) system with an average herd size of 157 cows. Nonetheless, the popular agrarian vision of US dairy farming involves cows grazing on pasture with a 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"[a] and 'industrialized warehouse-like facilities that significantly increase greenhouse gas (GHG) emissions per animal'.[14]

The dichotomous challenge of producing more food from a dwindling resource supply has led some to suggest that adopting low-input production systems may be the key to improving agricultural sustainability. However, this defies the First Law of Thermodynamics which states that 'energy can neither be created or destroyed, it can only change form'. By definition, a low-energy-input system is a low-energy-output system, characterized by reduced productivity over a fixed time period. Nonetheless, improved efficiency as it relates to livestock production appears to be a profane suggestion, despite a recent Food and Agriculture Organization (FAO) report concluding that to reduce environmental impact there exists "a need for continued efficiency gains in resource use for livestock production".[30]

Accounting for the 'Fixed Costs' of Dairy Production

In any industrial situation, improving productive efficiency (output per unit of resource input) has a positive effect upon economic sustainability. If the fixed costs (rent, utility bills, etc) are spread out over more units of production, the product can be produced at a lower cost. In the context of the dairy herd, the maintenance nutrient requirements act as a fixed cost that must be met before production (growth, pregnancy or lactation) can occur. These requirements have an economic cost associated with them, but also have an environmental cost in terms of resource inputs (feed, water, cropland, fertilizer, fossil fuels) and waste outputs (GHG, manure). The 'dilution of maintenance' effect is exemplified in Figure 2, demonstrating the decrease in energy use per

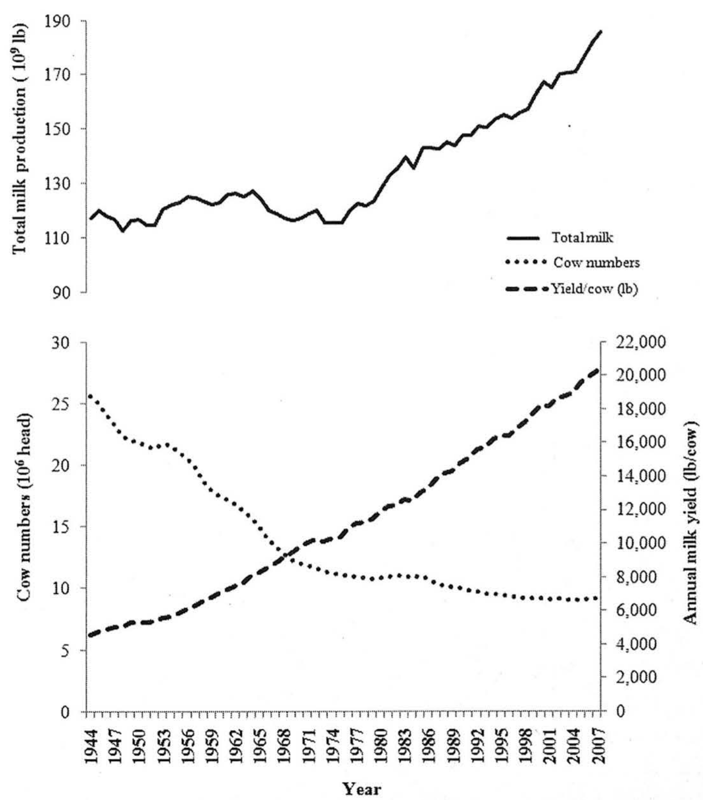

Figure 1. Changes in total US milk production, cow numbers, and individual cow milk yield between 1944 and 2007 (adapted from Capper *et al*[4]).

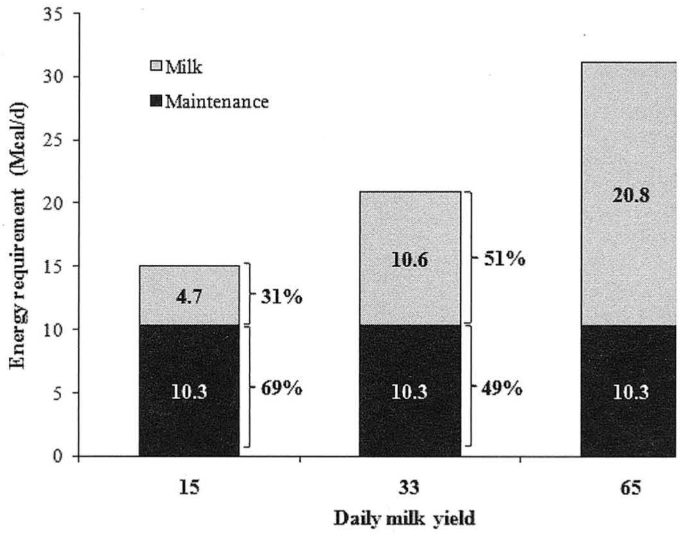

Figure 2. The 'dilution of maintenance' effect (adapted from Capper *et al*[4]).

pound of milk as milk yield is increased from 15 lb (6.8 kg)/day to 65 lb (29.5 kg)/day.

The maintenance cost for milk production does not change, but the maintenance energy is diluted out over more units of production, decreasing from 69% to 33% of the total. It should be remembered that 'energy' in this case can be considered a proxy for resources in terms of feed, land, water, and fossil fuels. This effect is not confined to the lactating cow but applies to the entire dairy herd. As milk yield increases, fewer lactating cows are required to produce a set amount of milk and the number of associated support animals (dry cows, replacement heifers, bulls) that serve to maintain the dairy herd infrastructure is also reduced. Improving productivity, therefore, reduces both the environmental cost per unit of milk produced through dilution of maintenance at the individual cow and the herd population level.[4,20] It is vital to consider the entire dairy population and to adopt a life-cycle assessment (LCA) approach when assessing the environmental impact of dairy production. The LCA methodology includes all resource inputs and waste outputs within the boundaries of the production system and expresses environmental impact per unit of product, i.e. per pound or gallon of milk produced.

Improving Productivity Reduces Environmental Impact

Since 1944, the US national herd has shifted away from high milk-solids breeds (e.g., Jersey, Guernsey) to the greater-volume producing Holstein cow. Holstein cows comprised only 39% of the dairy population in 1944 compared to 90% in 2007.[4] Although Holstein cows, on average, produce 18.2 lb (8.3 kg) more milk per day than Jersey cows (DairyMetrics™, Raleigh, NC), they have a greater body weight and increased maintenance nutrient cost. Improving productivity has therefore increased daily resource use and waste output per animal. As shown in Figure 3, daily GHG emissions per cow (measured in CO_2-equivalents) have increased considerably: the average dairy cow now produces 61.3 lb (27.8 kg) CO_2-equivalents compared to 29.8 lb (13.5 kg) CO_2-equivalents in 194.[4] However, expressing results on a 'per head' basis fails to take the entire system into account. When analyzed using LCA and expressed per pound of milk produced, it is clear that GHG emissions per pound of milk produced have declined from 3.66 lb (1.66 kg) in 1944 to 1.35 lb (0.61 kg) in 2007 (Figure 3). This has been achieved through considerable improvements in productivity. Annual milk yield per cow quadrupled between 1944 (4,572 lb; 2,074 kg) and 2007 (20,203 lb; 9,164 kg), allowing 59% more milk (186 billion lb (84.4 billion kg) vs 117 billion lb (53.1 billion kg)) to be produced using 64% fewer lactating cows (9.2 million vs 25.6 million). Despite the increase in total milk production, 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 (Figure 4).

The scientific consensus appears to be that climate change is a significant global concern, within which anthropogenic GHG play a significant role. However, environmental impact should not simply be assessed on the basis of GHG emissions or 'carbon footprints'. As the global population increases, a considerable challenge is posed in terms of competition for resource requirements. The demand for agricultural land is likely to increase in the future as a consequence of greater urban development and the emerging biofuels industry.[10] Water

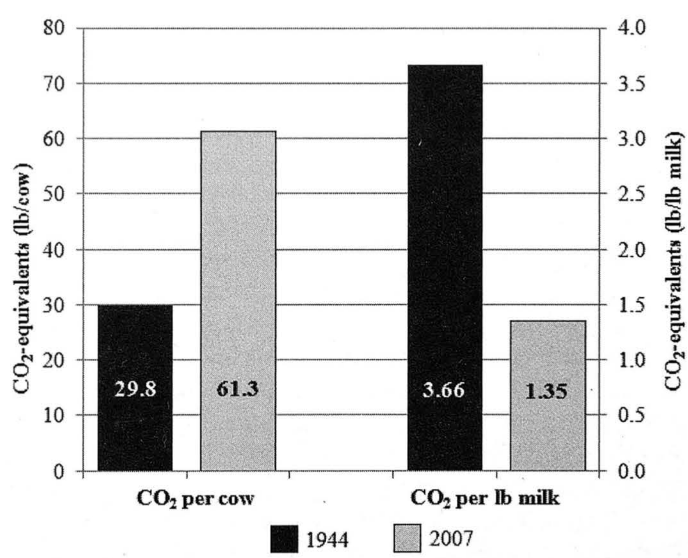

Figure 3. Carbon footprint per cow and per lb of milk for 1944 and 2007 US dairy production systems (adapted from Capper *et al*[4]).

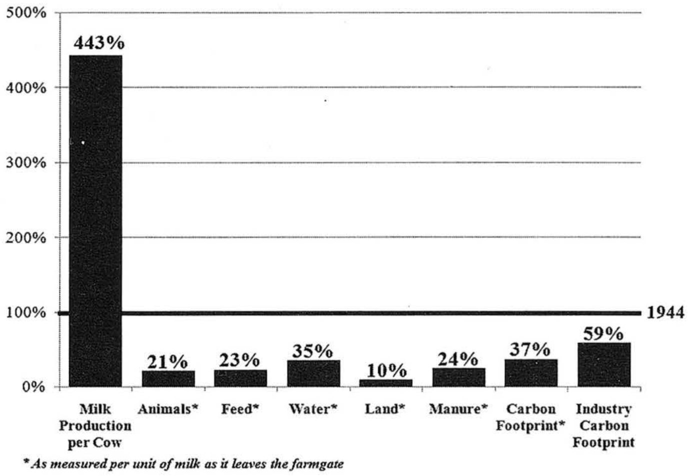

Figure 4. 2007 US milk production, resource use and emissions expressed as a percentage of the 1944 production system (adapted from Capper *et al*[4]).

use for livestock is similarly at a premium in specific geographical locations.[24] As previously discussed, the maintenance requirement for dairy production has an environmental resource cost. Improving productivity thus reduces resource use per unit of milk as shown in Figure 4. The 343% increase in milk yield per cow between 1944 and 2007 drove a 79% decrease in total animals (lactating and dry cows, heifers, mature and adolescent bulls) required to produce a set quantity of milk. Feed and water use were reduced by 77% and 65% respectively, while cropland required for milk production in 2007 was reduced by 90% compared to 1944 due to improved crop yields and the shift from pasture-based to TMR systems. Finally, manure output from producing a comparable amount of milk from the modern system was 76% lower than from the 1944 system, contributing to the aforementioned 63% decrease in the carbon footprint per unit of milk.

Productivity, Pasture and Environmental Impact

The reliance of modern agricultural systems on fossil fuel energy has been criticized by some authors who propose a return to pasture-based systems as a more sustainable alternative.[22] On a global basis, a significant proportion of land used for grazing ruminants is not suitable for growing crops for human consumption.[30] This conversion of indigestible plant material into high-quality animal protein provides an invaluable source of human nutrients and negates the suggestion that animal production competes for human food resources. However, 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 dairying, as it is associated with increased maintenance costs (due to activity) and decreased milk yields.[13,26]

Thomassen *et al*[34] reported greater ammonia volatilization per unit of organic milk due to reduced pasture stocking rates and the increased number of animals required to produce the same quantity of milk compared to conventional systems. A recent analysis from the Organic Center intended to demonstrate the advantages of moving from conventional to organic dairy production was based on a flawed premise, namely that productivity (milk yield per cow) does not differ between conventional and organic systems.[2] Furthermore, high-forage or pasture diets increase ruminal methanogenesis, thus increasing enteric GHG emissions[11,20] and global warming potentials from organic dairy systems.[8] When differences in productivity are accounted for, organic dairy production requires considerably more resources per unit of milk produced and has a greater environmental impact.[5]

Carbon sequestration (removal of carbon from the atmosphere and storing it in soil or plant biomass) is often quoted as a major environmental advantage of pasture-based systems. However, the suggestion that all pasture sequesters considerable quantities of carbon is based on a flawed premise, namely that pasture sequesters carbon indefinitely and at a constant rate. Carbon sequestration into soil can only be significantly altered as a result of alterations in land management[23,28] and should be considered a temporary strategy for reducing environmental impact.[7] To make the most efficient use of resource inputs and thus to reduce environmental impact, it is essential to match nutrient supply and demand within individual components of the production system. For example, extensive rangeland systems provide sufficient nutrients to support the cow-calf component of the US beef production system[19] but provide inadequate resources to finish the national growing steer/heifer population on pasture.[3] Relying on temporary sequestration strategies to overcome the effects of low productivity in pasture-based systems is a definitively unsustainable strategy.

Global Environmental Impact Data is not Representative of Regional Production Systems

The FAO[30] reported that livestock are responsible for 18% of global anthropogenic GHG emissions. This statistic has been adopted by various groups as evidence that significantly reducing animal protein consumption or even abolishing animal agriculture would have a beneficial environmental impact.[14,16,17,33] By contrast, a recent report from the US Environmental Protection Agency (EPA)[37] 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 human food crops. To reconcile the considerable difference between the global (18%) and national (3.4%) estimates of livestock's contribution to GHG emissions, it is therefore necessary to explore the data in more detail.

A recent review evaluating the FAO data reported several flaws in the methodology and the inadequacy of a 'global average' as a measure of individual system environmental impact.[21] Partitioning out the components of the global FAO figure reveals that almost half (48%) of the total is attributed to the carbon released by clearing forestland 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.[27] 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 US feedstuffs are produced domestically; available cropland area has remained stable,[39] with increased crop yields compensating for an increase in feed and food crop production. In contrast to the deforestation occurring in South American countries, the US is actively reforesting, with an average increase in forestland area of 0.2%/year over the past 30 years.[29] Reforestation increases the amount of carbon sequestered from the atmosphere into plant tissue and soil, with an average of 14.1 lb (6.4 kg) carbon sequestered annually per (mature) tree.[25] The mitigating effect of carbon sequestered by new forest growth is not accounted for in the US EPA[37] calculations, but would further mitigate the contribution made by agriculture.

Even after the component of total GHG emissions attributed to deforestation is disregarded, the global estimate remains approximately three times higher than the US national estimate. Environmental impact is directly affected by system productivity (output per unit of resource input), but by its very nature, the global average includes a wide range of system efficiencies. In 2007, the average dairy cow produced 20,203 lb (9,164 kg) milk per year in highly efficient US dairy production systems. In contrast, the average annual yield for the top six milk-producing counties in Europe was 14,026 lb (6,362 kg) milk per year and annual production in Canada and New Zealand averaged 18,051 lb (8,188 kg) milk/cow and 8,380 lb (3,801 kg) milk/cow respectively.[9]

Figure 5 shows trends in milk production per cow from 1960 to 2007 for the US, Canada, an aggregate of the top six milk producing countries in Europe

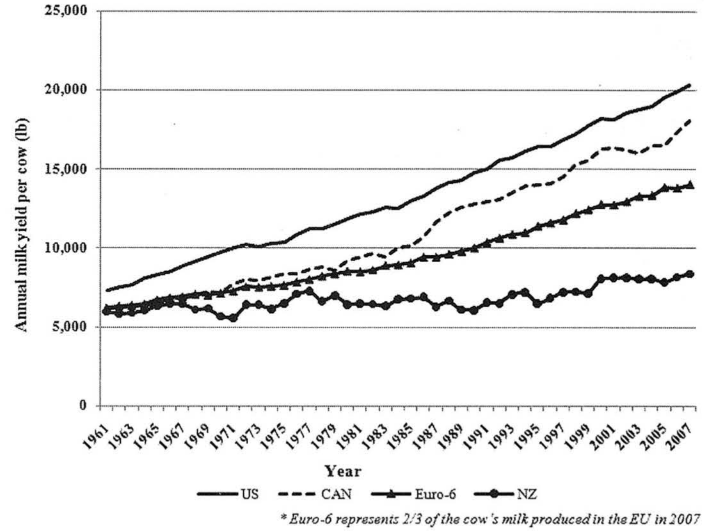

Figure 5. Annual milk yield per cow for four major dairy producing regions (adapted from Capper *et al*[3]).

(Netherlands, UK, Germany, France, Italy, Poland) and New Zealand. Although milk yields were somewhat equivalent between regions back in 1960, the lines have diverged markedly over time. The US has shown the fastest rate of improvement, Canada and Europe are intermediate, and New Zealand production has remained relatively static. Improvements in productivity for the US, Canada, and Europe were made possible by advances in genetics, nutrition, management, and animal health. Differences in the rate of improvement may, therefore, be partially explained by the attitude towards and the adoption of technology and innovative management practices within the various regions. The US is generally pro-biotechnology, whereas Europe is less receptive.[18,41] Furthermore, the New Zealand system is pasture-based, with an average lactation length of only 252 days.[15] Higher productivity reduces the environmental impact of dairy production as, regardless of system specifics, fewer animals are required to produce the same amount of milk.

For every one animal within the 2007 US dairy population, Canada required 1.1 animals, Europe required 1.4 animals, and New Zealand required 2.4 animals to achieve the same level of production (Figure 6). Although the energy use for milk production would remain constant between the systems (assuming a relatively constant milk composition), the increased nutrient requirements and waste output associated with population maintenance would therefore considerably increase both resource use and GHG emissions per unit of milk. The productivity issue is not confined to regions that have highly-developed dairy industries. In 2008, the Chinese government recommended that the dairy

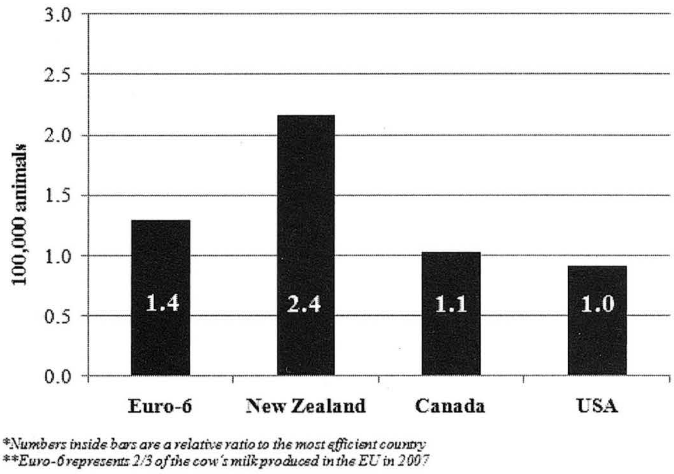

Figure 6. Dairy animals (cows, heifers, and bulls) required to produce one billion lb of milk in 2007.[3]

product intake of each citizen should increase from 3.5 oz/day to 10.6 oz/day. At current levels of milk production, this would require China to add 65 million dairy animals in China, with a huge increase in resource (feed, cropland, water, etc) use. This resource requirement could be reduced if productivity was improved to current US levels – the additional number of animals required to meet Chinese milk supply goals would be reduced by two-thirds to 23 million.

Productivity vs 'Magic Bullets'

It is crucial to note that there is no 'magic bullet' that can be applied to a single component or process within the dairy system to reduce environmental impact. The recent memorandum of understanding between USDA and the Innovation Center for US Dairy cites the use of anaerobic digesters as a major component of the stated intention to cut "dairy industry's greenhouse gas emissions by 25 percent by the year 2020". Methane digesters have only been adopted on approximately 140 livestock operations[32] – this agreement aims to considerably increase this number. However, there are various sound reasons why this technology has not been widely adopted. Most importantly, digesters are not a size-neutral technology. Digester installation and maintenance requires huge capital investment and is not an economically feasible solution on small farms – at present it is suggested that digesters may only generate sufficient income to be fiscally-prudent investments on farms with >500 cows.[31] According to USDA/NASS data for 2009, 76% of dairy farms had <100 cows and 95% had <500 cows, indicating that digester technology will have to move extremely rapidly and become significantly more affordable before it can be adopted by a significant number of farms. Keeping the digester running correctly also appears to be an art that few have successfully mastered – anecdotal tales of digesters overflowing or the digestion processes failing to occur are commonly heard. Although digesters reduce methane emissions from manure, emissions of other air pollutants (e.g. nitrous oxide, NO_x) may also increase to unacceptable levels in areas that don't currently meet federal air quality standards, such as the Central Valley of CA.[6] It is essential to remember that methane from manure is only one component of total dairy GHG emissions. These also include methane and carbon dioxide from the cows themselves, nitrous oxide from fertilizer, and manure application and carbon dioxide from fuel combustion. Even if methane digesters were installed on every single US dairy farm and worked at optimal efficiency, this would still fall short of reducing the US dairy industry's total GHG emissions by 25%.

A considerable amount of research is also being devoted to reducing enteric methane emissions from lactating cows by feeding fish oil or other feed components that shift the rumen population away from methanogenic bacteria. Although laudable in intention, this shift is also associated with a decrease in milk fat yield.[1] In a dairy market where the majority of milk produced is directed towards manufactured dairy products, a reduction in component yield becomes of critical importance as more animals (lactating cows plus support population) are required to maintain milk solids production, thus increasing resource input and waste output per unit of dairy product. This example again demonstrates that directing environmental initiatives at only one component of the production system may have significant negative trade-offs.

The need to consider milk on the basis of nutrient density will also be of increasing importance as greater product differentiation between dairy products comes into play. Labeling schemes that show the 'carbon footprint' per liter of milk are already in place in European retail grocery chains and such schemes may be adopted in the US in future. This is particularly an area of concern when comparing, for example, fluid milk to cheese. Given that it takes approximately 10 lb (4.5 kg) of milk to make 1 lb (0.45 kg) of cheese, a unit weight of cheese would be labeled with a carbon footprint approximately 10 times that of the same unit weight of milk. This might lead the consumer to discriminate against products that have a larger carbon footprint per unit of weight, regardless of nutritional value.

Conclusions

Instead of relying on a single 'magic bullet' to solve the dairy industry sustainability issue, we need to take a system-wide view and focus on productivity. In an industry where average production is just over 20,000 lb

(9,071 kg) per year, we have herds averaging over 30,000 lb (13,608 kg) and individual cows producing over 40,000 lb (18,144 kg) per year. The gains in productivity made over the past 70 years should therefore continue to occur for some time, thus reducing environmental impact. The global average for livestock's contribution to GHG emissions cannot be assumed to be representative of all agricultural systems, and is neither diagnostic nor prescriptive in providing a means to reduce GHG emissions. To be used as a valid part of discussion relating to dairy production and environmental impact, it must therefore be applied in its correct context. Improving productivity will have a beneficial environmental effect within any dairy production system, regardless of region, breed or management differences.

Footnote

[a]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.

References

1. Ahnadi CE, Beswick N, Delbecchi L, Kennelly JJ, Lacasse P: Addition of fish oil to diets for dairy cows. II. Effects on milk fat and gene expression of mammary lipogenic enzymes. *J Dairy Res* 69:521-531, 2002.
2. Benbrook C: *Shades of Green: Quantifying the Benefits of Organic Dairy Production.* The Organic Center, 2009.
3. Capper JL, Cady RA, Bauman DE: Demystifying the environmental sustainability of food production. *Proc Cornell Nutrition Conf,* 2009.
4. Capper JL, Cady RA, Bauman DE: The environmental impact of dairy production: 1944 compared with 2007. *J Anim Sci* 87:2160-2167, 2009.
5. Capper JL, Castañeda-Gutiérrez E, Cady RA, Bauman DE: The environmental impact of recombinant bovine somatotropin (rbST) use in dairy production. *Proc Natl Acad Sci USA* 105:9668-9673, 2008.
6. Chianese DS, Harrison JO, Lester JC: Anaerobic digesters: Benefits, barriers, and policy implications
7. Congress of the United States: *The Potential for Carbon Sequestration in the United States.* Washington, DC, Congress of the United States Congressional Budget Office, 2007.
8. de Boer IJM: Environmental impact assessment of conventional and organic milk production. *Livest Prod Sci* 80:69–77, 2003.
9. Food and Agriculture Organization: *FAOSTAT* http://faostat.fao.org/ Date accessed: September 2009.
10. Johansson DJA, Azar C: A scenario based analysis of land competition between food and bioenergy production in the US. *Clim Change* 82:267-291, 2007.
11. Johnson KA, Johnson DE: Methane emissions from cattle. *J Anim Sci* 73:2483-2492, 1995.
12. Keyzer MA, Merbis MD, Pavel IFPW, van Wesenbeeck CFA: Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? *Ecol Econ* 55:187-202, 2005.
13. Kolver ES: Nutritional limitations to increased production on pasture-based systems. *Proc Nutr Soc* 62:291–300, 2003.
14. Koneswaran G, Nierenberg D: Global farm animal production and global warming: impacting and mitigating climate change. *Environ Health Perspect* 116:578-582, 2008.
15. LIC: *New Zealand Dairy Statistics 2007-08.* Hamilton, New Zealand, LIC, 2008.
16. McMichael AJ, Powles JD, Butler CD, Uauy R: Food, livestock production, energy, climate change, and health. *Lancet* 370:1253-1263, 2007.
17. Millward DJ, Garnett T: Food and the planet: nutritional dilemmas of greenhouse gas emission reductions through reduced intakes of meat and dairy foods. *Proc Nutr Soc* 69:103-118, 2010.
18. Moses V: Biotechnology products and European consumers. *Biotechnol Adv* 17:647-678, 1999.
19. NRC: *Nutrient Requirements of Beef Cattle,* ed 7. Washington, DC, National Academy Press, 2000.
20. Pinares-Patiño CS, Waghorn GC, Hegarty RS, Hoskin SO: Effects of intensification of pastoral farming on greenhouse gas emissions in New Zealand. *NZ Vet J* 57:252-261, 2009.
21. Pitesky ME, Stackhouse KR, Mitloehner FM: Clearing the air: livestock's contribution to climate change. *Advances in Agronomy* 103:3-40, 2009.
22. Pollan M: *The Omnivore's Dilemma.* The Penguin Group, 2007.
23. Post WM, Kwon KC: Soil carbon sequestration and land-use change: processes and potential. *Global Change Biol* 6:317-328, 2000.
24. Rosegrant MW, Ringler C: Impact on food security and rural development of transferring water out of agriculture. *Water Policy* 1:567-586, 1998.
25. Sampson RN, Hair D: *Forests and Global Change.* Washington, DC, American Forests, 1996.
26. Sato K, Bartlett PC, Erskine RJ, Kaneene JB: A comparison of production and management between Wisconsin organic and conventional dairy herds. *Livest Prod Sci* 93:105-115, 2005.
27. Sawyer D: Climate change, biofuels and eco-social impacts in the Brazilian Amazon and Cerrado. *Philos T Roy Soc B* 363:1747-1752, 2008.
28. Schlesinger WH: Carbon sequestration in soils: some cautions amidst optimism. *Agric Ecosyst Environ* 82:121-127, 2000.
29. Smith WB, Miles PD, Vissage JS, Pugh SA: *Forest Resources of the United States, 2002.* Washington, DC, USDA Forest Service, 2005.
30. Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan: *Livestock's Long Shadow - Environmental Issues and Options.* Rome, Food and Agriculture Organization of the United Nations, 2006.
31. The AgSTAR Program: *AgSTAR Handbook,* ed 2. Washington, DC, EPA, 2007.
32. The AgSTAR Program. *Guide to Anaerobic Digesters,* Washington, DC, EPA, http://www.epa.gov/agstar/operational.html Date accessed: March 2010.
33. The Humane Society of the United States: *An HSUS Report: The Impact of Animal Agriculture on Global Warming and Climate Change.* Washington, DC, HSUS, 2008.
34. Thomassen MA, van Calker KJ, Smits MCJ, Iepema GL, de Boer IJM: Life cycle assessment of conventional and organic milk production in the Netherlands. *Agricultural Systems* 96:95-107, 2008.
35. Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S: Agricultural sustainability and intensive production practices. *Nature* 418:671-677, 2002.
36. U.S. Census Bureau. *Total Midyear Population for the World: 1950-2050.* http://www.census.gov/ipc/www/idb/worldpop.html Date accessed: July 2009.
37. U.S. EPA: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007.* Washington, DC, U.S. EPA, 2009.
38. U.S. EPA: *What is Sustainability?* http://www.epa.gov/Sustainability/basicinfo.htm Date accessed: March 2010.
39. USDA: *Major Land Uses in the United States, 2002 (EIB-14).* Washington, DC, USDA, Economic Research Service, 2002.
40. Voelker D: *History of Dairy Recordkeeping.* Iowa, The National Dairy Database, 1992.
41. Wilcock A, Pun M, Khanona J, Aung M: Consumer attitudes, knowledge and behaviour: a review of food safety issues. *Trends Food Sci Technol* 15:56-66, 2004.