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**The environmental impact of dairy production: 1944 compared with 2007<sup>1</sup>**

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**ABSTRACT:** A common perception is that pasture-based, low-input dairy systems characteristic of the 1940s were more conducive to environmental stewardship than modern milk production systems. The objective of this study was to compare the environmental impact of modern (2007) U.S. dairy production with historical production practices as exemplified by the U.S. dairy system in 1944. A deterministic model based on the metabolism and nutrient requirements of the dairy herd was used to estimate resource inputs and waste outputs per billion kg of milk. Both the modern and historical production systems were modeled using characteristic management practices, herd population dynamics and production data from U.S. dairy farms. Modern dairy practices require considerably fewer resources than dairying in 1944 with 21% of animals, 23% of feedstuffs, 35% of the water and only 10% of the land required to produce the same one billion kg of milk. Waste outputs were similarly reduced, with modern dairy systems producing 24% of the manure, 43% CH<sub>4</sub> and 56% N<sub>2</sub>O per billion kg of milk compared to equivalent milk from historical dairying. The carbon footprint per billion kg of milk produced in 2007 was 37% of equivalent milk production in 1944. To fulfill the increasing U.S. population's requirement for dairy products it is essential to adopt management practices and technologies that improve productive efficiency allowing milk production to be increased while reducing resource use and mitigating environmental impact.

**Key words:** carbon footprint, dairy, dilution of maintenance, environmental impact, greenhouse gas, productive efficiency,

## INTRODUCTION

Environmental considerations are receiving increasing priority upon political, social and economic agendas, especially when related to agriculture. All food production has an environmental impact and as the U.S. and global populations continue to increase, it is critical to produce sufficient high-quality food from a finite resource supply while minimizing effects upon the environment. Agricultural practices have changed considerably over the past century: dairy production in the 1930-40's was characterized by pasture-based, low-input systems with correspondingly low milk production, providing a sharp contrast to modern high-input:high-output systems (Meigs, 1939; VandeHaar and St-Pierre, 2006). To achieve an economically and environmentally sustainable food supply, agriculturalists need to identify systems and practices that make the best use of available resources and minimize the potential environmental impact (Capper et al., 2008). However, a common perception is that historical methods of food production were inherently more environmentally-friendly than modern agricultural practices. This is often reinforced by media portrayal of rustic pastoral scenes as the "good old days" compared to today's perception of "factory farming." We used a deterministic model (Capper et al., 2008) based on NRC (2001) nutrient requirements to evaluate the environmental impact of historical U.S. milk production as exemplified by the U.S. dairy system in 1944, compared to modern (2007) practices.

## MATERIALS AND METHODS

Dairy systems were modeled according to characteristic production practices of U.S. dairy farms for the two time-points according to published production data, with system inputs, population dynamics and procedures as previously described in Capper et al. (2008), save for the amendments listed below. The system characteristics for each year are summarized in Table 1.

### *2007 Dairy Population Characteristics*

The 2007 dairy system was modeled according to characteristic production practices of U.S. dairy farms (USDA, 2007) with the total environmental impact based on national milk production and animal numbers ([www.nass.usda.gov/QuickStats](http://www.nass.usda.gov/QuickStats)). The 2007 annual milk yield averaged 9,193 kg per cow, which is equivalent to 29.3 kg/d when adjusted for a 14-mo calving interval (426 d) and a 60 d dry period (USDA, 2007). Milk fat (3.69%) and true protein (3.05%) concentrations represented U.S. averages for 2007 (USDA/AMS, 2007). The current U.S. dairy herd is predominantly Holstein, with AI accounting for 70% of successful conceptions (De Vries et al., 2008); therefore sufficient bulls were included in the population to represent 30% of conceptions at a bull:cow ratio of 1:25 (Overton, 2005). No published nutrient requirements are specific to mature dairy bulls; therefore rations for bulls were based on National Research Council (NRC, 2001) recommendations for non-pregnant, non-lactating cows at 45 mo of age and 825 kg BW weight. Replacement adolescent bulls were included in the population at an ratio of 0.83 replacements for each adult bull, and rations formulated according to the nutrient

requirements for 352 kg, the median weight for adolescent bulls with a growth rate of 880 g/d (NRC, 2001). Corn silage, alfalfa hay, dry ground corn grain and soybean meal were identified by Mowrey and Spain (1999) as the major feedstuffs used in dairy production and were thus used to formulate rations, with grass hay added to dry cow and bull diets to achieve balanced diets. Emissions of CH<sub>4</sub> from stored manure were calculated according to the Intergovernmental Panel on Climate Change (IPCC, 2006) based on the quantity of volatile solids excreted, maximum CH<sub>4</sub>-producing potential (0.24 cubic m per kg of volatile solids) and a CH<sub>4</sub> emission factor of 21.7% for liquid storage as reported by the U.S. Environmental Protection Agency (U.S. EPA, 2007). Manure N<sub>2</sub>O was calculated according to IPCC (2006) emission factors for manure stored in liquid systems before spreading on cropland. Losses of N<sub>2</sub>O from fertilizer application were also calculated according to IPCC (2006) guidelines using the most recent USDA-published application rates for corn (USDA/NASS, 2006) and soybeans (USDA/NASS, 2007), and estimates for alfalfa (Pimentel and Pimentel, 1996).

### ***1944 Dairy Population Characteristics***

Production practices and characteristics used within the 1944 dairy model were determined and validated by examination of scientific literature from 1935-1955. Additional sources included the annual USDA Yearbook of Agriculture series and extension bulletins from Cornell University and the Universities of Missouri, Minnesota and Wisconsin (1940-1950). Modeling procedures were as previously described in Capper et al. (2008) with inputs adjusted for characteristics of 1944 production systems. The dairy cow population in 1944 comprised 54% small breeds (Jersey, Guernsey, Ayrshire) and 46% large breeds (Holstein, Brown Swiss)

[http://www.agnr.umd.edu/DairyKnowledge/dairy/status\\_of\\_United\\_States\\_dairy\\_cattle.html](http://www.agnr.umd.edu/DairyKnowledge/dairy/status_of_United_States_dairy_cattle.html)).

Two sub-models based on milk yield and nutrient requirements for small or large breeds were therefore employed to estimate the environmental impact of the two groups, with the population results weighted accordingly for the proportion of each group within the total U.S. herd. The average U.S. milk yield/cow in 1944 was 2,074 kg/y ([www.nass.usda.gov/QuickStats](http://www.nass.usda.gov/QuickStats)); adjusted for a 14-mo calving interval (426 d) and a 60 d dry period (VanDemark and Salisbury, 1950), this was equivalent to 5.6 kg/d for small breeds and 7.8 kg/d for large breeds according to the Jersey-Holstein differential reported by Copeland (1939). Milk composition was characteristic of the breeds used, at 4.20% fat and 3.60% protein for small breeds, and 3.50% fat and 3.20% protein for large breeds (Davis et al., 1947). Lactating and dry cows averaged 45 mo of age, with bodyweights of 439 kg (small breeds) or 610 kg (large breeds) (Davis et al., 1943). Rations were formulated for replacement heifers at a median weight of 187 kg (small) or 255 kg (large) BW and with growth rates of 416 g/d and 589 g/d for small and large breeds, respectively (Plum and Lush, 1934; Seath, 1940; Nevens, 1944). The number of heifers within the population were calculated using the existing model (Capper et al., 2008), modified for a 27 mo age at first calving (Bayley and Heizer, 1952), to give an ratio of 0.89 heifers/cow. Use of AI was rare in 1944, so all pregnancies were assumed to result from natural service. Bulls were therefore added to the population model at a ratio of one bull per 25 cows (Overton, 2005), with rations formulated (NRC, 2001) for 557 kg (small) and 774 kg (large) bulls at 45 mo of age. Adolescent replacement bulls were included in the population at a ratio of 0.89 replacements per adult bull, with rations formulated to fulfill nutrient requirements for small (238 kg BW, 594 g/d growth rate) and large (330 kg BW, 826 g/d growth rate) breeds. Pasture was the predominant forage source on dairy farms in the 1940's; therefore diets were formulated based on 40% of daily DMI

from grass and the remainder from grass hay, corn and soybean meal (Crandell and Turk, 1945). The nutrient composition of fresh pasture and hay was adjusted to reflect grass species of the time (Archibald et al., 1946), with reduced ME (7.5 MJ/kg DM for grass, 6.9 MJ/kg DM for hay) and CP (9.7% of DM for grass, 8.1% of DM for hay), and a digestibility coefficient of 55% for pasture (AFRC, 1996). Manure output was calculated according to diet digestibility, with a 15% dry matter content (Dado and Allen, 1995). Emissions of CH<sub>4</sub> and N<sub>2</sub>O from manure were estimated as per the 2007 system using CH<sub>4</sub> emission factors of 1.5% (pasture) and 4.0% (solid storage), and N<sub>2</sub>O emission factors of 0.02 kg N<sub>2</sub>O-N/kg for direct deposition onto pasture during grazing (IPCC, 2006). The model did not include N<sub>2</sub>O emissions from inorganic fertilizers as these were not widely used in U.S. agriculture until the late 1940's when ammonia synthesis technologies developed for ammunition production in World War II were adapted for agricultural chemical production (Smil, 2001).

## *Cropland Characteristics*

Cropland requirements for both models were calculated using average U.S. crop yields for 1944 (USDA/NASS, 2003) and 2007 ([www.nass.usda.gov](http://www.nass.usda.gov)). Pasture-based U.S. dairy production systems originally served to utilize land that was unsuitable for crop production due to characteristics such as unfavorable topography or soil type (Cardon et al., 1939). The majority of grazed and hayed grassland therefore functioned as permanent pasture, and there was no significant inflow of pasture or cropland into the system during the decade prior to 1944 (Cardon et al., 1939). For the purposes of this study, all pasture was considered to be permanent, i.e. present as pasture and undisturbed by tillage for >25 years. In contrast to land recently converted from cropland to pasture, mature temperate pasture subject to biomass removal by grazing/haying (Skinner, 2008) or burning (Sukyer and Verma, 2001) is considered to have a net carbon balance close to zero. Conservation tillage systems were not widely practiced in the U.S. until the mid-seventies; conventional (i.e. inversion) tillage was used for crop production in 1944 and this practice was assumed to been in place for >25 years. Sequestration factors of zero for both pasture and cropland were therefore employed in the 1944 model, with appropriate multiplication factors to correct for manure inputs (IPCC, 2006). Crop management practices have undergone major changes over the past 30 years, with increases in the quantity of land managed under conservation or no-till systems (Hobbs et al., 2007). Sequestration is a dynamic process following a logarithmic decay curve; therefore quantifying the potential for changes in tillage practice at a particular point in time (i.e. 2007) is beyond the scope of this paper. However, it should be noted that by not including the carbon sequestration contributions made by conservation and the transition to no-till practices within modern production, the total carbon

footprint for 2007 is overestimated. Within both models, water use was estimated only for the dairy population's free water intake estimated according to Holter (1992).

Given the advances in technology and mechanization over the past 60 years and a lack of available data, comparison of fuel requirements between the two systems was not possible. Nonetheless, the change in energy requirements incurred by shifting from draft horse to tractor power in the 1944 system was assessed. Energy requirements for a two-horse team were calculated according to NRC (2007) based on two mature Clydesdale geldings under a moderate workload, each weighing 800 kg and with a daily feed intake equal to 2% of BW. Rations were formulated based on grass hay, rolled barley and rolled oats, and total cropland area calculated according to the average U.S. crop yields from 1944 for each dietary component (USDA/NASS, 2003). Mechanical energy consumption was based on the maximum power take-off speed (29.6 hp) for a John Deere Series A tractor used in the equation developed for use in the Nebraska Tractor Test (Grisso et al., 2004) at average U.S. usage of 434 tractor-hours/year (Hertel and Williamson, 1940) and 34.6 MJ/liter gasoline.

## RESULTS AND DISCUSSION

In 1944, the U.S. dairy population totaled 25.6 million cows producing a total of 53.0 billion kg milk annually (Figure 1; [www.nass.usda.gov/QuickStats](http://www.nass.usda.gov/QuickStats)). Dairy production in 1944 was characterized by pasture-based systems with rations reliant on home-grown forages with few purchased concentrate feeds (Woodward, 1939). Draft horses powered the majority of agronomical operations, with only 1.2 tractors employed per farm (U.S. Census Bureau, 1950). Inorganic fertilizer use was not yet widespread: instead animal manure was used to fulfill crop nutrient requirements (Yeck, 1981; Hoban, 1997). Interestingly, many of these characteristics (low-yielding, pasture-based, no antibiotics, inorganic fertilizers or chemical pesticides) are similar to those of modern organic systems. By contrast, the 2007 U.S. dairy herd comprised only 9.2 million cows, with an annual milk production of 84.2 billion kg (Figure 1). Typical modern dairy production systems are characterized by the use of total mixed rations (TMR) formulated to fulfill nutrient requirements, together with herd health and management programs and facilities designed to minimize stress and maximize production (USDA, 2007). Furthermore, feedstuffs used in modern systems are harvested from high intensity row-crop farming practices.

All food production systems have an environmental impact, which must be assessed according to the output unit of the production system, i.e. kg of milk or loaf of bread. Within the dairy industry, from production through retail sales, the majority (80-95%) of global warming, eutrophication and acidification potentials occur during the on-farm production phase (Berlin, 2002; Høgaas Eide, 2002). Consequently, our production system model includes all primary crop and milk production practices integrated into the process of life cycle assessment (LCA) up through and including milk harvest, and does not include any transportation, processing or sales

system parameters post-milk harvest. Accurate evaluation allows quantification of the impact of technologies and management practices that improve productive efficiency; defined as “units of milk produced per unit of resource input” (Capper et al., 2008). The importance of improving productive efficiency as a foundation to provide sufficient food for the increasing U.S. population was recognized as early as 1927 (McDowell, 1927), however, it was only made possible by specialization and intensification of agricultural production after World War II. Average milk yield per cow in 1944 was 2,074 kg/y, compared to 9,193 kg in 2007. This improvement in productive efficiency facilitates the “dilution of maintenance” effect, by which the total resource cost per unit of milk is reduced (Bauman et al., 1985). The daily nutrient requirement of lactating cows comprises a specific quantity needed to maintain the animals’ vital functions and minimum activities in a thermo-neutral environment (maintenance requirement) plus extra nutrients to support the cost of lactation. As shown in Figure 2, the maintenance energy requirement does not change as a function of production, but the daily energy requirement increases as milk yield increases, thereby reducing the proportion of total energy used for maintenance. 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 (Figure 2).

Improved productive efficiency enables higher milk yields, thus meeting market demand for milk using fewer cows (Capper et al., 2008). Indeed, the dairy population needed to produce one billion kg of milk in 2007 was only 21% of that required in 1944 (Table 2). Genetic improvement has been a major contributor to this increase in productivity. Three factors have played into the genetic change. First, the most common dairy breeds have shifted from the high milk-solids breeds (e.g. Jersey, Guernsey) to the higher-volume producing Holstein cow.

Holstein cows comprised only 39% of the U.S. dairy herd in 1944 ([http://www.agnr.umd.edu/DairyKnowledge/dairy/status\\_of\\_United\\_States\\_dairy\\_cattle.html](http://www.agnr.umd.edu/DairyKnowledge/dairy/status_of_United_States_dairy_cattle.html)) compared to 90% in 2007 (USDA, 2007). Second, AI has been widely adopted since the 1970s (Weimar and Blayney, 1994). Finally, improved genetic evaluation procedures have greatly enhanced the ability to identify and select animals that are genetically superior for milk production. Shook (2006) estimates that of the 3,500 kg increase in lactation yields since 1980, 55% can be attributed to improved genetics. This agrees with published USDA-ARS-AIPL data dating back to 1960 (<http://aipl.arsusda.gov/eval/summary/trend.cfm>). The combined effect of AI adoption and genetic improvement has had a two-fold impact on the number of dairy animals required to produce one billion kg of milk. Increasing milk yields through genetic enhancement reduced the number of cows, and the advent of frozen semen use in AI has severely curtailed the number of bulls, as one sire was able to successfully breed many more cows than a natural service sire. The nutrients required to maintain the dairy population have therefore been reduced. The 1944 production system required 16.7 billion MJ ME and 165 million kg of CP per billion kg of milk produced, whereas the 2007 system required 3.9 billion MJ energy and 48 million kg of CP (Table 2).

The first National Research Council report regarding the nutrient requirements for dairy cows was published in 1945 allowing for considerable improvement in formulating diets targeted to specific animal requirements (NRC, 1945). Furthermore, introduction of ration-formulation software and widespread acceptance of TMR in the 1980s (Weimar and Blayney, 1994) allowed dairy producers to improve nutrient supply from diets and include greater amounts of by-products from human food and fiber industries (Van Horn et al., 1996). The reduction in feedstuff use per billion kg milk in 2007 compared to 1944 not only reflects the reduced

population size but is also a function of the improved nutritive value of feedstuffs fed in modern dairy systems, providing more nutrient-dense rations (Archibald et al., 1946; NRC, 2001). Pasture-based systems employed in 1944 required considerably more land to support the dairy population, both for grazing and production of hay and cereal crops. The recommended stocking rate for lactating dairy cows in the 1940's was one cow/ha (Henderson and Reaves, 1954) compared to 2.3 cows/ha for modern systems (McCall and Clark, 1999), reflecting the lower yield and nutritive value of native grass pastures compared to modern grass species. Furthermore, advances made in crop genetics (e.g. trait selection in hybrid seed, Bt corn, herbicide-resistant soybeans), agronomy (e.g. minimum and no-till systems) and nutrition (e.g. soil testing, application of inorganic fertilizers) between 1944 and 2007 have resulted in a corn grain yield increase from 2,071 kg/ha to 9,484 kg/ha, and a soybean yield increase from 1,264 kg/ha to 2,804 kg/ha ((USDA/NASS, 2003); <http://www.nass.usda.gov>). Improved efficiency of both milk and crop production has therefore reduced the amount of cropland needed to support the production of one billion kg milk to 162,000 ha: 10% of the land required in 1944.

Pasture grass species employed within 1944 dairy production included Kentucky bluegrass, timothy and orchard grass (Cardon et al., 1939), with lower protein contents than modern varieties (Huffman, 1939). Consequently, N intake per animal was considerably lower and the index for N excretion somewhat lower than would be predicted from the extrapolation of animal numbers from 1944 to 2007 (Table 2). Despite the capacity of the 1944 system to have a greater transfer of nutrients (N and P) into groundwater, it is interesting to note that historical manure management practices had a slight mitigating effect upon CH<sub>4</sub> production. This is directly attributable to differences in manure storage; according to IPCC (2006), the 1944 production system, with cows spending equal time grazing and housed, would have an average methane

conversion factor (MCF) of 2.75% of excreted N (1.5% while grazing and 4.0% for solid manure storage) compared to 21.7% for modern lagoon-storage. However, this advantage was negated by the 1944 population size, which resulted in increased total production of CH<sub>4</sub> and N<sub>2</sub>O from enteric fermentation and manure.

A recent report from the Food and Agriculture Organization (Steinfeld et al., 2006), concludes that livestock are responsible for 18% of global anthropogenic greenhouse gas (GHG) emissions. This statistic needs to be applied in the correct context, and not to consider the global view to be wholly representative of U.S. agriculture. Deforestation for pasture and cropland is a major contributor to global carbon dioxide emissions and has been exacerbated by the use of formerly food-producing agricultural land to grow biofuel crops (Sawyer, 2008). However, the majority of U.S. feedstuffs are produced domestically, with increased crop yields compensating for a reduction in available cropland. Furthermore, the FAO's global figure includes a significant contribution from extensive livestock systems producing meat or milk at very low efficiencies, thus considerably inflating the GHG output per unit of food. The effect of improved agricultural production efficiency is reinforced by figures from the U.S. Environmental Protection Agency (2008) estimating that only 6.4% (454 teragrams CO<sub>2</sub>-equivalents) of national GHG emissions arise from agriculture. Dairy production is only responsible for 11.5% (52 teragrams CO<sub>2</sub>-equivalents) of this figure, resulting in a total contribution of <1% to U.S. GHG emissions.

Improved productive efficiency demonstrably reduces the GHG emissions and overall environmental impact of dairy production (Capper et al., 2008). The ultimate goal of the dairy system is to supply sufficient milk to satisfy both the requirements of the U.S. population and export demand, and thus environmental impact should be quantified per unit of milk produced by

LCA standards. Nonetheless, estimates of environmental impact are often quoted per animal or per unit of land. The increased carbon footprint of an average 2007 cow compared to its 1944 equivalent (Figure 3A) appears to prove the argument that modern-day intensive productive practices are less environmentally sustainable than their 1944 equivalents, and that it would be beneficial to return to the husbandry systems practiced 60 years ago. However, when expressed on an outcome basis (per kg of milk; Figure 3B), the carbon footprint per kg of milk in 2007 is only 37% of that in 1944. Accounting for the increased use of by-products from the human food and fiber industries within modern dairy production would further reduce the carbon footprint of milk production in 2007. Despite the paucity of data relating to fossil fuel inputs, it is possible to estimate the relative magnitude of the industry carbon footprint based on total milk production when comparing these two years. The total carbon footprint for the 1944 dairy industry was 194 million metric tonnes of CO<sub>2</sub>-equivalents compared to 114 million metric tonnes of CO<sub>2</sub>-equivalents for 2007. This 41% reduction in the carbon footprint of the modern system compared to the 1944 system, taken in conjunction with the greater total milk supply, underlines the importance of improved productive efficiency in reducing the environmental impact of dairy production.

The shift from the draft animal-powered agronomy of the first half of the twentieth century to the highly mechanized operations practiced today is characterized by a more efficient use of labor and time, but is difficult to evaluate on a GHG emission basis. Nonetheless, in an effort to quantify the difference in fossil fuel input between the two systems we have characterized the primary means of work energy within the two time periods. Interestingly, energetic inputs associated with fulfilling the requirements of a team of draft animals under moderate work were 12% higher than the equivalent energy cost of the same work supplied by tractor power (Table

3). In an analysis of fossil fuel usage on U.S. farms, Cleveland (1995) demonstrated that the ratio of on-farm productivity to energy use declined from 1910-1970 and attributes this to inefficiency promoted by low fuel costs. This trend reversed as intensification, farm sizes and fuel costs increased in the 1970s, and these factors are likely to further improve energy productivity in future (Cleveland, 1995). Rydberg and Jansén (2002) noted that although man-hours and energy use are considerably reduced when using modern tractors compared to horse traction, the majority (91%) of energy inputs to the tractor-based system originate from non-renewable fossil fuels, whereas 60% of draft energy inputs are renewable. Thus, not only energy efficiency, but also energy source must be considered when evaluating the environmental impact of agricultural practices.

Remarkable advances have been made in dairy production over the past 60 years with demonstrable increases in productive efficiency conferred by genetic selection, ration formulation, preventative health programs, improved cow comfort and better management practices (Eastridge, 2006; LeBlanc et al., 2006; Shook, 2006). This is underlined by the ability of modern dairy cows to produce considerably more milk than their historical counterparts through improved welfare and reduced disease incidence (LeBlanc et al., 2006). It is also clear that the environmental impact of the modern U.S. dairy production system is considerably less than that of the historical system with substantial reductions in resource use (feedstuffs, crop land, energy and water), waste output (manure, N and P excretion) and GHG emissions. Contrary to the negative image often associated with “factory farms”, fulfilling the U.S. population’s requirement for dairy products while improving environmental stewardship can only be achieved by using modern agricultural techniques. The immediate challenge for the dairy industry is to actively communicate the gains made since World War II and the

considerable potential for environmental mitigation yet to be gained through use of modern dairy production systems.

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**Table 1.** Characteristics of the 1944 and 2007 dairy production systems<sup>1</sup>

Variable	1944	2007
Breed	54% Jersey/Guernsey/Ayrshire (small) 46% Holstein/Brown Swiss (large)	90% Holstein
Milk yield per cow (kg/y)	2,074	9,193
Milk fat content (%)	4.20 (small breed) 3.60 (large breed)	3.69
Milk protein content (%)	3.50 (small breed) 3.20 (large breed)	3.05
Heifer:cow ratio	0.89	0.83
Heifer growth rate (kg/d)	0.42 (small breed) 0.59 (large breed)	0.68
Age at first calving (mo)	27.0	25.5
Breeding method	100% natural service	70% AI, 30% natural service
Bull:cow ratio	1:25	1:83
Principal forage sources	Pasture, hay	Corn silage, alfalfa silage
Diet type	Forage + concentrate	TMR

<sup>1</sup> Further details of 1944 system characteristics are given in the Materials and Methods section; details of 2007 system inputs and characteristics are presented in Capper et al. (2008)

**Table 2.** Comparison of resource inputs, waste output and environmental impact of dairy production systems in 1944 and 2007

Variable	1944	2007
Milk produced (billion kg)	53.1	84.2
Resources/waste per billion kg milk produced		
Animals		
Lactating cows (x 10 <sup>3</sup> )	414.8	93.6
Dry cows (x 10 <sup>3</sup> )	67.4	15.2
Heifers (x 10 <sup>3</sup> )	429.2	90.3
Mature bulls (x 10 <sup>3</sup> )	19.29	1.31
Adolescent bulls (x 10 <sup>3</sup> )	17.17	1.08
Total population (x 10 <sup>3</sup> )	948	202
Nutrition resources		
Maintenance energy requirement <sup>1</sup> (MJ x 10 <sup>9</sup> )	16.66	3.87
Maintenance protein requirement <sup>1</sup> (kg x 10 <sup>6</sup> )	165.4	48.4
Feedstuffs (kg freshweight x 10 <sup>9</sup> )	8.26	1.88
Land (ha x 10 <sup>3</sup> )	1,705	162
Water (liters x 10 <sup>9</sup> )	10.76	3.79
Waste output		
Nitrogen excretion (kg x 10 <sup>6</sup> )	17.47	7.91
Phosphorus excretion (kg x 10 <sup>6</sup> )	11.21	3.31
Manure, freshweight (kg x 10 <sup>9</sup> )	7.86	1.91
Gas emissions		
Methane <sup>2</sup> (kg 10 <sup>6</sup> )	61.8	26.8
Nitrous oxide <sup>3</sup> (kg 10 <sup>3</sup> )	412	230
Carbon footprint <sup>4</sup> (kg CO <sub>2</sub> x 10 <sup>9</sup> )	3.66	1.35

<sup>1</sup> Refers to nutrients required for maintenance (all animals), pregnancy (dry cows) and growth (heifers and adolescent bulls).

<sup>2</sup> Includes CH<sub>4</sub> emissions from enteric fermentation and manure.

<sup>3</sup> Includes N<sub>2</sub>O emissions from manure (both years) and from inorganic fertilizer application (2007 only).

<sup>4</sup> Includes CO<sub>2</sub> emissions from animals, plus CO<sub>2</sub> equivalents from CH<sub>4</sub> and N<sub>2</sub>O.

**Table 3.** Annual energy requirements for a team of draft horses vs. a 30-horsepower (hp) tractor characteristic of 1944 dairy production systems

Resource use	Team of draft horses <sup>1</sup>	30-hp tractor <sup>2</sup>
Annual energy requirement (MJ)	1.14 x 10 <sup>5</sup>	1.02 x 10 <sup>5</sup>
Cropland required to support horses (ha) <sup>3</sup>	7.34	-
Gasoline equivalent (liters)	-	2.93 x 10 <sup>3</sup>

<sup>1</sup> Based on two x 800 kg Clydesdales eating 2% BW/d of hay-oat-barley ration formulated for moderate work (NRC, 2007)

<sup>2</sup> Calculated from technical specification for John Deere series A, 29.6 max hp from PTO shaft, 434 tractor h/year (Hertel and Williamson, 1940)

<sup>3</sup> Cropland required to produce sufficient feed under 1944 conditions (USDA/NASS, 2003)

## FIGURE TITLES

**Figure 1.** Changes in total U.S. milk production, cow numbers and individual cow milk yield between 1944 and 2007.

**Figure 2.** The “dilution of maintenance” effect conferred by increasing milk production in a lactating dairy cow (650 kg bodyweight, 3.69% milk fat).

**Figure 3.** Carbon footprint per cow (A) and per kg milk (B) for 1944 and 2007 U.S. dairy production systems. The carbon footprint per kg milk includes all sources of GHG emissions from milk production including animals, cropping, fertilizer and manure.

Figure 1.

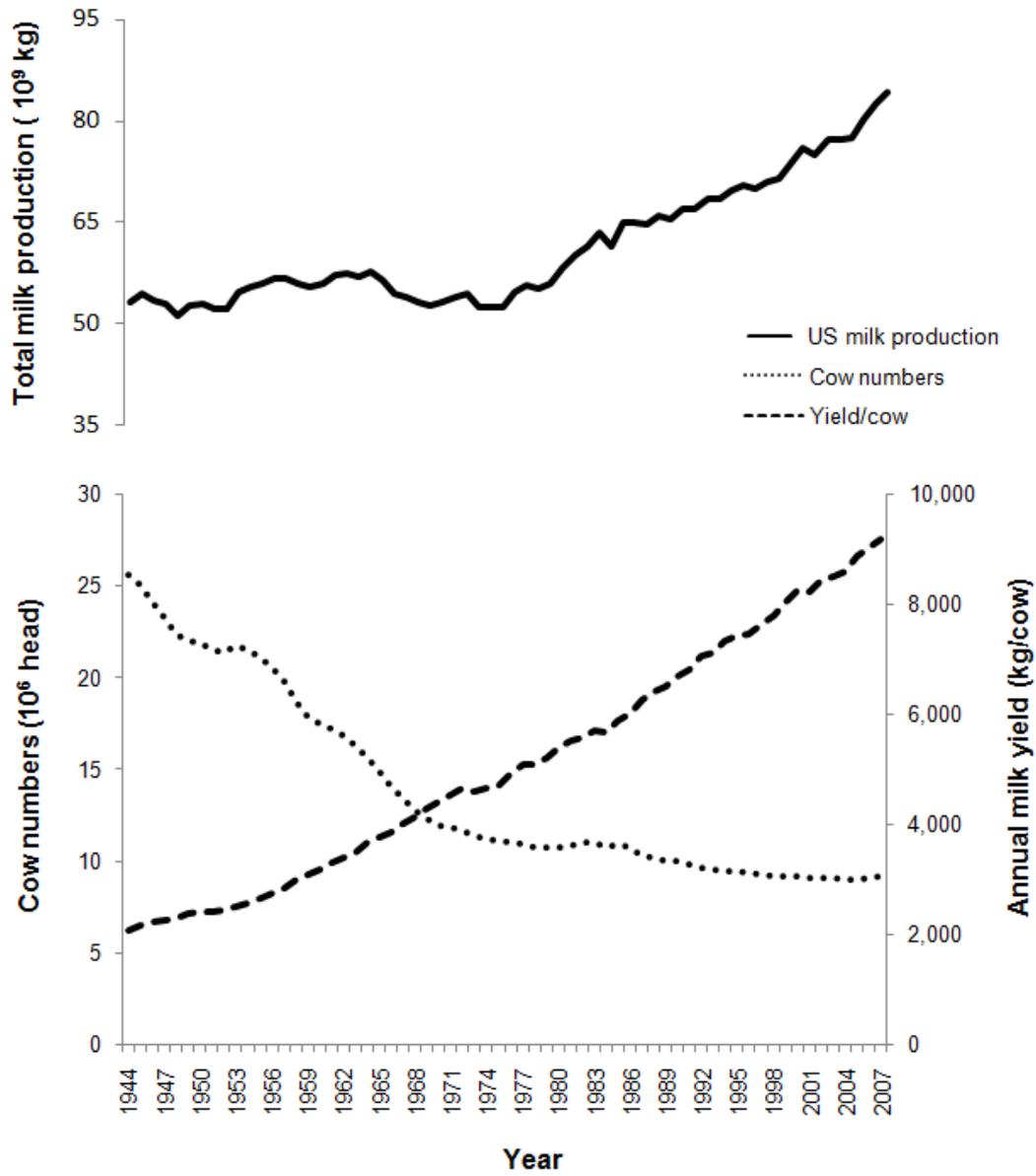


Figure 2.

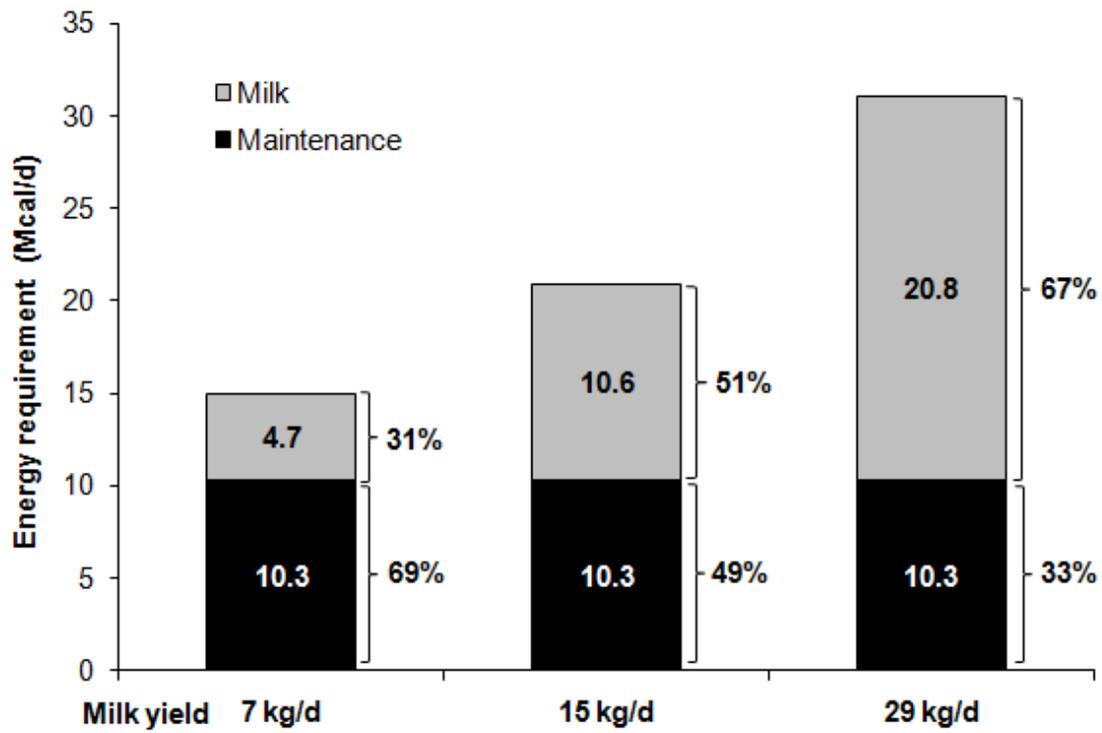


Figure 3.

