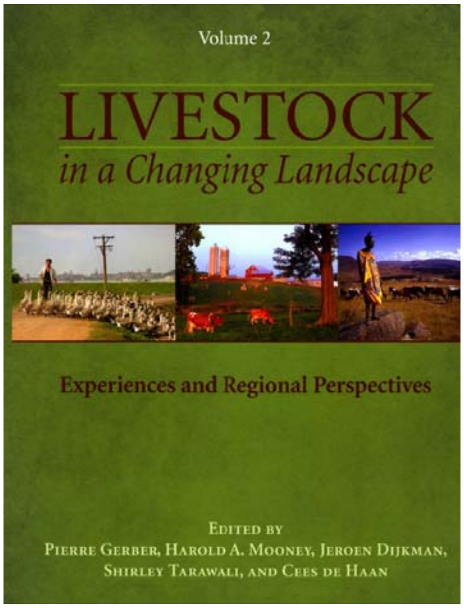
The United States

Trends in the Dairy Industry and Their Implications for Producers and the Environment

by J. Mark Powell [1], Michael P. Russelle [2], and Neal P. Martin [1]

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Volume 2

LIVESTOCK *in a Changing Landscape*

Experiences and Regional Perspectives

Edited by
Pierre Gerber, Harold A. Mooney, Jeroen Dijkman,
Shirley Tarawali, and Cees de Haan

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Abstract

Animal agriculture in the United States continues to be transformed by changes in consumer demand, production economies of scale, enhanced animal genetics and nutrition, and the widespread use of historically inexpensive feeds, diet supplements, and fertilizers. The ongoing trend toward fewer and larger dairy farms has encompassed a greater use of imported feed and has led to production of quantities of manure nutrients that can exceed the recycling capacity of associated pastures and croplands.

The liberal use of relatively inexpensive fertilizers, in combination with manure and other agricultural nutrient sources, can result in numerous adverse environmental impacts, including damage to water quality through runoff and leaching, and gaseous emissions that can adversely affect human health, fertilize natural ecosystems, and contribute to global climate change. Federal and state regulations and local ordinances have been created to mitigate nutrient loss and environmental risks associated with animal production. On many farms, nutrient use can be reduced by matching livestock rations to their nutritional needs more closely, and by increasing the availability of nutrients in feed. For dairy, this would maximize feed conversion into milk and minimize nutrient concentrations in manure, without losses in productivity.

In some dairy systems, manure transport for land spreading can be made easier by reducing water use during manure collection and storage. Cost-effective methods of manure handling, treatment, and storage are available, although the level of adoption varies by farm size and the planning horizon of producers.

Current environmental policies focus on the largest livestock operations, but small- and medium-scale livestock farms often lack the resources to improve manure collection and management. Other important farm operational features and management should also be considered as targets for environmental regulations: for example, the balance between livestock numbers and pasture/cropland available for manure land spreading, optimal livestock feeding, and the abilities of farmers to collect and land-spread manure under the diverse biophysical and socioeconomic conditions they face.

Trends in the US Dairy Industry

Over the last half-century, global agriculture has been dramatically transformed by mechanization, inexpensive fuel, feed grain, fertilizers, and the use of other petroleum-based products. During this period, dairy farmers in the United States gradually specialized in milk production rather than raising multiple livestock types and selling various products. They increased their dairy herd sizes and shifted from grazing to feeding harvested forages and grain to cattle that rarely leave barns (Harper 2000).

The dairy sector is now a substantial element in the US livestock industry. During the last agricultural census in the United States (USDA 2004a), total sales of agricultural products equaled US$200.6 billion, of which approximately one half was derived from livestock, poultry, and their products. Dairy products accounted for $20.1 billion, or about 20% of all sales of livestock and poultry products (Table 7.1).

Great changes continue apace in the US dairy industry. There are shifts in the geographic regions where milk is produced, and increases in herd stocking densities (number of cows per unit area of cropland or pasture). There is a greater use of purchased feeds, manure storage, and contracting services for manure hauling and land spreading. On a national scale, efficiency has increased: more milk is produced today with fewer cows than in the past. The proportion of the nation's milk being produced on the largest farms continues to increase.

Table 7.1. Livestock and poultry inventories and sales in the United States, 2002

Livestock and Poultry Type	2002 Inventory (million head)	2002 Cash Receipts (billion US dollars)
Beef cattle and calves	33.4	45.1
Dairy cows (lactating)	9.1	20.1
Hogs and pigs	60.4	12.4
Poultry, layers ≥ 20 weeks old	334.4	24.0
Poultry, broilers	1389.3	

Source: USDA 2004a.

During 2008, the price of liquid milk was at a historic high, fueled by a great increase in global demand and escalating feed grain prices.

More Milk from Fewer Cows on Fewer Dairy Farms

Currently there are approximately 9.1 million dairy cows and 4.1 million replacement heifers in the United States. Dairy heifer replacements weighing less than 220 kg probably number from two to three million. During the past 20 years or so, the number of dairy cows in the United States has declined by about 25%, yet milk production continues to increase (Figure 7.1). Increases in the amount of milk produced on dairy farms are due to steady, consistent increases in milk production per cow. This has been attributed primarily to enhanced genetics, better nutrition and disease control, and reproductive management, along with other less important factors (CAST 1999). These trends of declining dairy cow numbers and increasing national and per cow milk production are expected to continue. In 2006 in the United States 9.1 million cows were producing an annual average of 9048 kg milk per head. Projections for 2016 are for 8.5 million cows producing 10,496 kg milk annually per head (USDA 2007).

There has been a steady trend of concentration in dairy farms. From 1969 to 1992 there was a 70% decline in the number of dairy farms in the United States (McBride 1997). This decline is ongoing and quite rapid. The number of dairy farms has fallen from about 181,270 in 1991 to 75,140 in 2006. It is projected that most future increases in milk production (Figure 7.1) will come from the largest dairy farms. Less than 10 years ago most milk was produced on dairy farms having fewer than 200 cows; today most milk is produced on farms having more than 500 cows (Figure 7.2). This trend led to the regulatory term *concentrated animal feeding operation* (CAFO), defined as animal operations having more than 1000 animal units (one AU = 454 kg), equivalent to approximately 700 adult dairy cows the size of Holsteins. CAFOs currently represent about 4.5% of the 450,000 animal feeding operations in the United States, yet they account for approximately 47% of the total manure generated on all US animal feeding operations (Aillery et al., 2006a,b).

A recent survey of dairy farmers strongly indicates that the trend toward fewer small farms and more large farms will continue (MacDonald et al., 2007). Seventy percent of the farmers milking fewer than 50 cows expected to be out of business within 10 years. At greater farm sizes, fewer expected to exit dairying: 48% among farms with 50 to 99 cows, and only 20% of farms milking at least 1000 cows. Because current returns to milk production on small dairy farms do not cover costs (Table 7.2), more small farms are leaving dairy farming than entering. The small farms that do continue to produce milk well into the future will have to be exceptionally well managed, and/or will have favorable input or product prices that provide them with above-average profits (MacDonald et al., 2007). Some farms will adopt

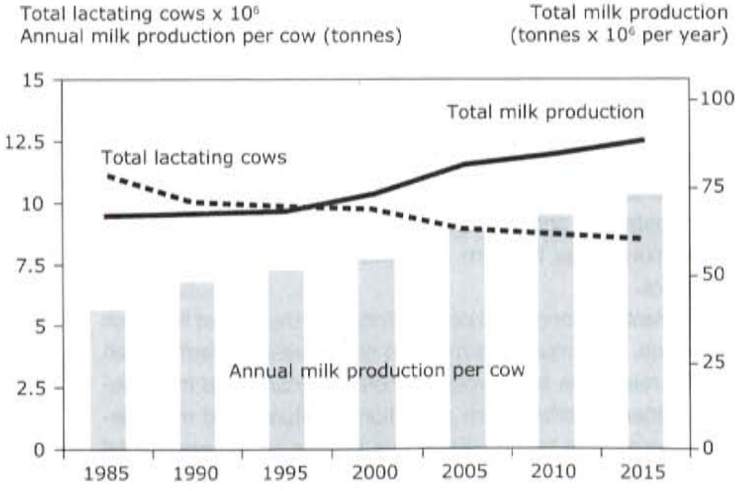

Figure 7.1. Cow population and milk production trends and forecasts in the US dairy industry. *Source:* USDA 2007.

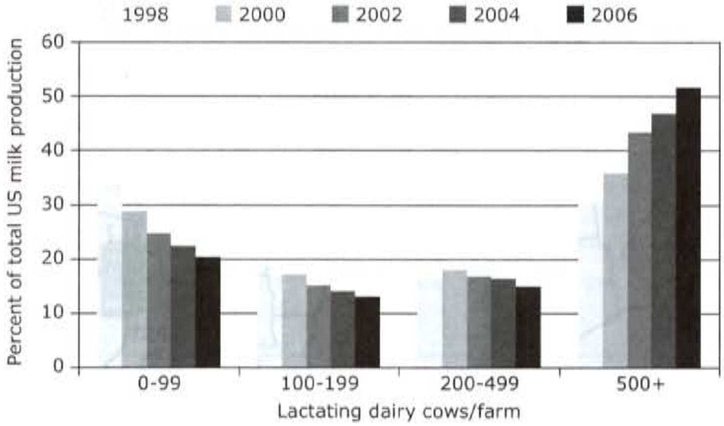

Figure 7.2. Percentages of national milk production in the United States produced on different farm sizes, 1998–2006. *Source:* USDA 2007.

alternative production strategies, such as organic dairy production, to meet niche market demands.

Organic dairy farming is one of the fastest-growing animal agricultural sectors in the United States. Although organic milk makes up approximately 3% of total fluid milk sales, this share is growing rapidly (Greene 2007, Huffman 2008). Despite this rapid growth, organic milk cows currently account for only about 2% of the total dairy cow populations in California and Wisconsin, the two top dairy states for both organic and conventional milk production. The cost of production for organic dairy farms tends to be greater than for conventional dairy farms of similar size, in part due to higher organic feed costs and higher labor and capital costs per unit of milk produced. Higher costs are offset by the premium prices organic farmers receive for their products, enhancing overall financial returns. In 2005 about 37% of the organic operations with 50 to 99 cows covered all costs, except for capital recovery, compared to only 25% of conventional dairy farms of similar size (MacDonald et al., 2007). Given that organic standards require that cows have access to pasture, most expansion of organic dairy production will likely come from farms with small and medium herd sizes.

Geographic Redistribution of Dairy Farms

The US Midwest produces the highest percentage of the national milk supply, although this percentage is declining (Figure 7.3). Over the past 10 years or so, increases in milk production have occurred on dairy farms situated in the US Southwest. Whereas the Midwest has historically been the major milk production region, today the Southwest produces approximately the same percentage of milk as the Midwest. Dairy farm expansion in the western state of Idaho has been particularly strong—this state recently surpassed the traditional dairy states of Pennsylvania (northeastern region) and Minnesota (Midwest) in total milk production, and now ranks fourth nationally in milk production, behind California, Wisconsin, and New York (USDA 2007). New Mexico and Arizona have led dairy farm expansion in the Southwest, now ranking seventh and thirteenth of all states, respectively, in total milk production.

Table 7.2. Cost and profits of milk production on US dairy farms, by herd size

	Herd Size (Milk Cows)					
	1–49	50–99	100–199	200–499	500–999	1000+
Item	USD per 100 kg of fluid milk produced					
Gross value of production	39.40	38.72	37.93	38.03	36.51	36.47
Operating costs	27.12	28.53	25.38	24.94	24.41	21.48
Overhead costs	39.27	27.69	20.52	14.57	11.02	8.49
Unpaid labor	23.37	13.45	6.90	5.62	1.19	0.37
Capital recovery	11.60	10.05	8.58	5.62	4.48	3.66
Total costs	66.35	56.23	45.91	39.51	35.43	29.97
Net returns	−26.45	−17.51	−7.98	−1.48	1.08	6.50

Source: Adapted from MacDonald et al., 2007.

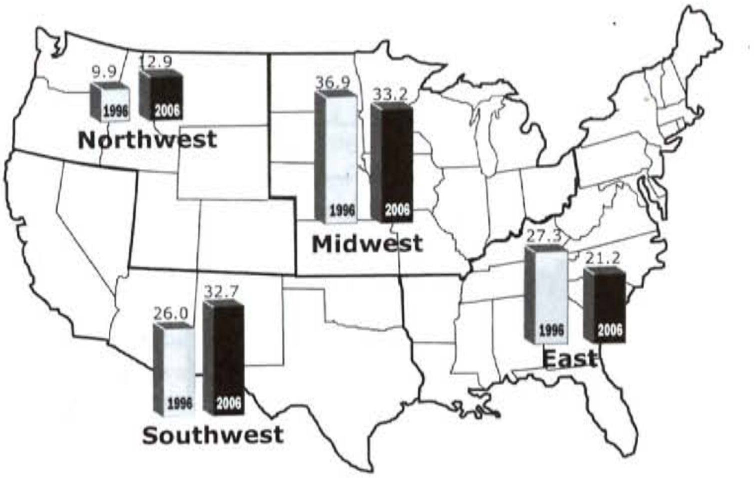

Figure 7.3. Regional percentages of national milk production in the United States, 1996 and 2006. *Source:* USDA 2007.

The geographic distribution of dairy farms in the United States (Figure 7.3) reflects the need to produce a bulky perishable product (fluid milk) near centers of population and consumption. Dairy pricing policy was initiated to support these localized markets. Major drivers of the dairy industry's westward shift have been the availability of less expensive land, favorable climate that permits large-scale operations with lower animal housing costs, local availability of high-quality feed at low cost, access to cheap hired labor, and proximity to major new markets for dairy products (USDA 2004b). Although milk production for fluid consumption remains concentrated near large population centers, production of milk for manufacturing purposes is increasingly located in low-cost areas of the West and Southwest. However, the current policy structure may lower the financial returns of some western dairy operations (USDA 2004b).

Increasing Dairy Cow Population Densities

The land area and number of dairy cows managed by US dairy farmers varies by region. In the traditional Northeast and Midwest dairy regions, farms tend to have smaller herds and a larger land base for forage and grain production compared to western US dairy farms. For example, in Wisconsin, the median ratio of lactating cows to land owned and operated by a dairy farmer was about 0.49 cows/ha in 2002, the time of the last national agricultural census (Figure 7.4). In contrast, in the Central Valley of California where dairy production has grown rapidly over the past 10 years, the median ratio was 8 cows/ha.

Changes in dairy cattle density have also varied regionally over the past decade. In Wisconsin, the number of dairy farms declined by 44%, yet the number of cows declined by only 18%. This resulted in an increase in the number of cows per unit land area on most farms, except those with very low or very high densities (lower panel of Figure 7.4). By contrast, in the Central Valley of California, there were significant increases over a wide range of cow/land densities by 2002. The overall number of farms decreased by 11%, whereas the number of cows increased by 31%. The average density of the densest 1% of reporting farms was 44.5 cows/ha in Wisconsin, compared to 955 cows/ha in the Central Valley. These averages declined by nearly one half in Wisconsin between 1992 and 2002, yet in California they increased by nearly 75% over the same period. This contrast in the land base reflects differences in the structure of dairy farming, including capital investment, relative costs and logistics of obtaining forages, local and statewide regulations, and availability of land for spreading manure. Isik (2004) found that dairy cow inventories per farm were lower in counties with more land suitable for agriculture, highlighting the fact that new, larger facilities are increasingly avoiding capital investment in land.

Changes in Forage Production

As herd sizes increase, dairy farmers seek to maximize forage yields per unit of cropland area. Over the past decade, the most significant shift in dairy diets has been the switch from alfalfa (lucerne, *Medicago sativa* L.) as a major source of fiber to corn (maize, *Zea mays* L.) silage. This change was driven by several more favorable economic characteristics of corn silage versus alfalfa (Klemme 1998):

- Higher dry mass yield, especially in the warmer environments where dairy has been expanding
- Higher energy content
- More uniform quality
- Fewer required harvests.

The statewide yield of corn silage in California has averaged 56 tonnes/ha since 1990, up from 42 tonnes/ha in the mid-1970s. In the cooler environment of Wisconsin, corn silage yield increased only 8% between the mid-1970s and 1990, but has since increased 30% to 38 tonnes/ha, in part due to genetic improvements. By

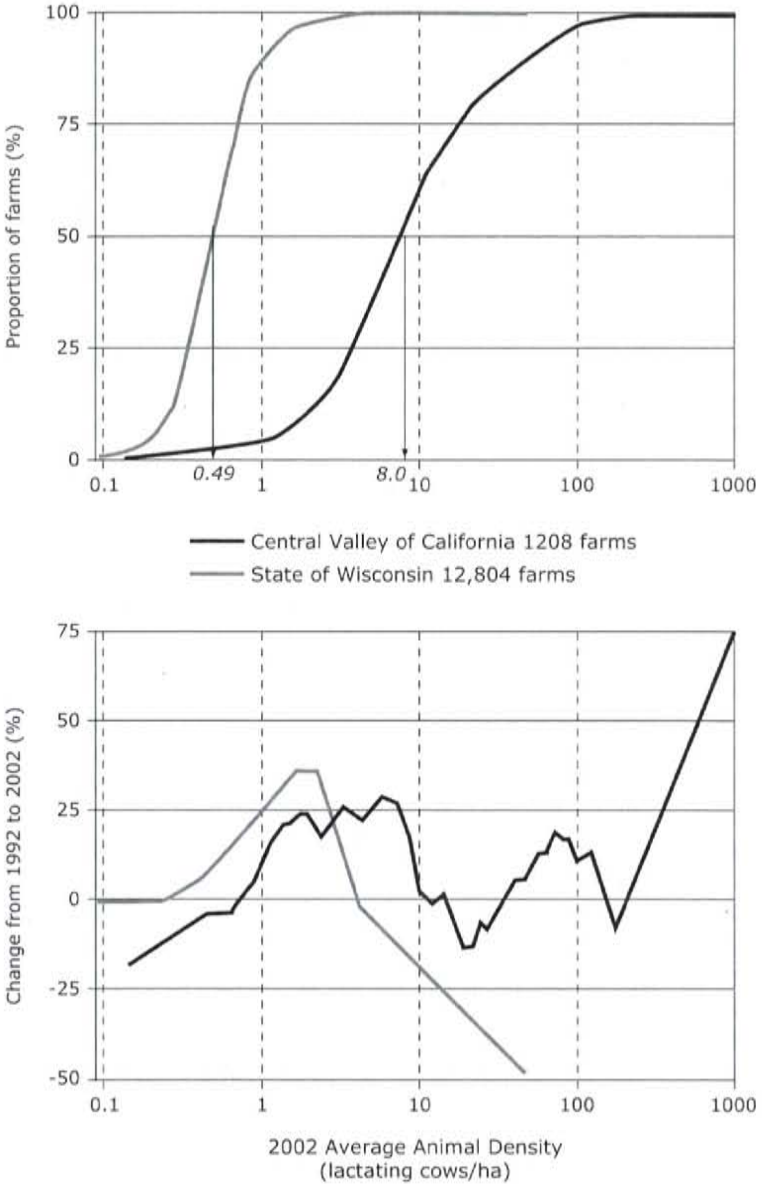

Figure 7.4. Cumulative frequency diagram of dairy cow densities in 2002, and the relative change in density from 1992 to 2002. *Source:* NASS 2008.

contrast, for alfalfa the yields of new cultivars are not markedly higher than older cultivars except in stressful environments, despite improvements in disease resistance (Lamb et al., 2006). Statewide average yields of alfalfa hay have stagnated during the past 25 years, at 15.2 tonnes/ha in California and 5.4 tonnes/ha in Wisconsin. The yield advantage for corn silage is very significant.

Dairy Production Systems

The dairy industry is characterized by very diverse production systems, each with different cost structures, capital, and labor requirements. Once their production system is established, many dairy farmers find themselves less able to change and diversify as a strategy for managing risks. The principal aim of US dairy policy has been to stabilize milk prices and profits, because dairy farmers are more dependent on income from the farm business than other farm types. Three general dairy farm types can be distinguished in the United States (USDA 2004b): confinement feeding systems, pasture-based dairy farms, and dry-lot dairy operations.

Confinement feeding systems (where cows are housed in barns) are the predominant dairy system type in the United States. Small to intermediate-size confinement dairy farms grow most of their own feed, and labor is supplied by the farm family. Large confinement operations make extensive use of purchased feed and hired labor. Over the past 15 years or so, many confinement dairy farms have converted from traditional stanchion barns (each lactating cow held and fed in an individual stall) to free-stall barns (cows move freely among stalls and are fed in alleyways that separate group stalls).

In the US Midwest and Northeast, dairy farmers have been following a fairly standard confinement system for producing milk. Cows and replacement heifers are fed primarily farm-grown feed, from crop rotations comprising alfalfa, corn, and soybean (soya, *Glycine max* (L.) Merr.). Protein and mineral supplements are usually purchased to supplement dairy rations. However, during an economic crisis in the dairy industry during the 1980s, some farmers began to pasture their cattle as a means of reducing costs.

Pasture-based dairy farms in the United States have been modeled on western European, New Zealand, or Australian dairy systems, where pastures are grazed for short periods, then left for several weeks of regrowth. Although definitive statistics are not available, about 10 to 20% of the dairy farms in the US Northeast depend on pasture as a major feed source. This practice is less prevalent elsewhere except in a small area of the South, where dairy farmers traditionally have depended on winter grazing of Italian ryegrass (*Lolium multiflorum*).

These pasture systems have lower labor costs than confinement operations (because cows harvest their own feed), and smaller investments in machinery and buildings. Pasture or grazing-based dairy systems have several other advantages, including lower fuel and veterinary costs. Milk production per cow and per unit area is lower on grazing-based dairy farms, and farmers must store feed for times of inadequate pasture availability.

A noteworthy characteristic of pasture systems is that farmers are willing to mentor others, share their ideas and experiences, and open their account ledgers to see if others have ideas for improving profit. Average net farm income per cow is higher for grazing- than for confinement-based dairy herds (Fischer et al., 2005), although financial management is key in both dairy system types. The switch from confinement to grazing dairy production systems was possible because milk producers could retain their marketing arrangements, unlike the swine and poultry sectors, which are more vertically integrated (Hinrichs and Welsh 2003).

On pasture-based dairy farms, there is a continuing interest in improving efficiency, for example, by the following:

- Improved pasture production and utilization (through fertilization, inter-seeding other pasture species, altered grazing management, etc.)
- Stockpiling feed in place for autumn and winter grazing
- Determining optimum supplementation of feed rations to improve profit
- Finding low-cost feed during drought.

In the few studies that have been conducted to date, pasture-based dairy systems appear to conserve soil nutrients better than the average confinement-based feeding operation. This is likely because pasture-based farms have lower animal units per unit land area, and most of the nutrients contained in both feces and urine are deposited directly on pastures by grazing animals. Nitrate leaching losses from pastures are higher on coarse-texture soils in humid environments, especially with shallow-rooted perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) mixtures, than on finer-texture soils in subhumid environments with more deeply rooted species (Rotz et al., 2005).

Drylot dairy operations, which are found in arid and semiarid regions (particularly in the West), are relatively new. These producers raise a large number of dairy cows, rely heavily on purchased feed, and make intensive, rather than extensive, use of land. As is evident from the high cow densities in the example of the Central Valley of California (Figure 7.4), many drylot dairy farms have no land on which to produce crops or spread manure. These are among the lowest-cost production systems because their low capital requirements and large size allow for economies of size (USDA 2004b).

Changing Farm Ownership and Labor Availability

An influx of dairy farmers to the United States and Canada has been occurring over the past two decades from Europe and other countries. The primary reason farmers gave for immigration was to escape milk quota systems in their countries of origin (Brolsma 2004). The availability of good opportunities for dairy producers was the second most important reason noted. The biggest constraints to immigration were legal issues, and these focused on converting temporary visas to permanent residency.

Major expansion of smaller dairy herds depends on increasing milk production while decreasing labor and management expenses per unit of milk produced. Major changes in the manager's tasks are also required during farm expansion, including a shift in focus from crops and herd to managing labor and finances; finding animals, land, and feed; meeting environmental regulations; and engaging in public relations (Hadley et al., 2002). Human resource management is another frequently listed priority and includes finding full-time workers, inexperience in communicating with employees, and developing fair criteria for evaluation.

Working conditions and relationships for immigrant laborers with management are not uniformly positive in the United States. Managers often cite language barriers with immigrant dairy farm workers as challenging. Spanish is the primary language of most immigrant dairy farm workers (Wilber et al., 2006). In a survey of 14 farms in East Central Wisconsin, immigrants were characterized as being more willing than US citizen workers to work additional hours. They received farm-supplied housing and utilities more frequently, and had pay rates, health insurance, and vacation leave similar to their US counterparts, but they were not in management positions. On most of the farms, both the manager and Spanish-speaking employees were attempting to learn the other language, but bilingual employees were often relied upon for translation. Managers frequently allowed immigrant employees to assist in recruiting, hiring, and training new employees.

The great structural change in the US dairy industry has raised concerns about the economic and social effects of different production systems. As large industrial-type dairy farms have gained in importance, concerns about their impact on the environment have grown. Increasing concentration of ownership has also raised concerns about competition in dairy markets and the viability of small farms. Dairy farm expansion in the West has been facilitated by federal grain support pricing, by less stringent environmental regulation in some states, and by milk support prices that disproportionately benefited large farms. Both pricing and regulation have become divisive issues among states.

Drivers of Change in the US Dairy Industry

A principle driver of change in the US dairy industry has been associated with regional shifts in human populations, which increased the demand for milk and therefore the number of dairy cows in the Southwest region (Figure 7.3). Economies of scale in milk production have also encouraged more large and fewer small dairy farms. Recent historic increases in the price of energy, feeds, and fertilizer, and the rising demand for grain and other biomass for ethanol production are putting new additional pressures on the US dairy industry. Although the steep price increases of 2007 and 2008 have subsided, it remains uncertain how input prices will impact change over the next few years. Environmental regulations will require greater investments in manure storage, energy conversion, and land application technologies. This will continue to add economic pressures to dairy farms with smaller herd sizes.

Economies of Scale Favor Large Dairy Farms

The ongoing trend of fewer and larger dairy farms in the United States can be attributed to their higher financial returns relative to the costs of production. In 2005 large dairy farms (> 1000 milk cows) had 15% lower production costs per unit of milk produced than farms with 500 to 599 cows, and 25 to 35% lower costs than farms with 100 to 499 cows (Table 7.2). The greatest financial advantage of the larger dairy farms was their ability to use capital and labor far more intensively than smaller dairy operations (MacDonald et al., 2007).

Changing prices have been an important driver of production and changes in farm size. Milk prices usually rise and fall in a pattern that reflects classic supply and demand economics. In the United States, fluid milk prices have recently reached historic highs (Figure 7.5). Under normal supply–demand conditions, higher milk prices have led to increased production and increased profitability for large-scale dairy farms, which have lower costs per unit of production,. This has enabled larger farms to expand herd size, add new buildings, buy new machinery, and increase market share. However, price rises from 2006 onward have been related primarily to escalating costs of major feed grains (Figure 7.5) and fuel. Hence net returns are not increasing as before, and many farmers may not increase their production as they would normally. This may help to keep milk prices higher over a longer period than usual.

Milk Pricing Policy

Dairy pricing policy in the United States was designed initially to stabilize farmers' incomes by influencing milk prices. Price support programs were designed to assure minimum prices for all farmers, regardless of herd size. These programs have had varied effects, some of which have not been neutral to farm size. For example, because of the great differences in production costs between small and large farms (Table 7.2), milk prices that may cover costs on midsize farms would, on large farms,

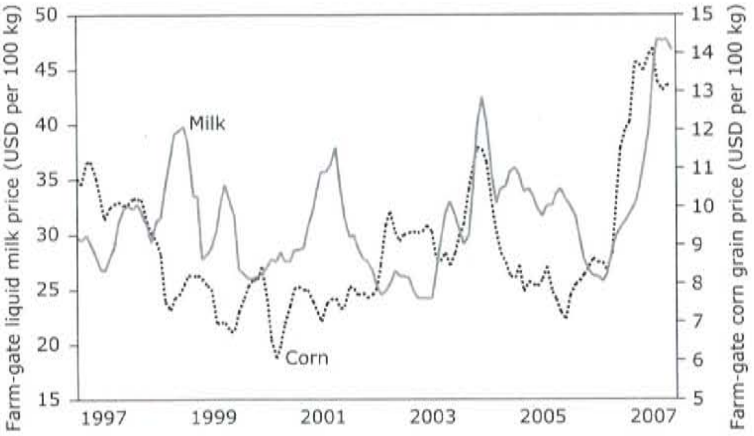

Figure 7.5. Trends in liquid milk and corn grain prices, United States, 1997–2007. *Source:* USDA 2007.

yield large profits, and even provide very strong incentives for expansion (MacDonald et al., 2007). To address this disparity, the Milk Income Loss Contract (MILC) program promulgated in 2002 put limits on farmer payments. Under this program, farmers are paid premiums only up to the first 1.1 million kilograms of production—the annual production from about 120 cows. Payments under MILC begin when milk prices fall below a reference level, and during periods of low prices they provide stronger revenue support to small operations and to regions where such farms predominate (Midwest and East; Figure 7.3). MILC provides targeted assistance to small farms during market downswings, and this helps to prevent foreclosures. Despite this, the powerful cost advantages of large dairy farms are likely to sustain the ongoing trend toward fewer small dairy farms in the United States (MacDonald et al., 2007).

Environmental Regulations

Federal, state, and local regulations have been implemented to minimize the environmental impacts of animal agriculture. Due to recent court decisions, federal regulations in the United States have been relaxed (EPA 2008) so that only those CAFOs that discharge or propose to discharge manure nutrients to navigable waters need to obtain a permit. State and local environmental regulations are often much more stringent than federal regulations, and this has impacted the regional distribution and consolidation of dairy farms in the United States. Fewer cows are kept and the greatest reduction in cow numbers occurs in those areas where local environmental regulations are most stringent (Isik 2004). Dairy farm operations may move into or expand within areas that have less stringent environmental regulations. However, their arrival is often followed by an increase in environmental problems and public concern, and promulgation of more regulation in those areas. The pressure from growing rural and exurban populations plays a role in this pattern. Human populations tend to increase faster in counties with greatest infrastructural change due to milk production, such as improved roads (McBride 1997), and this eventually leads to subsequent declines in dairy cow inventories as residential building permits increase (Isik 2004). Dairy farm size, regardless of its social ties, is a strong predictor of the level of complaints from neighbors (Jackson-Smith and Gillespie 2005) Nevertheless, new large-scale dairy farms are being established in the Midwest by operators who do address environmental concerns and engage in public relations to improve communication.

Price and Use of Feed Grain

Federal government feed grain policy has contributed to the rise of large-scale dairy farms and to the shift of dairy production to the West (USDA 2004b). Subsidies for feed grains have encouraged abundant supplies. The abundance of cheap corn transformed dairy cows from harvesters of pasture grasses and legumes grown on marginal cropland and in locations with marginal crop-growing weather, into consumers of energy in the form of grains grown on prime cereal cropland.

The recent escalation in corn grain prices (Figure 7.5) was fueled in part by recent government mandates to increase ethanol production (RFA 2006). It is uncertain how ethanol production will impact feed costs and overall dairy farm profits in the future, because it increases demand for corn grain, but also produces coproducts—wet and dry distillers' grains—that are used in ruminant rations. However, for the foreseeable future, large dairy farms will continue to have substantial capital and labor cost advantages over small dairy operations (Table 7.2), and will continue to increase their production. This will continue to place downward pressure on industrywide costs and prices, thereby offsetting some of the impact of any long-term increases in feed costs.

Price and Use of Fertilizer

As we describe in the consequences section, excessive use of nutrients in feed production and dairy farming can lead to significant environmental problems, especially air and water pollution. There are many reasons for the excess use. Nutrients, whether for land producing feedstuffs or for the animals themselves, have been relatively inexpensive in the United States. Efficiencies of scale in fertilizer manufacture and delivery have helped reduce prices relative to inflation. When expressed in constant dollars adjusted for changes in the gross national product (GNP), fertilizer costs declined by 20 to 50% between 1960 and 2002, with marked cycles of cost swings (Figure 7.6). The rapid rise in fertilizer cost in 2007 and 2008 exceeds the price spike in the mid-1970s; both were related to increases in the cost of fuel. Nevertheless, on a constant dollar basis, urea was less expensive in early 2008 than in 1960.

Because of the low prices, nutrients were generally applied in excess of crop and livestock requirements. Fertilizers and manure have been applied to the land in amounts that maximize economic returns of cropland. In addition, nutrient-rich diets have been recommended by nutritionists and veterinarians to maximize animal production and maintain good animal health and reproduction. However, overfeeding livestock and overfertilizing crops has exacerbated the potential for on-farm nutrient surpluses. These practices have increased the buildup of nutrients in the soil, and subsequent losses to and contamination of the environment.

Changes in overall fertilizer use nationally have varied among the main fertilizers (Figure 7.7). Between 1960 and 1980, use of nitrogen increased about fivefold. Slower rates of increase occurred in use of phosphorus and potassium. Use of phosphorus and potassium plateaued after 1980, whereas nitrogen use did not plateau until 1995. Although there are no national data on

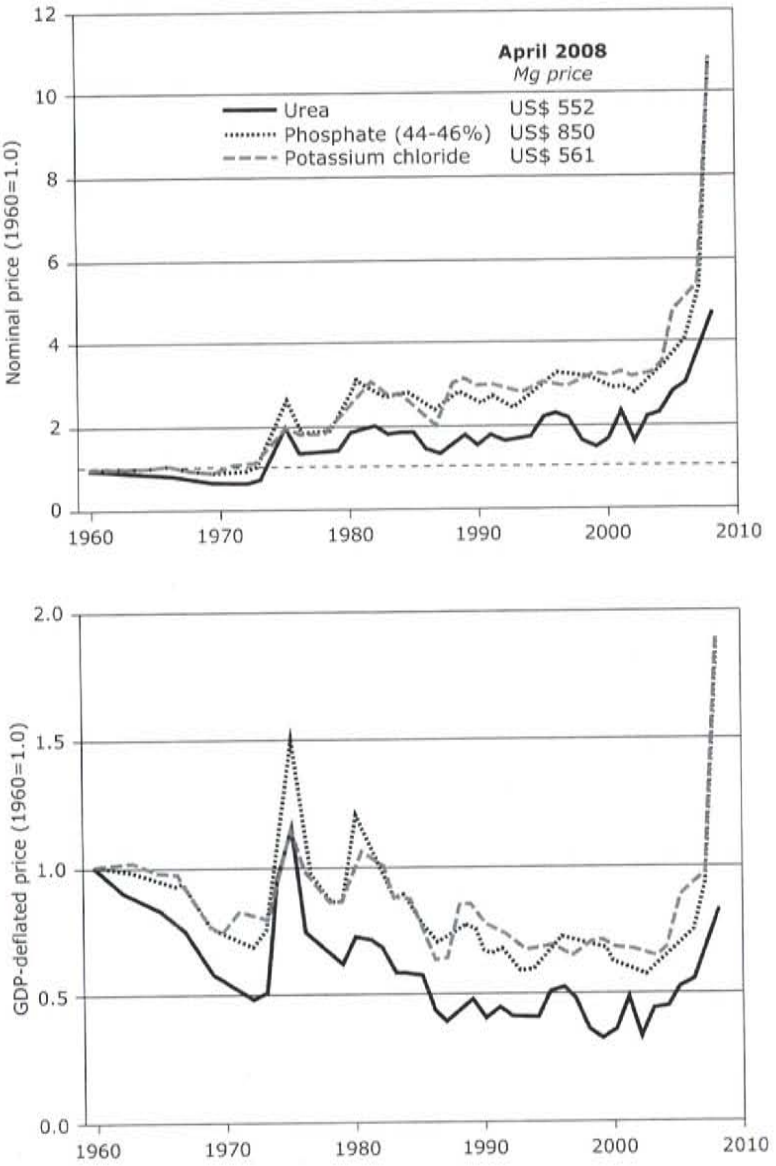

Figure 7.6. Trends in fertilizer prices in the USA, 1960-2008.
Source: NASS 2008.

fertilizer use specifically on dairy farms, if we assume that nutrient use for all farms reflects nutrient use on dairy farms, it appears that fertilizer use has been increasing while dairy manure production has been decreasing. It is unclear how fertilizer use will be affected by high prices. Anecdotally, dairy farmers have expressed increased interest in optimizing their use of manure nutrients. This is in contrast to earlier surveys that indicated poor farmer recognition of manure's nutrient value (Schmitt et al., 1999, Gassman et al., 2002).

In addition to nutrients being relatively inexpensive, farmers also apply additional nutrients to avoid the risks of nutrient undersupply, which could lead to adverse impacts on production and the environment. However, some of the high nutrient use in agriculture can be associated with inevitable biological inefficiencies with which nutrients are incorporated into crop and livestock products. For example, of total feed protein and minerals consumed by livestock, general averages of 60% for poultry, 50% for swine, 30% for lactating dairy, and 20% for beef steers, respectively, are incorporated into animal products; the remainder is excreted in manure (Kornegay 1996). Excessive dietary protein (Wu and Satter 2000, Olmos Colmenero and Broderick 2006) and phosphorus (Satter et al., 2005) is fed to dairy cows in the range of 20 to 30% above recommended levels. Field crops incorporate only a general average range of 30 to 60% of applied fertilizer and manure N and P into grain and other crop products.

Because of inevitable inefficiencies of nutrient use, most feed N and P for dairy cattle will always be excreted in manure, and after land application, manure N and P losses are inevitable. A continuous general challenge facing animal agriculture is to apply nutrients in recommended amounts in order to minimize nutrient loss and the resulting environmental contamination

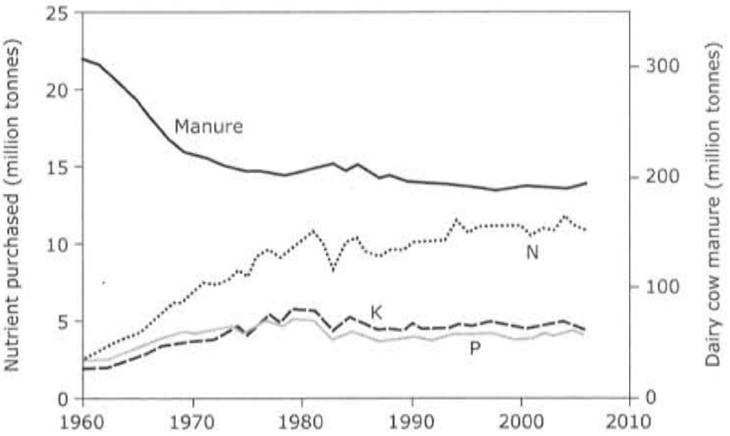

Figure 7.7. National fertilizer nutrient use (all farms) and estimated dairy cow manure production in the United States, 1960–2007. *Source:* NASS 2008.

through good management. The recent great increases in feed (Figure 7.5) and fertilizer prices (Figure 7.6) created new opportunities for dairy farmers and their feed and crop consultants to devise improved strategies to optimize overall nutrient use.

Consequences of Change

The combined trends of separate crop and livestock production and geographical concentration, and excess use of feed and fertilizer nutrients, has various consequences, including greater export of nutrients to the wider environment. In the United States, the N from animal wastes that is transferred to surface waters or is volatilized to the atmosphere as ammonia may be the single largest source of N that moves from agricultural operations into coastal waters (Howarth et al., 2002). Balancing nutrient inputs and outputs through proper animal density, feed, fertilizer, and manure management has become a major environmental challenge facing not only the US dairy industry but animal agriculture in most industrialized countries (Steinfeld et al., 2006).

Unlinking Crop and Livestock Production

The changes that have taken place in agricultural production since the mid-1900s can best be summed up in the term *industrialization* (Lanyon and Thompson 1996), encompassing specialized production techniques, geographic concentration of crops and livestock, increasingly specialized management functions, and substitution of capital for labor. Industrial agriculture has radically changed the relationship of livestock production to land resources and the environment. Before industrialization, crops and livestock were closely linked: agricultural production depended on on-site recycling of nutrients from animal manure or from biological N fixation by legumes. Since industrialization, inexpensive fertilizer and low transport costs have allowed crop and livestock production to be unlinked. Today crops can be grown in one location and fed to livestock in other locations, while human populations live in distant urban centers.

Close proximity of livestock and manure production to farms where crops are grown is fundamental to making the fullest and most effective use of manure for its agronomic benefits. The more livestock and crops are separated, the less likely the manure will be used to boost fertility, and the more likely it will be wasted or disposed of in ways that lead to environmental problems. In the United States, livestock specialization separated from crop production is most pronounced in the vertically integrated feedlot cattle, swine, and poultry industries. In dairy production, many dairy operations in the Northeast and Midwest regions of the United States continue to be associated with crop and pasture production. However, these traditional modes of dairy production are giving way to more specialized production, including irrigated forage in the Northwest and Southwest regions.

Many environmentalists and others contend that the "ecological footprint" of animal agriculture should be considered when assessing the total consequences of animal production. This means that environmental impact assessments should include not only the nutrient losses and resulting pollution that is generated on-farm, but also runoff, emissions, and pollutants generated during the production of the feed that farmers import onto their farms. For the purpose of this chapter, we consider only implications of on-farm nutrient use and how this may impact the environmental performance of dairy operations.

Environmental Problems of Excess Use of Feed and Fertilizer Nutrients

Only 20 to 30% of the N (crude protein) fed to dairy cows is converted into milk. The remaining feed nitrogen (N) is excreted about equally in urine and feces at moderate N intake, but at higher intakes more of the excess protein is excreted in urine than in feces (Figure 7.8). Urinary N is much more susceptible to environmental loss than fecal N through its rapid conversion to ammonia gas or to nitrate, which can be leached and denitrify in soils.

Excreted N follows several different pathways into the atmosphere and aquatic environment. About three

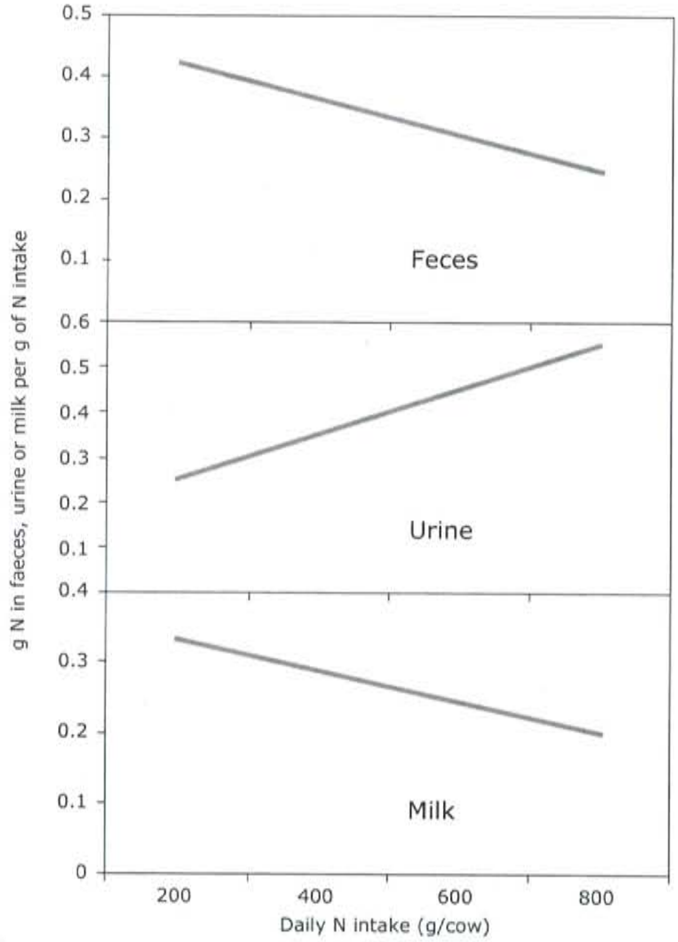

Figure 7.8. Generalized effects of increasing feed N intake by dairy cows on N levels in feces, urine, and milk.
Source: Adapted from Castillo et al., 2000.

fourths of the N contained in urine is in the form of urea. Urease enzymes, present in feces and soil, rapidly convert urea to ammonium. Ammonium, in turn, can be transformed quickly into ammonia gas and lost to the atmosphere.

Of the total amount of manure N excreted by dairy cows, approximately 30 to 40% is often lost as ammonia gas from barns, manure storage, and after land application. After release, ammonia gas combines with other chemicals in the atmosphere to form ammonium-containing dust particles that adversely affect human health. Ammonia is also redeposited as acid rain and nitrates that can be detrimental to natural ecosystems, especially aquatic ones. The ammonia produced by dairy farms in the Midwest may be a major contributor to the N loading of the Mississippi River and the hypoxia ("dead") zone in the Gulf of Mexico (Burkart and James 1999).

When N (as fertilizer, manure, legume N, and other organic sources) is applied to cropland and pastures in excess of agronomic requirements, nitrate leaching can increase (Figure 7.9). High nitrate leaching can contaminate ground and surface water and increase losses of N in gaseous form via denitrification. Although denitrification may constitute only a small fraction (2 to 5%) of applied N, production of nitrous oxide contributes to global warming and ozone depletion. In addition, application of manure slurries with low dry matter to artificially drained soils can rapidly contaminate surface and ground waters with pathogens, excess nutrients, and organic compounds that increase biological oxygen demand.

A similar picture applies for the mineral phosphorus (P) in dairy cow feed and P in fertilizer, which have also been used in excess due to their relatively low cost. Many dairy farms have accumulated P in soils over time, because imports of P in the form of feed and fertilizer exceed exports in the form of milk, cattle, and surplus grain or hay (Table 7.3).

The excessive dietary P supplements fed to dairy cows increase total and soluble P in manure (Figure 7.10). When the manure is applied to land, this greatly increases the potential for runoff of P into streams and lakes, where it promotes algae growth and eutrophication of surface waters (Ebeling et al., 2002). Excessive dietary P also decreases the N:P ratio of manure relative to N:P requirements of most crops (Powell et al., 2001). When such manure is applied to cropland in amounts sufficient to meet crop N demand, crops will be unable to take up all the P. Thus soil P increases much more quickly than when manure is derived from cows fed appropriate amounts of P.

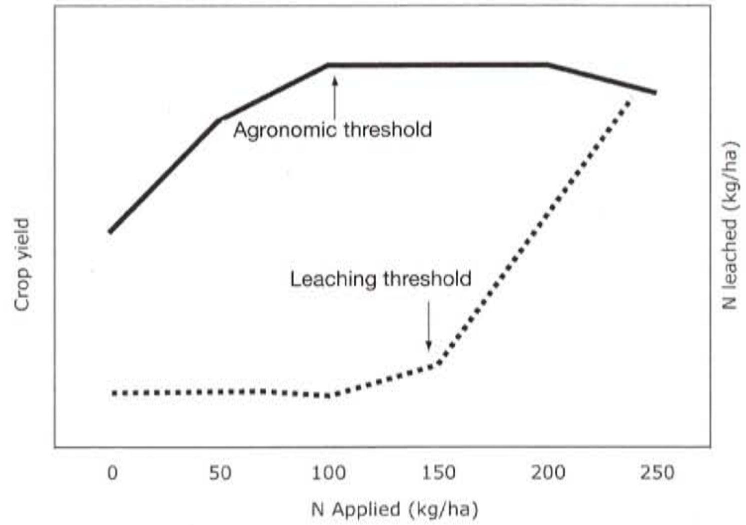

Figure 7.9. Relationships between N applications, relative crop yield, and N leaching.

Note: Agronomic threshold for crop yields is lower than leaching threshold. This means that N application in excess of agronomic threshold increases the risk of loss via nitrate leaching.

Source: Lord and Mitchell 1998.

In many areas of intensive livestock production the amount of P in manure often exceeds local crop requirements (Kingery et al., 1994, Sharpley et al., 1993), because manure has been applied at rates determined by disposal needs rather than agronomic requirements. In most dairy regions of the United States, soil test P levels are in the high plant availability range (Figure 7.11). When P levels rise above agronomic recommended levels the risk of P in runoff increases greatly (Figure 7.12).

The result of these excessive N and P inputs for lakes and streams has been to accelerate eutrophication and impair water quality. Excessive P runoff into surface waters increases growth of weeds and algae. When these decompose, dissolved oxygen levels are depleted, leading to fish kills, odors, and a general decline in the aesthetic and recreational value of the environment. The US Environmental Protection Agency (USEPA 1996) has identified agriculture as the major source of nutrients in 50% of the lakes and 60% of the river length of impaired water quality. Environmental pollution deriving from livestock production, including dairy, is highly significant among agricultural sources (Steinfeld et al., 2006).

It is difficult to control the exchange of N between the atmosphere and a water body, and the fixation of atmospheric N by blue-green algae (Krogstad and Lovstad 1991). This means that the control of P inputs is of prime importance in reducing eutrophication (Sharpley et al., 1994). Management aimed at reducing P losses to the

Table 7.3. Annual mass phosphorus balance for dairy farms, New York, USA

	Size of dairy, cows/farm			
Item	45	85	320	500
	kg P/year			
Inputs				
Purchased feed	907	1,542	7,619	12,880
Purchased fertilizer	1,088	816	1,814	9,070
Purchased animals	0	0	27	0
Outputs				
Milk	363	617	3,477	4,988
Meat	45	91	453	453
Crops sold	18	54	0	0
Remainder				
Tons	1,569	1,596	5,530	16,509
% of Inputs	79	68	59	75

Source: Klausner 1995.

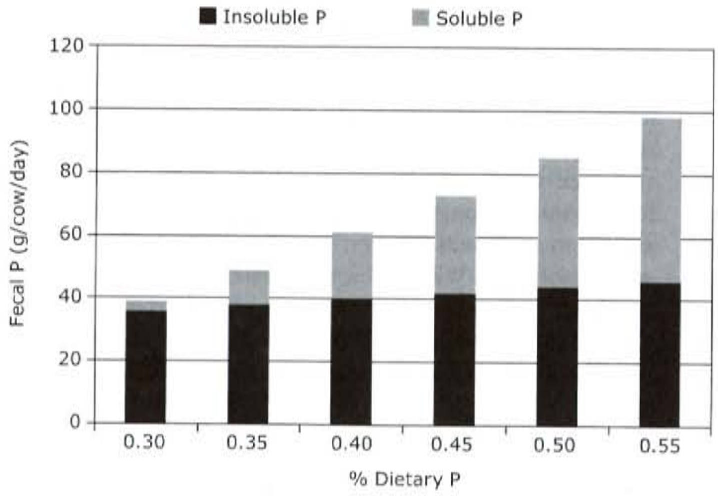

Figure 7.10. Effect of increasing feed P intake on P levels in feces of lactating dairy cows.
Source: Satter et al., 2005.

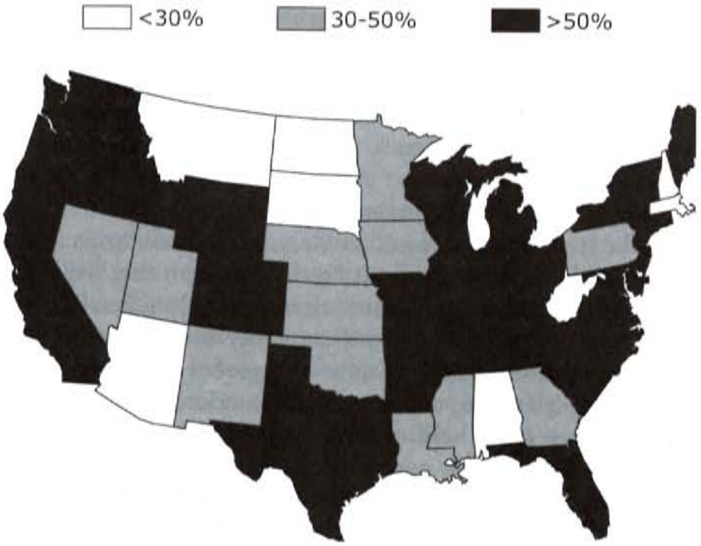

Figure 7.11. Percent of soils testing high or greater for P. In most states of the continental United States, soil test P levels are in the agronomic high or greater availability range.
Source: Fixen 1998.

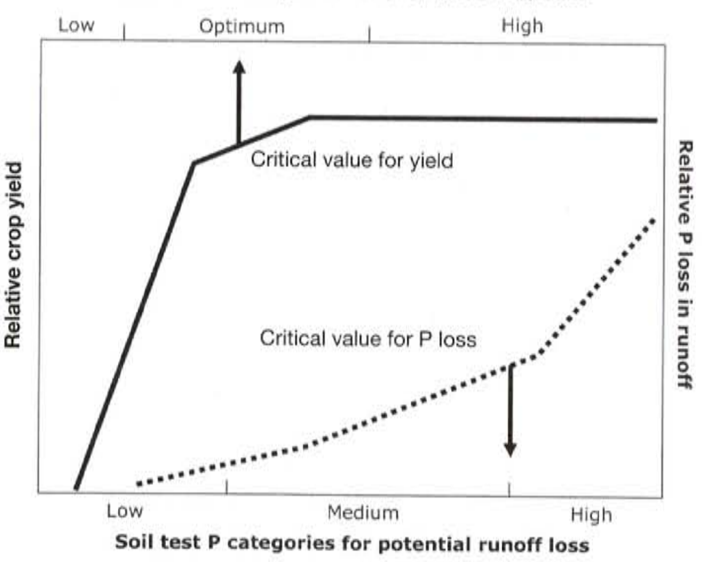

Figure 7.12. Relationships between soil test P levels, relative crop yield, and P loss in runoff.

Note: Critical soil test P level for optimum crop yield is lower than critical soil test P level for P losses in runoff. Because most US agricultural soils have high soil test P levels (Figure 7.11), additional P application will not increase crop yields but increases the risk of P runoff.

Source: Kleinman et al., 2000.

environment must therefore try to minimize P imports onto the farm (Table 7.3), while also controlling surface runoff and erosion (Sharpley and Withers 1994).

Other adverse impacts of dairy farming on water quality have been attributed to lack of appropriate manure management, generally in relation to the rate and timing of nutrients applied. Barn flush water systems used in the western United States produce dilute manure that is often used for irrigation after solids have been removed. Conventional management in the Central Valley of California has been to apply a blend of manure pond water with irrigation water during the spring and the fall. Commercial fertilizer is applied to corn in summer and sometimes to small grains in winter, and excess pond water is disposed of on fields in the winter (Harter et al., 2001). This overapplication of both N and water has resulted in nitrate contamination of shallow groundwater. Such losses can be reduced by a simple accounting scheme for total N applications (Campbell-Mathews 2007). In this scheme, farmers install water meters to quantify pond water application rates. They are taught to calculate the total N application rate in pond water, and learn to manage both pond water and fertilizer rates to more closely match crop N needs.

Impacts on Human Health

Concentrated animal feeding operations (CAFOs) can potentially have significant impacts on human health. The international scientific conference Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions (Thorne 2007) identified several major concerns associated with all types of CAFOs, including the following:

- Air and water contamination
- The rise of antibiotic-resistant bacteria in livestock
- The potential of influenza outbreaks arising from siting industrialized poultry and swine production in proximity to each other and to humans.

However, there is very little information on public health hazards associated specifically with dairy farms. The National Commission on Industrial Farm Animal Production (NCIFAP), including representatives from veterinary medicine, agriculture, public health, business, government, rural advocacy, and animal welfare, was established in 2005 (NCIFAP 2007). The principal mandate of NCIFAP has been to conduct an assessment of the industry's impact on public health, the environment, farm communities, and animal health and well-being. Scientific workshops and public meetings have been held to help inform NCIFAP commissioners and the public about the major environmental health issues associated with large, industrial-style livestock production facilities. However, the NCIFAP workgroups have listed few direct public health hazards associated with dairy farms, other than the long-held general concerns related to air and water quality.

There are concerns related to worker exposure to toxic levels of ammonia, but these are more associated with densely populated poultry houses than with expansive, well-ventilated dairy barns. However, fine particulates formed on ammonia can adversely affect human health distant from ammonia sources, including dairy farms (Asman et al., 1998). As will be discussed later, the Clean Air Act requires farmers to report ammonia emissions greater than 45.5 kg over a 24-hour period (Aillery et al., 2006a).

The NCIFAP workgroup on impacts of CAFOs on water quality made several recommendations related to human health impacts (Burkholder et al., 2007), including the following:

- Monitoring whole watersheds to understand the effects of extreme emission and deposition events on human and ecosystems health
- Toxicological assessment of water contamination from CAFOs
- Studies of primary effluents and metabolites in soils, sediments, and water.

Impacts on Greenhouse Gas Emissions

The trend toward fewer and larger livestock farms in the United States has increased public concern that livestock operations emit pollutants that adversely affect human health and soil, air, and water quality and also contribute to greenhouse gas emissions and global warming (NRC 2003). Methane, carbon dioxide, and nitrous oxide are the three gases held most responsible for global climate change. Livestock contribute about 28% of total methane emission in the United States (EPA 2005). The main source of methane from ruminant livestock is enteric fermentation (most released via belching and less by flatulence), which contributes about 75% of total livestock emissions. Methane production from dairy cows can be reduced by increasing starch or rapidly fermentable carbohydrates in the diet, which impact ruminal pH and microbial populations and regulate methane production (Johnson and Johnson 1995).

Small concentrations of nitrous oxide in the atmosphere are thought to contribute over 6% of the warming effect of all greenhouse gases because of nitrous oxide's extended atmospheric lifetime (about 150 years) and high thermal absorptivity (Godish 2004, Dalal et al., 2003). Although ammonia is the main pollutant gas emitted from dairy barns, small emissions of nitrous oxide, which originate primarily from manure, have been detected (Zhang et al., 2005). Nitrate derived from land-applied manure and fertilizers can denitrify and be emitted as nitrous oxide from soil.

Volatile organic compounds (VOCs) are a group of hundreds of reactive compounds, many of which are associated with odor. Some VOCs lead to global warming, others to ozone depletion, smog, and decreased visibility. Effects of VOCs are mostly associated with odor-producing compounds and their effects on human health (Schiffman et al., 1995). The majority of VOC emissions from dairy farms come directly from the cow, with smaller amounts emitted from fresh manure two to three hours after excretion (Mitloehner 2006). Additionally, ensiled feedstuffs (silages) are a significant source of VOCs (Rovner 2006). Different types of silage have different VOC emission potentials, but those low in sugar will have the least VOC emissions because of reduced fermentation rates.

Responses and Remedies

The regional shifts and intensification of dairy farming in the United States have elicited a wide range of responses from federal, state, and local governments, dairy supply and service sectors, and producers. Federal milk price support programs are being reevaluated for their impact on the profitability and viability of small- and medium-sized dairy farms. Environmental regulations are being modified to account for new public demands for cleaner air and water, as well as federal government response to pollution litigation. Feed and fertilizer dealers and veterinarians continue to revise their nutrient use recommendations in efforts to enhance the environmental performance of dairy operations. Improved manure handling, storage, and land-application strategies are being developed to maximize manure nutrient recycling through crops and pasture. Socioeconomic research is being incorporated into technology development so that recommended practices align more closely with producer resources including management skills.

Milk Pricing Policy

The notable trend toward larger dairy farms (Figure 7.2) has led to recent evaluations and proposed revisions of milk pricing policy. The Farm Security and Rural Investment Act of 2002 called for an evaluation of the economic impacts of all dairy policy programs. The resulting report *Economic Effects of U.S. Dairy Policy and Alternative Approaches to Milk Pricing* (USDA 2004c) provides a comprehensive description of 70 years of dairy support programs, and analyses of their impacts on farms, rural economies, and markets for dairy products. The report concluded that dairy support programs have had only modest benefits to producers. They raised milk prices by only about 1%, and total producer revenues (returns plus government payments) by 3% over a 5-year period. Short-term effects can be significantly higher, however, and impacts are more pronounced during years of low milk prices.

Because of this modest influence on milk prices and returns, dairy support programs have had limited impacts on the profitability and viability of US dairy farms. For example, the dairy support programs could be associated with only a 5% increase in the ability of midcost and high-cost dairy farms (usually the smaller-scale producers) to meet expenses (USDA 2004c). The support programs increase returns and allow some high-cost dairy operations to stay in business over the short or medium term. But in the longer term, higher milk prices improve the profitability of low-cost, large-scale dairy farms, which historically has enabled them to expand production and increase market share.

The USDA report (2004c) provided several other conclusions about federal policy and dairy support. Overall, dairy support programs have raised consumer costs and increased government expenditures. There are also program conflicts. For example, price support programs established a safety net for milk prices, which would allow milk prices to fall to certain levels to induce a correction in oversupply or underconsumption. When the milk price falls toward the price support safety net, however, the MILC program, which provides production-linked payments, may encourage production and retard the supply adjustment. The result is that milk prices may stay lower for longer periods and raise government costs to maintain the programs. Non-MILC dairy programs alone raise the all-milk price by 4%, but when MILC is included, all-milk price is raised by only about 1% (USDA 2004c).

Water and Air Quality Legislation

Current political concerns focus on pollution of lakes, streams, and groundwater, and on air emissions, especially from farms close to environmentally sensitive areas (e.g., forests and other natural habitats or shallow groundwater) and urban centers. The first federal law in the United States to stem pollution of surface and ground waters was passed in 1948 and focused almost exclusively on point sources of sewage. The trend toward fewer and larger livestock farms led to heightened public concern about pollution from animal agriculture. In the 1970s the US Environmental Protection Agency (EPA) created two rules under the Clean Water Act that affected animal agriculture: (1) The National Pollutant Discharge Elimination System (NPDES); and (2) Effluent Limitations Guidelines (ELGs). In 2003, the EPA implemented pollution standards for all CAFOs. The rules were recently relaxed (EPA 2008) to include only those CAFOs that currently discharge or plan to discharge pollutants to US navigable waters.

Under the NPDES, CAFOs are required to follow individualized Comprehensive Nutrient Management Plans (CNMPs) designed to protect surface and ground water (Moody and Burns 2006). Adherence to CAFO-based manure management regulations that meet both water and air quality standards would be most costly to the hog and beef cattle industries because these animal production facilities usually lack land for manure spreading (Aillery et al., 2006b). Large dairy facilities typical of the western United States face similar costs for compliance because they have insufficient land (Figure 7.4). By contrast, most dairy farms in the traditional Northeast and Midwest regions of the United States are land based. Most forage and grain is grown on-farm, and farmers have adequate land for manure spreading (Powell et al., 2002, Saam et al., 2005).

For animal agriculture in the United States, environmental regulations have focused mainly on the amount and timing of manure application to cropland. The current regulatory focus is on large livestock operations, based on the assumption that they produce the most manure and therefore pose the greatest environmental risk. However, it is becoming increasingly evident that farms of any size can generate negative environmental impacts. Indeed it has been suggested that economies of scale, more modern technologies, and potentially higher management skills associated with large-scale operations may make these operations less likely to pollute compared to smaller, older facilities (Norris and Batie 2000). For example, stanchion or tie-stall barns are the most common housing types on dairy farms that have small to medium herd sizes, mostly in the US Midwest and Northeast (USDA 2004c). Cows are confined to stalls, and manure is collected in a gutter behind the cows. Cows also have access to small exercise lots, or may be allowed access to a pasture to graze for part of the day. These farms face particular challenges in managing manure in outside confinement areas. On Wisconsin dairy farms, relatively less manure is collected on farms that manage tie-stall barns than from those that manage free-stall barns, and manure collection per animal is relatively lower on farms having small to medium herd sizes than on farms having large herds kept in free-stall housing (Table 7.4). The current regulatory focus on large farms, therefore, may not address all significant sources of pollution from dairy operations.

Table 7.4. Housing type and herd class differences in manure collection on Wisconsin dairy farms

Category	Subcategory	Manure Collection (% of total manure mass)
Housing type	Freestall (13)[1]	89 (16.5)[2] a[3]
	Stanchion (34)	66 (18.9) b
Herd class	< 50 cows (20)	57 (12.6) c
	50–99 (24)	76 (18.2) b
	100–199 (6)	95 (5.1) a
	200+ (4)	100 (0) a

[1] Number of farms sampled in parentheses.

[2] Mean, standard deviation in parentheses.

[3] Within a category, subcategory means followed by different letters are significantly different ($P < 0.05$).

Source: Adapted from Powell et al., 2005.

States have widely differing regulations regarding water quality protection, and these regulations often vary even among local units of government. In response to widespread nitrate and salt contamination of groundwater and assessments of sources on dairy farms (Chang et al., 2005, Harter and Menke 2004), the Regional Water Quality Control Board (RWQCB) of California's Central Valley has ordered new waste discharge requirements for dairy farms. For those dairy farms covered by this discharge order (about 1600 facilities when the order was published in 2007), all domestic and agricultural supply wells and subsurface soil drainage systems in the production and/or manure land application areas must be sampled annually to verify that ground and surface water quality goals are being met. In addition, these farmers must develop whole-farm nutrient balances, follow a waste management plan targeted at various areas of the farm (fields, manure storage ponds, loafing areas, etc.), and file detailed annual reports (California RWQCB, Central Valley Region 2007). To help farmers comply with the discharge order, sampling procedures for water, manure, soil and plant tissue have been developed (California RWQCB, Central Valley Region 2008). This level of monitoring apparently is the first of its kind to be required of livestock farmers in the United States.

Current environmental regulations in the United States related to animal agriculture are generally based on the number of livestock per farm, but various other environmental performance indicators have been proposed. Whole-farm nutrient balances, or the difference between nutrients imported and exported from farms, provide general indicators of a farm's risk for nutrient buildup, loss, and environmental contamination (Beegle and Lanyon 1994, Koelsch 2005). Online guides are available to help producers and their advisers make these calculations (Harrison and White 2008). Animal-to-cropland ratios relate livestock numbers and the manure they produce to the cropland area available for manure application (Westphal et al., 1989, Saam et al., 2005). There is a direct relationship between a farm's ability to grow feed for its livestock and its ability to recycle manure nutrients through cropland. For example, dairy farms in Wisconsin having approximately 0.91 ha per lactating cow (1.1 cows/ha, 92% of the farms surveyed in Figure 7.4) are self-sufficient in forage and grain production and have adequate cropland area for recycling manure N and P (Powell et al., 2002, Saam et al., 2005). Only 5% of the surveyed farms in the Central Valley of California meet this criterion.

Air quality legislation targeted at animal agriculture is now being promulgated by the EPA. The Comprehensive

Environmental Response, Compensation and Liability Act (CERCLA) enacted in 1980 aims to control the release of hazardous substances that might endanger public health. The Clean Air Act amendments of 1990 required the EPA to establish National Ambient Air Quality Standards for pollutants considered harmful to human health. Of principal concern are fine particles in the atmosphere, referred to as PM 2.5, or particles less than 2.5 micrometers in size. Ammonia is a major precursor for fine particulates (NRC 2003). CERCLA requires the reporting of the release of a hazardous substance in excess of threshold levels (e.g., 45.5 kg of ammonia over a 24-h period). Although CERCLA is focused mainly on emissions of hazardous wastes from industrial plants, the increased size and geographic consolidation of animal feeding operations make their ammonia emissions subject to the notification provisions (Aillery et al., 2006a).

A major challenge facing environmental policy related to animal agriculture is to devise practices that simultaneously protect both air and water quality. Legislation and on-farm practices aimed at controlling air emissions may actually exacerbate the potential for water pollution (Table 7.5). For example, manure injection into soil may reduce ammonia loss (and improve air quality), but it may also increase nitrate leaching (thus reducing groundwater quality), denitrification, and the production of nitrous oxide. Thus technologies to enhance manure recycling must address potential impacts at all stages of the production chain. Tillage practices recommended for decreasing N losses will also have to consider possible impacts on manure P losses in runoff.

Enhanced Feed Management

More precise feeding of protein and mineral supplements can reduce feed costs and imports, concentrations of N and P in manure, and therefore risks of environmental pollution (Table 7.6). Feed use efficiencies (the relative amount of feed nutrients converted into product) provide an indirect basis for evaluating feed management impacts on nutrient concentrations in manure. On dairy farms, management methods can have a large impact on the amount of feed N and P that is transformed into milk and excreted in manure. In Wisconsin, milk production and feed N use efficiency are highest on farms that use total mixed rations, balance rations four times per year, and milk three times per day (Table7.7). Feed P use efficiency is higher on farms that balance rations at least four times per year. These practices transform relatively more feed nutrients into product (milk), and less into manure.

Although some dairy farmers formulate their own dairy cow rations, most rations are formulated by dairy nutrition consultants, many of whom sell feed and may have an economic conflict of interest pushing them to promote overfeeding. Many dairy cows continue to be fed protein and P in excess of the requirements for the milk levels they produce, despite the fact that the relationship between feed levels, manure, and environmental risks is becoming more apparent. Reductions in manure N and P excretion can be obtained simply by feeding closer to the recommendations of the National Research Council's Subcommittee on Dairy Cattle Nutrition (NRC 2003). In Wisconsin, about 40% of 98 surveyed dairy farms had a positive P balance (Powell et al., 2002).

Table 7.5. Comparisons of major N loss pathways for manure application under various management regimes and environmental conditions

Manure Management		Soil Drainage	Nitrogen Loss Pathway		
Rate	Placement		Ammonia	Denitrification	Leaching
Placement Comparisons				*Relative loss*	
Medium	Surface	Well-drained	High	Low	Medium
Medium	Incorporated	Well-drained	Low	Medium	Medium
Medium	Injected	Well-drained	Low	Medium	Medium
Soil Drainage Comparisons					
Medium	Incorporated	Excessively drained	Low	Low	High
Medium	Incorporated	Poorly drained	Low	High	Medium
Application Rate Comparisons					
Low	Incorporated	Poorly drained	Low	Low	Low
Medium	Incorporated	Poorly drained	Low	Medium	Medium
High	Incorporated	Poorly drained	Low	Medium	High

Source: Adapted from Meisinger and Thompson 1996.

Table 7.6. Dietary strategies that reduce the mass and nitrogen (N) and phosphorus (P) content of dairy manure

Feed Management Strategy	Principal Effect of Manure and the Environment
Feed protein in relation to milk production	Reduces total N, urine N, and ammonia production
Refine mineral supplementation	Reduces total P, water-soluble P, and runoff P
Increase feed intake and improve forage quality	Reduces mass and N content per unit milk output

The simple practice of adopting the National Research Council's dietary P recommendations (that is, 0.38% P in the diet for high-producing dairy cows) would reduce the number of farms and amount of land in positive P balance by approximately two thirds.

Dietary P levels on dairy farms in the United States appear to be declining. Regional and national surveys indicate that the average dairy diet P content recommended by consultants and the feed industry in 1999 was 0.48% of ration dry matter. Yet by 2003, feed analysis of over 300 dairy total mixed rations submitted for testing to a commercial laboratory showed a P content of about 0.44 to 0.45% (Satter, unpublished information). Surveys in Wisconsin (CVTC 2004, Powell et al., 2002, 2006) and anecdotal evidence from nutritionists and feed companies confirm that dietary P levels have been reduced.

The decline in dietary P levels can be attributed to two causes: (1) the need to conform to P-based manure land application regulations; and (2) improved confidence that reducing dietary P will not decrease reproductive performance or milk production or quality. Many states have adopted nutrient management regulations to protect surface water quality based on topsoil P levels and risk of runoff (e.g., the Wisconsin soil test P index http://wpindex.soils.wisc.edu/). Full lactation trials (Satter et al., 2005) and related research have engendered higher confidence among feed consultants and producers that dietary P levels could be safely reduced. Lower manure P concentrations resulting from reduced P concentration in the ration helps farmers meet land application limits, thus improving farm profitability and reducing negative environmental impacts of manure.

In addition, water conservation strategies can reduce manure mass, thereby making manure more transportable for land application. The use of water as part of barn cleaning systems can impact nutrient losses in housing facilities, and the amount of manure and waste produced. Low-labor alternatives to water-dependent barn flush systems may be needed to reduce manure mass and facilitate manure handling, storage, and land application. In some locations, the price of water has risen because of water shortages and labor and transportation costs for manure handling, compelling some farmers to drastically reduce water use during barn cleaning, manure handling, and storage.

Improved Manure Handling and Storage

Improved manure handling and storage offers another valuable approach to meeting environmental challenges. The management of animal manure includes collection, handling, storage, treatment, and land application. The specifics of these activities differ depending on the operational

Table 7.7. Impact of feed management and milking frequency on milk production, and feed N (FNUE), and feed P (FPUE) use efficiencies on 54 Wisconsin dairy farms

Practice	Practice Use	Milk Production	FNUE[1]	FPUE[1]
		kg/cow/d	%	%
Use of total mixed rations (TMRs)	Yes	33.5a[2]	27.0a	28.9
	No	26.1b	24.1b	29.0
Balance rations 4x/y	Yes	30.6a	26.5a	30.0a
	No	24.7b	21.0b	24.8b
Milk thrice daily	Yes	40.2a	32.6a	34.6
	No	28.8b	24.9b	28.7
Use Posilac	Yes	37.1a	29.0a	28.7
	No	27.7b	24.6b	29.1

[1] Percentages of feed N and P transformed into milk.

[2] Within a practice, means followed by different letters differ significantly ($P < 0.05$).

Source: Adapted from Powell et al., 2006.

features of a dairy farm, such as housing (Table 7.4) and the presence or absence of manure storage. The recommended expansion of manure storage during the 1980s and '90s was premised on labor efficiency, the notion that storage would facilitate calculation of manure nutrients available, and also allow for land application during favorable weather conditions and close to crop nutrient demands. The appropriateness of manure storage depends, however, on cost levels and on the farmer's ability to spread the costs over many animal units. Most small-scale dairy farms are not able to afford long-term manure storage. Small-scale operations need low-cost alternatives to current practices, such as filter strips, or cement pads with retaining walls for stacking manure. These are also technologies that do not put additional burdens on family labor. Small-scale dairy farms rely almost exclusively on family labor, and the frequent removal and land spreading of manure are compatible with their labor supply. These frequent applications of small quantities of manure are not usually incorporated in the soil, are not uniform with regard to rate over a field, and are subject to volatilization losses of ammonia and runoff of nutrients and other constituents. It is difficult to predict nutrient supply in these systems, so farmers often compensate by ignoring manure nutrient credits.

Manure's impact on air and water pollution can also be reduced by using it as an energy source. Covered lagoons, complete mix digester systems, and plug flow digester systems capture methane, which can be converted into energy and used for gas or electricity production, heating, and cooling. Methane generation, recovery, and energy conversion is becoming increasingly attractive in areas where dairy farm concentration, and therefore the supply of manure and other organic sources, is high. Under these conditions it can produce energy that is competitive with classical energy sources. Community-scale, multiple dairy farm anaerobic digesters are being marketed where 2500 cow-equivalents are available for economic, steady biogas production (Bunting 2007). Starting in 2008, a private company, BioEnergy Solutions, began producing methane from manure digestion for the regional gas and electric company in central and southern California (PG&E 2008), After solid/liquid separation, methane produced by the liquid fraction is cleaned and transported by pipe to local storage, to replace natural gas or to fuel turbines producing electricity.

Enhanced Manure Recycling through Crops

Nationwide, US livestock producers have not been making full use of the nutrients contained in manure. Improvements in this situation are likely only under conditions of more intense regulation and price pressures (Schmitt et al., 1999). Tighter manure management regulations and rapid increases in fertilizer prices now have stimulated a growing interest in using manure in place of fertilizer. The potential here is considerable. As excreted, dairy manure contains about 1.1 million metric tons of N in the United States—a significant amount, when compared with an annual average of around 12 million nutrient tonnes of N applied to plants between 1992 and 2006 (USDA 2008). However, a significant share of manure is still not collected and managed, which may lead to point sources of water contamination (Harter et al., 2001, Powell et al., 2005, Russelle et al., 2007a).

Many dairy farmers now appear to be looking more favorably on manure to reduce fertilizer expenditures. Farm surveys approximately a decade ago (Nowak et al., 1998, Russelle, 1999) determined that Wisconsin and Minnesota dairy farmers were not allowing for applied manure nutrients when calculating the fertilizer requirements of their crops. However, Powell et al. (2007) recently found that most Wisconsin dairy farmers are now integrating fertilizer–manure–legume–N management, resulting in N and P application rates closer to agronomic recommendations. Increased use of manure as fertilizer promises a reduction in overall pollution risks.

Environmentally sound manure application strategies depend on the following:

- Land type (slope, soil texture, nutrient attenuation potential)
- Amounts and method of manure application (surface applied or incorporated
- Timing of application relative to crop growth
- The nutrient demands of the subsequent crops.

Strategies for reducing nutrient losses from manure are therefore necessarily site-specific (Table 7.5). For example, if the potential for nitrate leaching to drinking water aquifers is high, then N management should be a priority consideration. If runoff and erosion potentials to public surface water bodies are high, then P should be the main focus of management. Manure management based on site susceptibilities to N and P losses should aim to mitigate the excessive buildup and loss of soil P, and at the same time lower the risk for nitrate leaching to ground water. Manure land-application strategies need to be based on what pollutants are contributing to a problem (e.g., sediment, nutrients, bacteria), where pollutants are being transported (surface water, groundwater, air), and how the pollutants are being delivered.

Many considerations affect farmers' decisions about where to apply manure, including the amount of manure actually collected, the presence of manure storage, labor availability and machinery capacity for manure spreading, variations in the number of days manure can be spread given regional differences in weather and soil conditions, and the distances between the sites where manure is produced and the fields where it can be applied (Nowak et al., 1998). Manure spreading is also related to landownership—as the percentage of owned cropland operated by livestock farmers increases, so does the percentage of operated cropland that receives manure (Saam et al., 2005). More than half of all farmed land in the United States is rented by farmers, and this land is less likely to receive manure or other improvements, such as drainage.

Technology: No One Size Fits All

Numerous technologies have proven effective in minimizing pollution from livestock operations. However, farmer adoption of manure management technologies is closely linked to need, capability, and cost. Cost depends on farm size, or farmer ability to spread costs over many animal units. Most small-scale dairy farmers do not have additional resources to invest in the housing, manure collection, storage, and land-spreading options that are being promoted to improve manure management.

It is often assumed that pollution is simply a matter of choice, and that policy should "examine the question of how to induce farmers who cause water quality damages through their choice of production practices to adopt pollution prevention and pollution control practices that are consistent with societal environmental quality objectives" (Horan and Shortle 2001). Most livestock producers, however, do not actively choose to adopt practices that pollute, but rather may find themselves in environments that limit their management choices. Differences in soil type may hinder farmers in one geographic area in using as much of their cropland as possible for manure application (McCrory et al., 2004). For example, dairy farmers in the southwest part of Wisconsin, a region characterized by silt loam soils of relatively high permeability and drier field conditions in the spring and fall, have approximately 28% more days during the fall period (September–November) for surface application of manure and 60% more days available for fall tillage and manure injection operations than northeastern Wisconsin, a region of more finely textured and less permeable clayey and red loam soils (Figure 7.13). Flexible manure management regulations are therefore needed to reflect the diverse biophysical conditions farmers face. Advances in geographic information systems and weather forecasting are enhancing our ability to devise manure land-application options that minimize risks of nutrient runoff.

Although it is technologically possible to achieve significant improvements in the environmental performance of dairy farms, most advances will depend on producers voluntarily changing their behaviors. The socioeconomic literature suggests a number of possible reasons why farmers often fail to follow "best management practices," including individual characteristics of farmers and characteristics of the technologies.

Individual Characteristics of Farmers

It is often assumed that many farmers seek only maximum production and are less concerned about environmental issues (Horan et al., 2001). If farmers are unconcerned about environmental impact, the argument goes, one might therefore expect them to be reluctant to change management practices, or to make significant investments that would enhance the environmental performance of their farms. However, farmers are more aware of environmental concerns than is often appreciated. Most farmers agree that manure management is a critical issue in the industry, that they must do a better job of protecting the environment, and that there is room for improvement. Most attitudinal surveys have documented that levels of environmental concern are higher if the questions focus on local, regional, or national level problems, and lower if the question asks farmers whether they were concerned about environmental impacts of their own farm operation. This latter attitude may stem from a desire to avoid self-incrimination and/or a lack of recognition about deficiencies in their own practices. Awareness and concern about environmental problems are only partial prerequisites for change. These first must be personalized, but then knowing what to do, being able to do it, and a willingness to act are required to achieve behavioral changes that affect environmental outcomes.

Characteristics of the Technologies

Many studies have shown that the costs of some environmentally sound technologies may outweigh the benefits farmers expect to receive. For example, the added costs and large labor input required to handle, store, transport, and land-spread manure—with little confidence of an economic return—deters many from managing manure more effectively (Nowak et al., 1998). Historically, commercial fertilizers have been relatively inexpensive (Figure 7.6), and can be more easily handled and supply plant nutrients more readily than manure. Perhaps the biggest challenge facing efforts to improve manure management is therefore to create more meaningful incentives.

The compatibility of new agricultural technologies with existing farm management, land, labor, and capital resources is another prime determinant of adoption patterns (Nowak 1987). Although lined and covered manure storage is obligatory in some European counties, this technology has been adopted by only the largest dairy operations in the United States (USDA 2004b). The adoption of lined manure storage depends on the ability of farmers to spread costs over many animal units. Thus, even when public funds are available to subsidize the construction of manure storage, larger operations will continue to be more likely than smaller farms to invest in such structures. There may also be different adoption rates depending on farmer age. Because significant capital investments are required for manure storage, this technology is likely to have a relatively long payback period. It may not make economic sense, therefore, for dairy farmers nearing the end of their career to invest in manure storage facilities.

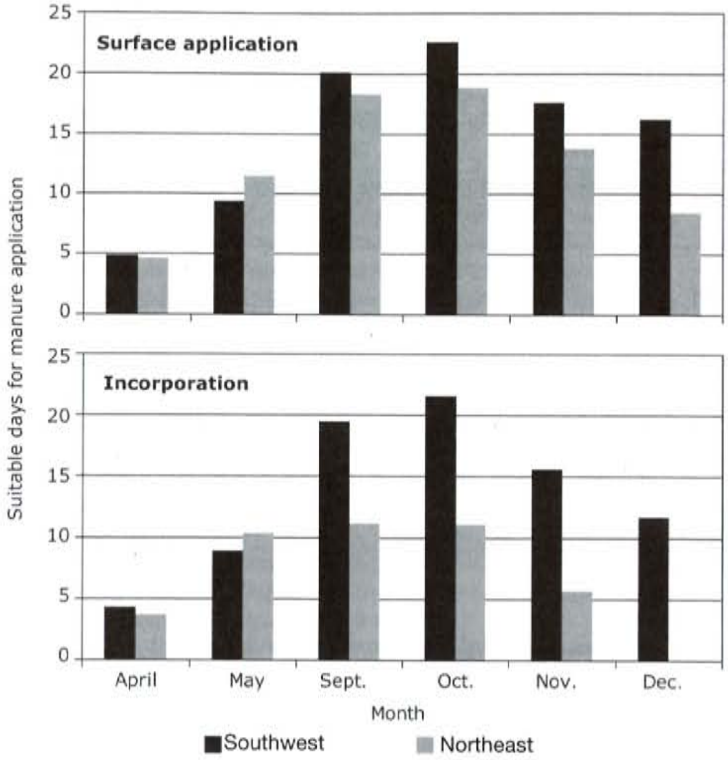

Figure 7.13. Regional differences in manure surface application and incorporation, Wisconsin.
Source: McCrory et al., 2004.

On farms that rely solely on family labor, improved manure management may be constrained by seasonal labor bottlenecks. In the US Northeast and Midwest, spreading large volumes of dairy manure in the spring can be a monumental task when farmers are already working long hours preparing and planting fields for a relatively short growing season. In these regions, timely planting is critical to high yields. Manure spreading within such seasonal labor constraints is best done in small installments, on a year-round basis, as and when labor is available. One promising alternative to frequent spreading of manure is corralling dairy cattle directly on cropland, which can improve N cycling and reduce gaseous and dissolved N losses (Powell and Russelle 2009).

Increasing herd size, greater animal-to-land ratios, and environmental regulation drive the need for regional integration of dairy farms with crop producers for manure sharing. This model has typified swine production in the United States and Canada for manure utilization, but dairy farms have greater potential to utilize the variety of feedstuffs produced by neighboring crop farms (Russelle et al., 2007b). This two-way flow of nutrients has the potential for improving sustainability of both crop and livestock enterprises (Steinfeld et al., 1997, Powell et al., 2004).

Partnerships to Enhance Nutrient Management on Dairy Farms

The development, dissemination, and adoption of technologies that enhance environmental performance are not straightforward processes. They necessitate partnerships consisting of key players, as well as policies that stimulate investments and inducements that integrate and improve nutrient management (Table 7.8). Hence attempts to improve nutrient management must engage dairy producers, their feed and fertilizer consultants, and policy makers in critical assessments of the real and perceived risks of nutrient utilization, the key factors that affect nutrient transformation and loss, and how these factors may be managed more effectively to enhance profitability and reduce environmental impacts. For example, nutrient supply dealers, such as representatives of the feed and fertilizer industries, need to be integral partners in any effort to reduce nutrient loads in manure through optimal feeding, or through land application techniques that combine manure and other nutrient sources (e.g., fertilizer, legume-N) to optimize plant nutrient use.

Involving the nutrient supply and service industries that affect farmer nutrient use behavior will be critical to achieving desired goals of improving regional and whole-farm nutrient balances. Pilot insurance policies are being tested to reduce risks to farmers of possible production loss due to reductions in feed or fertilizer nutrient use. Anecdotal evidence suggests that some policy makers would advocate disincentives, such as fines, to limit suppliers from selling feeds and fertilizers to farmers that exceed published recommended levels.

Improved manure collection, treatment, and storage technologies are expensive and will also require cost

Table 7.8. Possible investments and inducements to improve feed and manure management on dairy farms

Technology domain	Key players in technology implementation (order of importance)	Investments		Inducements	
		Capital	Supplies and Services	Incentives (e.g., cost share)	Disincentives (e.g., taxes or fines)
		Relative investment opportunity and use of inducements (1= low; 5 = high)			
Feeding strategies	Producer, feed industry, research, extension/outreach	1	4	2	1
Manure collection, treatment, and storage	Producer, extension/ outreach, research, policy	5	3	5	1
Manure land application	Producer, policy, custom manure haulers, extension/ outreach	3	5	3	3

sharing if farmers, especially small- to medium-size farms, are to adopt them. Conventional technologies may be financially out of reach of resource-limited dairy producers, and for them alternative low-cost technology options will likely be needed. Because of narrow profit margins, farms with small herd sizes are much less able than larger farms to afford technologies that improve environmental performance but not improve profits. Many current environmental technologies are cost effective for medium- and large-scale farms. Small farms having high pollution risks may require not only different technologies but also additional subsidies, which may include full cost subsidies.

Part of manure mismanagement can be attributed to shifts in educational messages. As dairy production has expanded and specialized, manure often has been viewed as an undesirable by-product. The widely adopted term *animal waste* has been counterproductive to the essential message that manure is a valuable source of fertilizer and energy. When *waste disposal* became an engineering term associated with industrial livestock systems, connotations of manure's intrinsic value were lost (Nowak et al., 1998). Alternative terminology to *waste* management should be sought when developing training materials aimed at affecting farmer behavior and environmental impact.

Conclusions

The US dairy industry has been undergoing great change. More cows are being kept on smaller land areas, and more feed is being purchased rather than homegrown. Greater cow numbers, supported by importation of relatively inexpensive feed and fertilizer, have increased the risk of on-farm nutrient surplus, soil nutrient buildup, nutrient loss, and environmental pollution. The dairy industry could benefit from a better understanding of the key factors that impact nutrient inputs and outputs and resource flow rates within subcomponents of the feed–animal–manure–soil–environment continuum. Such information needs to be incorporated into integrated nutrient management recommendations adaptable to prominent dairy system types.

Restoring the balance between livestock density and the nutrient adsorptive capacity of the surrounding environment will be central to any strategies aimed at improving the performance of any animal industry, including dairy. This will involve a series of different technological, financial, regulatory, and institutional tools. Technological tools encompass strategies such as optimal feeding to reduce the amount of manure nutrients produced, and therefore the land base required to recycle manure nutrients. Technology will also play a key role in enhancing manure collection, handling, storage, and land application to maximize manure nutrient recycling. Consensus needs to be sought on the comparative advantages of federal, state, and local governments in promulgating and enforcing environmental standards. In some locations, regulatory tools may be needed to strengthen zoning laws and regulations and to arrive at a better spatial distribution of crop/pasture and livestock production. Private institutions, especially different stakeholders in the feed and fertilizer industries, may need to change practices (such as commissions on sale of nutrients) to maximize the efficient use of agricultural nutrients. Associative institutions, such as cooperatives, may be able to facilitate areawide integration of specialized crop and dairy production and exert peer pressure to enhance environmental performance.

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