

Increased production reduces the dairy industry's environmental impact*

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Introduction

All food production systems have an impact upon the environment, regardless of how and where the food is produced. The effects that agricultural practices have upon environmental parameters are increasingly well-known, not only to the global and national industries, but also to policy-makers and consumers. Increased public awareness of these issues underlines the critical need to adopt dairy production systems that reduce the environmental impact of agricultural production. This may be achieved through the use of management practices and technologies that encourage conservation and environmental stewardship at the farm-level, as well as improving processing and transportation operations to reduce the eventual environmental and economic cost to the consumer. In the following sections we discuss the potential for improved production to act as a tool to mitigate the environmental impact of dairy production.

Why is dairy production important?

Globally, animal agriculture is estimated to contribute approximately 18% of total greenhouse gas emissions (Steinfeld et al., 2006) and the dairy industry is therefore often targeted as being particularly detrimental to the environment. Nonetheless, in the context of the US greenhouse gas (GHG) emissions, the Environmental Protection Agency (2008) estimates that all agricultural practices (crops, animals, horticulture etc) only contribute 6% of national GHG emissions, and that dairy production only comprises 11% of the animal agriculture portion. Thus, dairy production in the US accounts for approximately 0.7% of annual GHG production. Nevertheless, adopting practices and management techniques that reduce the environmental impact of dairy production demonstrate the industry's commitment to stewardship and conservation while having a small, yet significant mitigating effect.

The US population currently stands at approximately 300 million people, and the US Census Bureau (2000) predicts that it will plateau in 2040 at an estimated 377 million. However, given the finite resources available, the food supply required to sustain an increased population can only be achieved through the use of efficient, high-yielding systems. There is also an increasing awareness of the importance of dairy products as an invaluable source of essential nutrients and bioactive components that are beneficial in maintaining health and preventing chronic disease. This is underlined by the most recent "Dietary Guidelines for Americans", which recommended a daily intake of three 8-oz glasses of milk or their low-fat dairy product equivalents (USDA, 2005). This level of dairy intake is not yet being achieved within the US (USDA/ERS, 2008),

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but, projecting forwards to the year 2040, it would require an extra 23.7 million kg of milk to be produced annually to fulfill dietary recommendations (Capper et al., 2008).

A common misconception is that processing and transportation are the biggest contributors to the environmental impact of dairy production, hence the consumer interest in buying locally-produced food to reduce ‘food miles’. This has been disproved by a number of life cycle assessment (LCA) studies that evaluated the effects of agricultural production upon the environment by examining the entire production process from farm to consumer. Saunders et al. (2006) and Saunders and Barber (2007) concluded that lamb, apples and milk solids produced in New Zealand and exported to the UK had a lower carbon footprint than equivalent food produced and consumed in the UK. In a LCA of semi-hard cheese, Berlin (2002) concluded that 95% of the carbon footprint and 80% of fossil fuel and electricity use involved with cheese production occurs during primary on-farm production; similar results were also reported by Høgaas Eide (2002) in an LCA of fluid milk production. Improving producer-level efficiency therefore provides a significant opportunity to reduce whole system environmental impact.

Productive efficiency and the ‘dilution of maintenance’ effect

The idea of ‘efficiency’ has been somewhat fluid over the years; indeed, the cover of a Cornell University Extension Bulletin from 1953 entitled ‘Feeding the Dairy Cow Efficiently’ depicts a herd of Ayrshire cows placidly wading through a stream – a practice that would certainly incur the wrath of modern environmental agencies. Nonetheless, the idea that dairy production could be made more effective by improving productive efficiency, defined as ‘milk output per unit of resource input’, is not a new concept. A statement by J. C. McDowell (1927) in the 1927 edition of the US Yearbook of Agriculture reads as follows:

“When the population of this country increases to 200,000,000 it should be easily possible for the additional supply of dairy products needed to be produced not by more, but by better dairy cows... The average milk production of US cows is about 4,500 pounds a year. If this were increased at a rate of 100 pounds a year, in 45 years the average milk production per cow would be doubled. The present number of cows could then supply sufficient dairy products at the present rate of consumption for considerably more than 200,000,000 people.”

This is precisely the mechanism by which improving the productive efficiency of the dairy herd can mitigate environmental impact. Producing more milk from the same quantity of resources (or the same amount of milk with fewer resources) reduces the demand for non-renewable or energy-intensive inputs (including land, water, fossil fuels and fertilizers) and promotes environmental stewardship.

The biological process underlying improved productive efficiency is known as the ‘dilution of maintenance’ effect (Bauman et al., 1985). The daily nutrient requirement of all animals within the dairy herd comprises a specific quantity needed to maintain the animals’ vital functions (the maintenance requirement) plus extra nutrients to support the cost of growth, reproduction or lactation. As shown in Figure 1, the maintenance energy requirement of a 650 kg lactating cow

does not change as a function of production but remains constant at 10.3 Mcal/d. However, the daily energy requirement increases as milk yield increases, thereby reducing the proportion of total energy used for maintenance. A high-producing dairy cow requires more nutrients per day than a low-producing dairy cow, but all nutrients within the extra feed consumed are used for milk production. The total energy requirement per kg of milk produced is therefore reduced: a cow producing 7 kg/d requires 2.2 Mcal/kg milk, whereas a cow yielding 29 kg/d needs only 1.1 Mcal/kg milk. This is often wrongly referred to as an improvement in feed efficiency, the confusion arising because although the total nutrient requirement/kg milk produced is reduced, the amount of nutrients required to support each incremental increase in milk yield is not altered and the animal's basal maintenance nutrient requirement does not change. "Dilution of maintenance" comparison thus represents an effective proof of the 'productive efficiency' concept, i.e. 'making more with less'.

At first glance, the above concept seems counterintuitive: if high-producing cows are eating more feed, they are consuming more resources and emitting more waste products, all of which are environmental concerns. This is a message that is often propounded by the anti-animal agriculture groups, but it is both misleading and inaccurate. Accurate and complete evaluation of the environmental effects of dairy production necessitates a paradigm shift. The majority of studies to date have examined the resource input and waste output for an individual cow and multiplied this figure by the number of animals within the herd or national population to estimate the system impact. This method only examines one aspect of the milk production process, i.e. the lactating cow, ignoring the resources required to support the entire dairy population (lactating cows plus associated dry cows, heifer replacements and bulls) required to maintain the milk production infrastructure. Alternatively, data have been presented according to land use, e.g. per acre or hectare. The major flaw of this basis of expression is that environmental impact thus varies according to stocking rate, with extensive systems appearing to be superior to their intensive counterparts, regardless of the total amount of land required for food production. The ultimate purpose of the dairy industry is to produce sufficient milk to supply human population requirements; therefore, environmental impact must be assessed on an outcome basis per unit of food produced, i.e. per kg of milk, cheese or butter. This methodology allows valid comparisons to be made between different production systems and also relates milk production to demand, facilitating accurate evaluation of the resources required to fulfill human food requirements. Utilizing values from Figure 1, one can calculate that to produce a set amount of milk, e.g. 29,000 kg/d, would require 4,143 low-producing cows (7 kg/d), but only 1,000 high-producing cows (29 kg/d). When the remainder of the dairy population is taken into account, it can be seen that the dilution of maintenance effect not only reduces the number of milking cows required, but also decreases the associated dry cows, heifers and bulls within the population and the resources required to maintain that population.

Productive efficiency – the historical example

The dairy industry has made huge advances in efficiency over the past 60 years. According to USDA data, in 1944, the year when dairy cow numbers peaked at 25.6 million head, total milk production was 53 billion kg (Figure 2; http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/). By contrast, the 2007 US dairy

herd comprised 9.2 million animals, producing a total of 84 billion kg of milk. This is equivalent to a four-fold increase in the annual milk yield per cow, progressing from 2,074 kg/cow in 1944 to 9,193 kg/cow in 2007. This improvement has been achieved through the introduction of production and management practices that maximize potential yields while emphasizing cow health and welfare. For example, widespread adoption of genetic evaluation and artificial insemination in the late 1960's allowed producers to select the highest-yielding animals and improve the genetic merit of their current and future herd. These technologies have conferred approximately > 55% of the annual yield increase since 1980 (Shook, 2006). Improved knowledge of the nutrient requirements and metabolism of the dairy cow and formulation of diets to meet these requirements has been of particular significance in allowing the cow to reach her genetic potential. More recently, use of diet formulation software and total mixed rations have further facilitated feeding a diet balanced according to milk production and nutrient needs. Progress has also occurred as a result of better milking management systems and mastitis control, implementation of herd health programs, improved cow comfort (including housing and heat stress abatement) and the use of biotechnologies and feed additives that maximize milk production.

A common perception is that historical methods of food production were inherently more environmentally-friendly than modern agricultural practices. This is often reinforced by the media portrayal of rustic pastoral scenes as the 'good old days' compared to today's vision of a 'factory farm'. The carbon footprint of dairy production in 1944 compared to 2007 is shown in Figure 3. The left-hand bars are quantified according to the process basis, i.e. per cow, and, as expected, low-producing cows characteristic of the 1944 dairy system had a lower carbon footprint than high-producing modern cows. However, the advantage conferred by improved productive efficiency of modern milk production systems is clearly demonstrated when the data are expressed on an outcome basis: from 1944 to 2007 there has been a 63% reduction in the carbon footprint per kg of milk. Interestingly, many of the characteristics of 1940's dairy production (low-yielding, pasture-based, no antibiotics, inorganic fertilizers or chemical pesticides) are similar to those of modern organic systems. Indeed, studies investigating the environmental impact of organic systems have also described increases in the quantity of resources required and carbon footprint per kg of milk compared to conventional production (de Boer, 2003; Williams et al., 2006; Capper et al., 2008).

Productive efficiency – the technology example

Dairy producers are being encouraged to adopt management practices that facilitate improved environmental stewardship and conservation at all stages of the milk production process. These include initiatives to cut GHG emissions through reducing enteric methane production (Anderson et al., 2003), minimizing nutrient run-off by effective ration balancing and optimizing fertilizer application (James et al., 1999; Rotz, 2004; Dittert et al., 2005), and harnessing the potential for methane generated from waste to be converted for on-farm energy use (Cantrell et al., 2008). No single management practice has the ability to negate the environmental impact of dairy production, although considerable improvements may be made following the adoption of several co-existing strategies. Nonetheless, the most impactful mitigation effect may be achieved by employing technologies and practices that improve productive efficiency.

Consumers often have a negative image of technology within agriculture, regarding genetic modification, antibiotics and hormone use as threats to human or animal health despite assurances from reputable health organizations and government agencies. The introduction of artificial insemination was a case in point, with claims that its use would result in an ‘inferior, decadent, degenerative species’ (of cow) and that milk was unsuitable for human consumption (Tobe, 1967). Nonetheless, the use of agricultural technologies provides an invaluable opportunity to improve production, with concurrent effects upon environmental impact. For example, widespread adoption of genetically modified Bt-corn has significantly increased US corn yields (NCFAP, 2008) and the introduction of herbicide-resistant soybeans has not only improved yields, but also facilitated the use of no-till practices, thus reducing soil erosion, carbon loss and fossil fuel use (Hobbs et al., 2007).

Recombinant bovine somatotropin (rbST) has arguably provided the greatest technological contribution to improved dairy productivity since its approval by the FDA in 1994. The milk yield response to rbST supplementation is well-documented, and its potential as a tool to improve productive efficiency and thus reduce the environmental impact of dairy production has been noted in previous government and academy reports (NRC, 1994; The Executive Branch of the Federal Government, 1994; U.S. EPA, 1999) and scientific publications (Bauman, 1992; Johnson et al., 1992; Dunlap et al., 2000; Jonker et al., 2002; Bosch et al., 2006). Nonetheless, the environmental impact of rbST use in dairy production has not previously been evaluated through full, science-based lifecycle assessment. We developed a stochastic model based on the NRC (NRC, 2001) nutrient requirements of dairy cows and used this to determine the annual resources required and waste produced from a population containing one million eligible cows supplemented with rbST, compared to equivalent production from unsupplemented cows. All data within the model were collected from published scientific studies or governmental reports, with no undocumented assumptions. Rations were formulated for average US cows (Holstein, 650 kg body weight) producing 28.9 kg milk/d at 3.69% fat and 3.05 % protein (USDA/AMS, 2007). The response to rbST supplementation was 4.5 kg/d. The dairy population dynamics were based on characteristic US practices as documented in the NAHMS report (USDA, 2007). Full details of the materials and methods associated with the study are published in Capper et al (2008).

The environmental impact of rbST use in one million cows is shown in Table 1. Annual milk production from the rbST-supplemented population (2.51 million animals in total) was 14.1 billion kg; however, to produce the same amount of milk from an unsupplemented population would require an extra 157,000 milking cows and 177,000 associated dry cows and heifers. The rbST-supplemented population therefore requires fewer resources, including 2.3 million metric tonnes less feedstuffs, 540,000 less acres of land used for crop production (with concurrent reductions in soil erosion) and considerable savings in fertilizers and pesticides. Reducing resource input per kg of milk demonstrates the improved productive efficiency conferred by rbST use, and also has beneficial environmental effects. Using a smaller population to maintain an equivalent milk production decreases total manure production, thus releasing less methane and nitrous oxide (two extremely potent GHG) into the atmosphere. As noted by Jonker et al. (2002) and Dunlap et al. (2000), decreasing population manure production via rbST use reduces potential nutrient (N and P) flows into groundwater.

Consumption of non-renewable energy sources is a significant issue within dairy production as fossil fuel combustion not only depletes existing deposits, but also increases the industry's carbon footprint. By improving productive efficiency, rbST-supplementation of one million cows reduces annual fossil fuel and electricity use by 729 million MJ and 156 million kWh, respectively; equivalent to heating ~16,000 and powering ~15,000 homes (EIA, 2001). Furthermore, the amount of water saved by rbST use is equivalent to the annual amount required to supply ~10,000 homes - a considerable environmental benefit in areas where water consumption is a significant concern. Finally, the carbon footprint of the population supplemented with rbST is reduced by 1.9 billion kg/y; this is equivalent to removing ~400,000 cars from the road or planting ~300 million trees. A population containing one million rbST-supplemented cows is equivalent to ~15% of the current US dairy herd; therefore the potential for widespread rbST use to mitigate the environmental impact of dairy production should not be underestimated.

Further advances and possibilities for environmental mitigation

Mitigating the environmental impact of dairy production is not an issue that is going to disappear; indeed, it is gathering momentum and is likely to be supported by additional legislation and certification requirements for the dairy industry. It is therefore essential for dairy producers to identify opportunities to adapt or adopt management practices that promote environmental stewardship and resource conservation. At present, rbST is the only technology that has the potential to singly reduce total environmental impact by 9%; however, the implementation of strategic environmental planning that includes a variety of mitigation practices allows the producer to make decisions and combine practices according to both environmental and economic indices. Previous studies have evaluated the effects of milking frequency, ration formulation, photoperiod and reproductive management (Dunlap et al., 2000; Jonker et al., 2002; Garnsworthy, 2004; Bosch et al., 2006); while these evaluations provide insight, they focused on single environmental parameters (e.g. N or methane) and did not use the LCA approach. A more complete evaluation of the environmental impact of specific management factors that are under producer control, including calving interval, age at first calving, use of artificial insemination and somatic cell count, is the focus of current investigation by our group. Quantification of the environmental impact of single or combined management practices will therefore allow producers to make informed decisions as to whether to invest in, for example, a methane digester, a herd health program or embryo transfer.

Under normal market conditions, improving productive efficiency has a tangible economic benefit, but this also raises the question of how producers will assess the commercial value of environmental impact mitigation. Introduction of carbon credits or a cap and trade system would necessitate quantification of the impact of different management practices so to provide compensation for their implementation. Furthermore, discussion would be necessary as to the allocation of carbon credits between the dairy and beef industry, and adjustments made for the

carbon credits earned by the dairy industry when by-products from the human food and fiber industries are utilized as feed and converted to high-quality dairy products.

Conclusion

Dairy producers have made vast gains in productive efficiency over the past 60 years and should continue to do so, but only if the technologies and practices that improve productive efficiency continue to be available for use. It is thus essential to educate consumers, retailers, processors and policy-makers of the vital importance of scientific evaluation based on efficacy, human/animal safety and environmental analysis rather than misplaced ideological or anthropomorphic concerns. A scientific evaluation of the environmental component may be achieved through quantifying the impact on a system basis, incorporating the resources required and waste produced from the entire dairy population and expressing results per unit of milk produced. Such evaluation facilitates true consumer choice and avoids perpetration of non-scientific or flawed claims relating to the nutritional or environmental advantages of alternative systems.

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Table 1. Annual resource inputs and waste output from a population containing one million rbST-supplemented dairy cows^a compared to equivalent milk from an unsupplemented population (adapted from Capper et al., 2008)

	Without rbST	With rbST	Reduction with rbST use
Production Parameters			
Milk production (kg/y x 10 ⁹)	14.1	14.1	
Number of lactating cows (x 10 ³)	1,338	1,180	157
Number of dry cows (x 10 ³)	217	192	25
Number of heifers (x 10 ³)	1,291	1,139	152
Nutrient requirements			
Maintenance energy requirement ^b (MJ/y x 10 ⁹)	54.1	47.8	6.3
Maintenance protein requirement ^b (t/y x 10 ³)	667	606	61
Feedstuffs (t freshweight/y x 10 ⁶)	25.9	23.7	2.3
Waste output			
Nitrogen excretion (t/y x 10 ³)	100	91	9.6
Phosphorus excretion (t/y x 10 ³)	45.7	41.4	4.3
Manure, freshweight (t/y x 10 ⁶)	34.9	32.2	2.8
Gas emissions			
Methane ^c (kg/y x 10 ⁶)	495	454	41
Nitrous oxide (kg/y x 10 ³)	100	91	9.6
Total carbon footprint ^d (kg CO ₂ /y x 10 ⁹)	21.6	19.7	1.9
Cropping inputs			
Cropping land required (ha x 10 ³)	2,712	2,493	219
Nitrogen fertilizer (kg/y x 10 ⁶)	101	92	8.6
Fossil fuels ^e (MJ/y x 10 ⁶)	8,840	8,111	9.9
Resource use			
Electricity (kWh/y x 10 ⁶)	1,350	1,195	156
Water (l/y x 10 ⁹)	66.9	61.5	5.4

^a One million lactating cows supplemented with rbST plus associated ineligible lactating cows, dry cows and replacement heifers.

^b Refers to nutrients required for maintenance (all animals), pregnancy (dry cows) and growth (heifers).

^c Includes CH₄ from enteric fermentation and manure fermentation.

^d Includes CO₂ emissions from animals and cropping, plus CO₂ equivalents from CH₄ and N₂O.

^e Only includes fuel used for cropping.

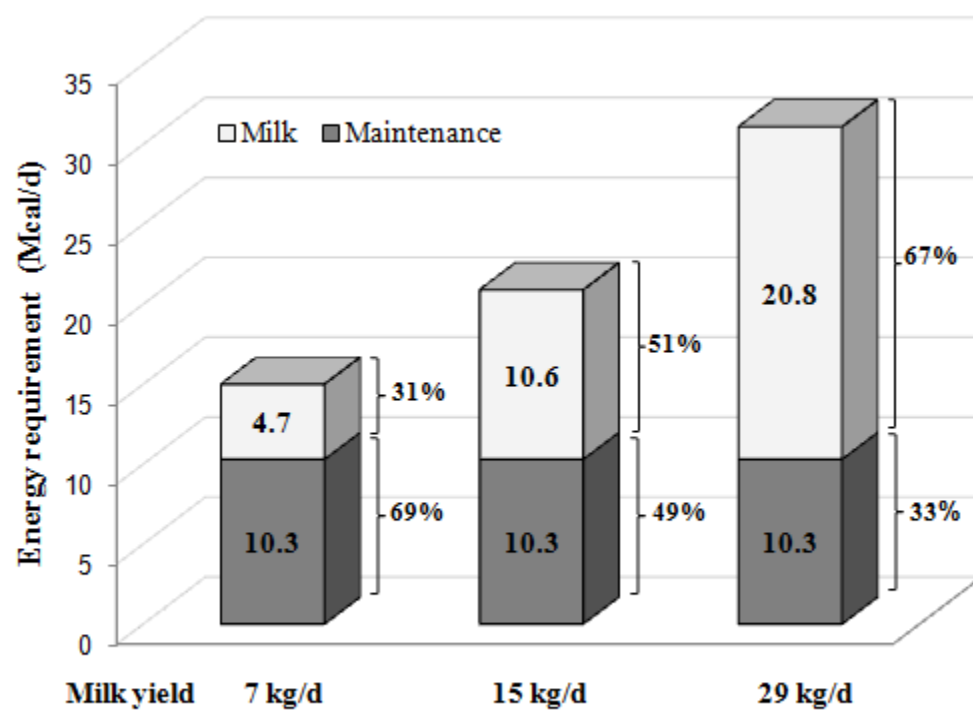


Figure 1. The 'dilution of maintenance' effect

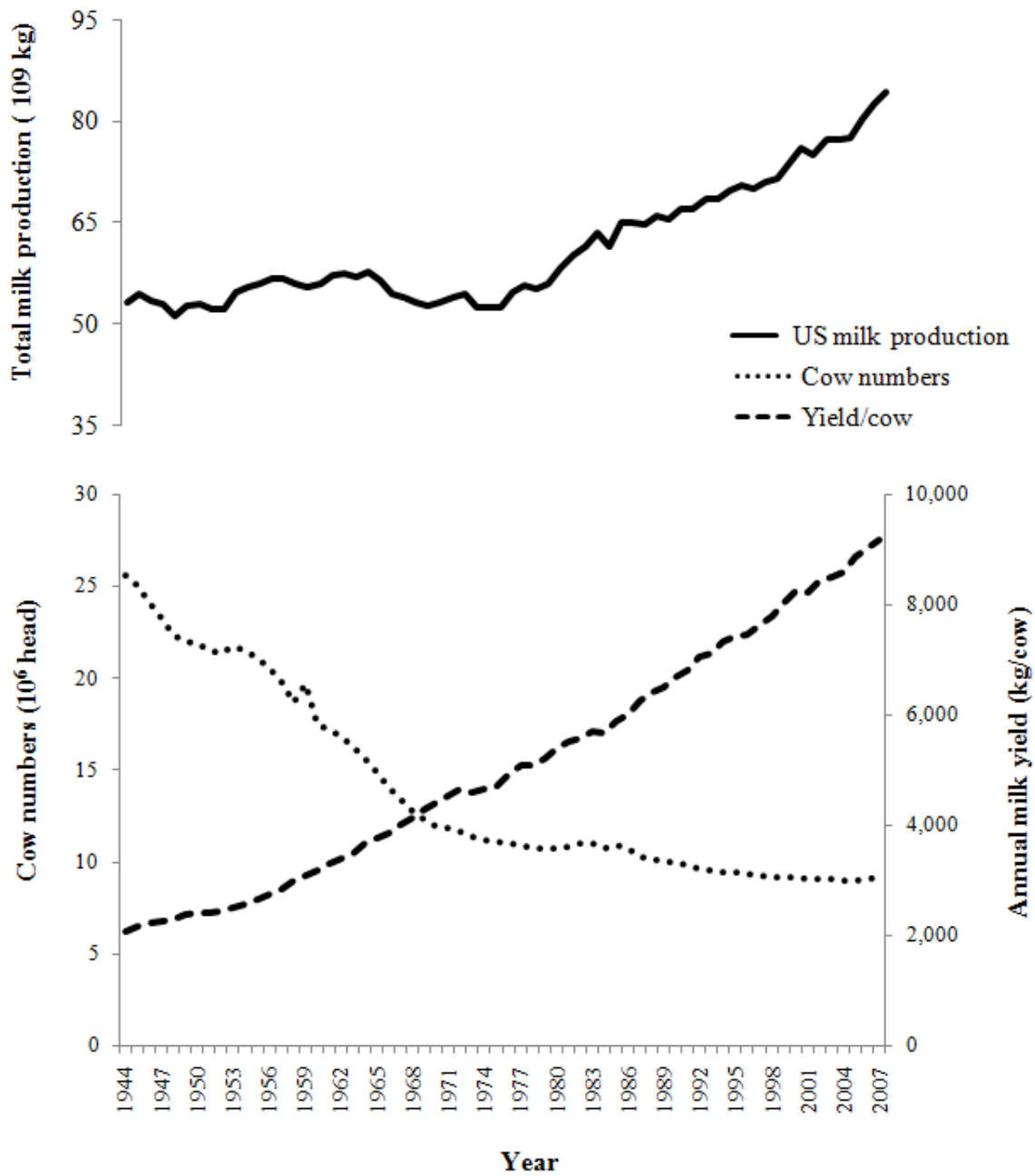


Figure 2. Changes in total US milk production, cow numbers and individual cow milk yield between 1944 and 2007

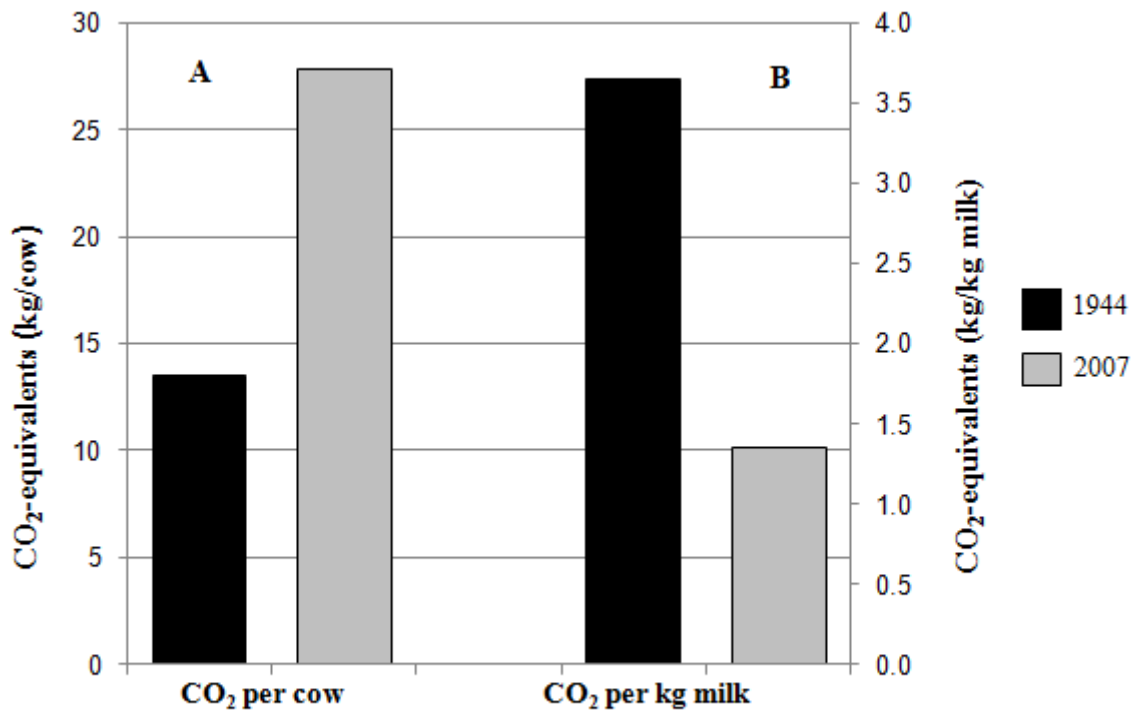


Figure 3. Carbon footprint per cow and per kg milk for 1944 and 2007 US dairy production systems