The Economic Impacts of EPA's CAFO Rule on Dairy Farms
in Cornbelt, upper-Midwest, and Northeast regions

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ABSTRACT. EPA has proposed a rule that would bring more dairy farms under regulation and restrict manure application more closely to a crop's need of phosphorous. This paper uses whole farm modeling applied to survey data to assess the impact of proposed regulations on dairy farms in the Cornbelt, upper-Midwest, and Northeast regions. Results show that the proposed rule affects 2.7 percent of surveyed dairy farms (over 200 milk cows) in these regions and causes income losses for 40 percent of farms spreading slurry manure on crops.

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The environmental effects of concentrated livestock feeding operations and their associated waste management practices are an increasing source of public concern (Innes, 2000). In response, USDA and EPA have developed a Unified National Strategy for Animal Feeding Operations (AFOs). This strategy calls for all AFOs to implement Comprehensive Nutrient Management Plans (CNMP) to minimize the impact on water quality and public health (USEPA, 1999). As part of this strategy, EPA has recently proposed several changes to the current National Pollutant Discharge Elimination System (NPDES) permit regulations (USEPA, 2001). These changes include redefining which facility of a concentrated animal feeding operation (CAFO) would be subject to the NPDES regulation, and specifying new permit requirements for CAFO manure application at crop production and land application areas.

The U.S. dairy industry in the last 50 years has undergone dramatic structural change. Technical innovations, changes in production system and specialization had lead to large concentrated dairy operations (Short 2000). The most encompassing alternative that EPA is proposing for defining a large dairy operation is a three-tier structure which specifies a dairy farm as a CAFO: (1) if the number of mature dairy cows is over 700, or (2) if it has between 200 and 700 dairy cows and meets certain conditions, or (3) if it has fewer than 200 dairy cows and is specifically designated by the permit authority. All facilities in the second group must either certify that they do not meet the conditions for being defined as a CAFO or must apply for a permit. This CAFO definition, lowering the minimum number of dairy cows in a regulated facility from the current over 700 to over 200 cows, will subject many more dairy farms to regulation than is currently the case.

Both new and existing CAFOs would be affected by EPA's proposed new NPDES guidelines covering animal confinement and manure storage areas, and land application and off-site transfer of manure. For land application of manure, all CAFO operators may need to follow phosphorous (P)-based nutrient management plans (NRCS, 2001). Under this plan, CAFOs must restrict manure application to the amount of P needed by crops or restrict manure application to the amount of nitrogen (N) needed by crops in areas of low P in the soil. These proposed changes in NPDES guidelines along with a new CAFO classification could affect milk production costs and reduce dairy farm profits.

OBJECTIVE

The primary objective of this research is to assess the economic impact of EPA's proposed regulation on dairy operation of CAFO farms and their profitability in the cold-and-cool humid region, which includes states in the Corn Belt, Upper-Midwest, and Northeast regions (Figure 1). In 2000, these regions had more than 84 percent of U.S. dairy farms and account for 65 percent of U.S. milk production. Most dairy farms in these regions spread manure on cropland and produced more than half of the feed for cattle consumption.

This research addresses the following questions: How many additional dairy farms would be subject to the proposed EPA regulation? What percent of regulated farms would have to arrange for additional land to properly disperse manure and what acreage would be needed? What would be the average cost per farm and per cwt of milk sold to comply with the restriction of land application of manure? What would be the marginal value (shadow price) to the farm from reducing the amount of manure? An individual whole-farm analysis was used for this study. The dairy operation of each affected farm surveyed was modeled using production characteristics of the farm reported in a national survey of dairy operations conducted under USDA's 2000 Agricultural Resources Management Study (ARMS).

ADDITIONAL FARMS AFFECTED

A total of 872 dairy farms responded to this survey, representing 71,331 U.S. dairy farms when expanded by survey weights. Table 1 shows the distribution of these farms by operation size and by region (Figure 1). Most dairy farms in the U.S. were small, having a facility size less than 200 milk cows in 2000. About 83 percent of these small farms were located in the cold-and-cool humid region. Most large dairy farms, having facility size greater than 200 milk cows in operation were located in the warm-and-hot arid region and the cold-and-cool humid region. Current EPA regulations, requiring farms over 700 cows to have permits, affect 1,214 dairy farms or about 1.7 percent of dairy farms in the nation. The proposed new CAFO definition would affect an additional 4,729 farms or about 6.6 percent of U.S. dairy farms. Two separate studies were conducted: one focuses on dairy farms in the warm-and-hot arid region and the other on dairy farms in the cold-and-cool humid region. There were significant differences between these two regions, particularly in feeding operation and in manure management system used.

In this study, we analyze and report the impact of the regulation on dairy farms only in the cold-and-cool humid region. The EPA's proposed regulation would affect a small number of dairy farms in this region. A total of 1,838 large dairy farms will be affected (Table 1). The proposed new definition of a CAFO would bring an additional 1,653 farms, about 2.7 percent of the dairy farms in the region.

ASSESSMENT MODELS

A mathematical programming method adapted for dairy operations was used to formulate individual whole-farm models for this study. A whole-farm model was constructed for each of the selected surveyed farms, assuming that the farm would maintain the same herd size and the same crop production practices under the proposed restrictions. The model was based on recommended levels of dairy feed rations comprised of roughage and concentrates, which were either grown on-farm or purchased off-farm. The model is presented. The definition of the parameters and variables used in the model is given in the Appendix.

Objective Function

We assume that the dairy farm operator will maximize the net return, Z, given the availability of manure produced on the farm and the crop acreage operated by the farm on which manure can be applied. The net return is defined as the residual return to operator labor and management, and land ownership, and the capital investment of the dairy operation (excluding fixed costs for crop production). The objective function that represents the net return is specified as:

$$
\begin{aligned}
(1)\quad \text{Maximize}\quad Z = & \; [\, mp\, \mathbf{mq}\, \mathbf{au}] + [\, \textstyle\sum_i (p_i\, \mathbf{y_i} - o_i) C_{ims} - \sum_i \sum_j f_j\, F_{ij}\, C_{ims} - MAC - r\, L_S \,] \\
& + [\, (\textstyle\sum_i (p_i\, \mathbf{y}_i - o_i - \sum_j f_j\, d_{ij} \mathbf{y}_i)\, C_{ins} \,] \\
& - \; [\textstyle\sum_i \sum_j f_j\, F_{ij}\, C_{imf} + \sum_j f_j\, d_{ij} \mathbf{y}_i)\, C_{inf}] \\
& - \; [\textstyle\sum_v n_v\, N_v]
\end{aligned}
$$

On the right-hand-side of (1), the terms in the first bracket define the returns from milk sales. The terms in the second bracket define the net returns from the sale of crops produced on acres treated with manure. The terms in the third bracket define the net returns from the sale of crops produced from non-manured acres. The terms in the fourth bracket define the cost to produce feed crops grown on manured and non-manured cropland, and the term in the last bracket is the cost for the purchased feeds. MAC in the second bracket is the manure application cost, which will be defined later. The bold parameters in equation (1) and in the equations that follow are estimated for each individual farm from the survey data. The optimization is subject to a variety of constraints.

Acreage Restriction. This constraint ensures that the sum of acres used to grow the different crops is less than or equal to the total number of acres available on the farm and additional land leased for manure application.

$$(2) \qquad \sum_i (C_{imf} + C_{ims} + C_{inf} + C_{ins}) = \boldsymbol{L_o} + L_s$$

Manure Use Restriction. This constraint ensures that all manure produced on the farm is spread on crops.

$$(3) \qquad \sum_i A_i \, (C_{imf} + C_{ims}) = \boldsymbol{w\,au}$$

Per-acre Nutrients Required by Crops. A crop requires nutrients (N, P, and K) to produce the yield expected. This constraint requires that the applied amount of each nutrient per acre from manure and supplemental commercial fertilizer meets the amount needed by the crop.

$$(4) \qquad F_{ij} + u_j A_i - d_{ij}\,\boldsymbol{y_i} \geq 0 \text{ for } i \text{ and } j$$

Nutrient Application Restrictions. EPA's proposed rule will restrict the per-acre amount of P or N from applied manure not to exceed the per-acre amount of the nutrient needed by the crop.

$$(5) \qquad F_{ij} + u_j A_i + \boldsymbol{y_s} - d_{ij}\,\boldsymbol{y_i} + S_{ij} \leq 0 \text{ for } i \text{ and } j$$

where S_{ij} is the amount of surplus manure nutrient j applied to crop i but not utilized by the crop and $S_{ij} > 0$. S_{ij} has no value to the farm. S_{ij} is set to zero when nutrient j is restricted. Surplus manure nutrients P can occur when the manure application rate is restricted based on N because one unit of manure supplies more P than N needed by the crop (such as corn).

Manure Application Cost (MAC). The cost of transporting manure by wagon from storage to the field and then applying it includes a base charge for manure application plus a mileage charge (Fleming et al.). Specifically, the cost is:

$$(7) \qquad MAC = [(bc)(\boldsymbol{ma})] + [(mc)(\boldsymbol{ma})\ TD]$$

where ***ma*** is the total volume (in 1000 gallons) of manure applied to the manured field, *bc* is the field application cost (in $ per 1000 gallons), and *mc* is the manure transportation cost (in $ per 1000 gallons per mile). The travel distance (*TD*) is the sum of travel miles to each block of the manured field. For example, $TD = (0.25)\{(\sum_i (C_{imf} + C_{ims})/160 + (\sum_i (C_{imf} + C_{ims})/160)(\sum_i (C_{imf} + C_{ims})/160 - 1)/2\}]$, assuming that the farm can divide each square mile (640 acres) of manured field into four 160-acres rectangular blocks. Each block is 0.25 mile by 1 mile. The total travel distance then is the sum of round trips from the storage to each of blocks.

Herd Feeding Requirements (NAS, 1978). The dairy herd obtains nutrient concentrations in the ration fed for milk production and herd maintenance. These concentrations include net energy, crude protein, and crude fiber from roughage. These nutrients can come from homegrown crops and/or purchased mixed feeds. The dairy operator must ensure that the recommended daily minimum requirements of these nutrients are provided in the rations. The following constraints ensure that the feeding requirements for net energy, crude protein, and crude fiber are met on an annual basis.

The annual supply of net energy from purchased feeds and homegrown crops is greater than that required by the herd.

$$(7) \qquad N_1 + \sum_i a_i (\boldsymbol{y_i} (C_{imf+} C_{inf})) \geq \boldsymbol{nen\ au}$$

The supply of crude protein from purchased feeds and homegrown crops must be greater than that required by the herd.

$$(8) \quad N_2 + \sum_i b_i(\boldsymbol{y_i}\,(C_{imf} + C_{inf})) \geq \boldsymbol{cpr\ au}$$

The supply of dry matter in the ration from purchased feeds and homegrown crops must be less than 4 percent of animal weight.

$$(9) \quad \sum_v h_v N_v + \sum_i g_i\,(\boldsymbol{y_i}\,C_{imf+}\,C_{inf}) \leq 0.04\,(1000*365\ \boldsymbol{au})$$

The supply of crude fiber in the dry matter of the ration must be greater than 1.5 percent of animal weight.

$$(11) \quad N_3 + \sum_i c_i\,(\boldsymbol{y_i}\,(C_{imf+}\,C_{inf})) \geq 0.015\,(1000*365\ \boldsymbol{au})$$

DATA AND ASSUMPTIONS

In this empirical research, we used data from the 2000 ARMS survey to estimate key parameters for the models. The parameters (indicated by the bold faced characters in the Appendix) estimated include crop yields, crop acres owned, pasture acres, number of animal unit, quantity of milk produced, amount of manure produced, minimum required amounts of net energy, crude protein, and crude fiber, and maximum amount of roughage per animal unit (au). In addition, the research performed in this study made several key assumptions.

1. All farms using a similar manure system were assumed to have the same coefficients for manure production, nutrients in manure, manure transportation and field application costs, and nutrients required by crops. These coefficients were obtained from published and unpublished sources (Tables 2 and 3). Manure from manure pits under buildings, other manure pits, slurry or other manure tanks was assumed to be slurry, with relatively high nutrient content. Manure from single and two- stage lagoons was assumed to be liquid with low levels of nutrients.
2. The operation maintained the same herd size, type of dairy operation, and manure storage

and application system regardless of the manure application restrictions.

3. The operation leased additional land when needed to meet manure nutrient application restrictions, and cropped and harvested this land the same as existing land. Cash rent paid for additional land was $100 per acre (NASS, 1999). Farms in the region would be able to lease additional land to utilize manure.
4. Crops grown on the farm were limited to the type of crops grown on the surveyed farm in 2000. Surveyed yields of these crops were used to determine the amount of nutrients needed for crop growth in complying with the restrictions. The same yields were assumed for crops grown on both manured and non-manured acres.
5. Gallons of manure that the farm must spread on cropland annually were the sum of manure generated by lactating and dry cows, replacement heifers, and bulls on the farm (Sutton et al., 1994).
6. Manure application costs include the field application cost and the hauling cost. The field application includes loading manure from the storage and spreading manure on the field. Hauling cost is the expense to transport manure from storage to the application field, using a 3000-gallon-tank wagon. The field application cost per 1000 gallons was $10 for slurry manure and $8 for lagoon liquid manure, and the hauling cost was $0.9 per mile per 1000 gallons (Iowa State University, 1999).
7. Cropland owned also included leased acres by the farm.
8. The computation of total animal units for the farm was based on body weights of different types (cows, heifers, and bulls) of animals in the farm. One animal unit is 1000 pounds. The computation of the amount of animal nutrients required for the herd in the farm was based on

the composition of animals on the farm (Table 4). The computation of the animal nutrients supplied by crops was based on information in Table 5.

9. Crop market prices (p_i) were the price for the crops in 2000: $1.89/bu for corn, $4.75/bu for soybeans, and $2.54/bu for wheat in the Cornbelt region (USDA, 2001). Fertilizer nutrient prices (f_j) used were $0.217/lb. for nitrogen, $0.31/lb. for phosphate and $0.17/lb. for potash based on April prices (USDA, 2000). These fertilizer nutrient prices also include application costs.

10. Crop production costs (o_i) excluding fertilizer and land ownership costs were $228/ac for corn, $156/ac for soybeans, $105/ac for wheat in 1999 (ERS, 2001), $13.67/ton for corn silage, $54/ton for alfalfa haylage, and $19/ac for maintaining grass pastures (Wisconsin and Iowa crop budgets, 2000). Alfalfa Hay was re-seeded every five years.

11. The costs for purchased feeds (n_v) were based on the estimated nutrient prices of feeds. The estimated price for net energy was $0.0284/Mcal, for crude protein $0.1328, and for crude fiber $0.0164. A regression analysis was used performed by using feed purchased data from the 2000 ARMS and the feed nutrient composition data from National Academy of Science.

12. The amount of dry matter (h_v) for one Mcal purchased was 1.08 lbs, based on corn grain, for one pound of crude protein was 2.5 lbs, based on cotton meal purchased, and for one pound of crude fiber was 3.22 lbs, based on alfalfa purchased. (NAS, 1978).

SCENARIOS AND INDICATORS

One baseline scenario and two restriction scenarios were specified for assessing the farm-level impacts:

Baseline: The manure application rate was unrestricted and manure was applied to the number of manured acres reported by the survey farms. The baseline simulated the land application of manure by surveyed farms in the year 2000.

N-restriction: The manure application rate was restricted not to exceed the nitrogen needs of individual crops. Acres receiving manure were bounded by tillable land owned and leased. This restriction is part of CNMP for the areas where P in soil is low (NRCS, 2000).

P-restriction: The manure application rate was restricted not to exceed the phosphorous needs of an individual crop. Acres receiving manure were bounded by tillable land owned and leased. This restriction is part of CNMP for areas where P in soil is high.

Three indicators are used to assess the farm-level impacts of the restrictions: (1) additional leased acres needed to comply with the restrictions, (2) changes in net returns from dairy production, and (3) changes in the marginal cost of manure (in 1000 gallons). Net returns were the residual returns from the sale of milk and crops from both manured and non-manured acres, less the costs of crop production and feeds purchased. Crop production costs included fixed and variable costs and land rent for additional leased acres. The marginal cost of manure is a reduction in the net farm income from applying the last 1000 gallons of manure on the farm. The average and the range (the maximum and minimum) of each indicator are reported.

RESULTS OF THE ANALYSIS

There are 20 surveyed large farms in the region that will be affected by the proposed regulation. Of these farms, only 18 of them used all manure produced on the farm, representing 89 percent of affected farms in the region. These 18 affected farms were divided into two groups according to the manure storage system used to assess the impact of the regulation on the farms. Nine surveyed farms mainly used slurry storage systems, and the other nine surveyed farms mainly used the lagoon storage system. Each of these 18 farms was analyzed individually. Tables 6 and 7 show results for the two groups investigated. Each table summarizes the average animal units, average manure produced, and acres owned. Each table also summarizes manured acres, fertilizers used, home-grown and purchased feeds in terms of animal nutrients, cost of crop production, return from sales of milk and crop, and net returns under each scenario.

Additional acres needed

Table 8 shows additional leased acres needed to comply with a N-restriction or a P-restriction. The results indicate that both N- and P- restrictions had no impact on the surveyed dairy farms using the lagoon storage system. Farms in this group had adequate additional acres for spraying lagoon liquid manure to comply with the restrictions. The restrictions, however, would have a significant impact on farms using slurry storage systems. With the N-restriction, 57 percent of the affected farms needed to lease, on average, 328 additional acres for spreading manure, and with the P-restriction, 40 percent of the affected farms needed to lease, on average, 236 additional acres. A larger acreage is needed under the N-restriction than under the P-restriction to spread manure. This implies that, if CAFO operators follow P-based nutrient management plans under the proposed regulation, some of them could over apply manure N for crop production.

Average Compliance Costs.

Some farms would have to expand manured acres for crop to comply with the restrictions and might affect their incomes. An increase in crop production from the expanded manure acres would result in an increase in the supply of animal nutrients from homegrown crops and reduce the cost of purchased feeds by the farm. A positive (negative) compliance cost indicates the saving from the feed cost plus the returns from the sale of the excess crops produced from the expanded manured acres is less (greater) than the cost to produce crops. Table 9 shows the average compliance cost per farm and per cwt of milk sold to comply with the restrictions by the surveyed farms in both groups. The average compliance cost for the farms with the slurry manure in the first group was $41,536 under the N-restriction, and $37,217 under the P-restriction. The largest income reduction for the farms was $101,953 and $104,362, respectively. About 57 percent of the surveyed dairy farms would have a net income loss and 33 percent would have a net income gain under both restriction scenarios. The average compliance cost to the farms with lagoon liquid manure in the second group was -$1,455 (an income gain of $1,455) under both restriction scenarios. The largest income gain for the farms was $12,865 under both restriction scenarios. About 46 percent of the farms would have an income gain, while 36 percent had no cost increase or income gain. An income gain for some farms in this group was mainly the result of reducing their feed purchase cost due to the additional feed produced on own and leased acres.

Table 9 also shows compliance costs per cwt of milk sold. As expected, surveyed dairy farms in the first group had a relatively large compliance cost. The average compliance cost for the farms in the first group was relatively large. The average cost was $0.51, ranging from a small net income gain, $0.09 to $2.73 under the N-restriction, while the average cost was $0.37, ranging from a small net income gain, $0.10 to $1.35 under the P-restriction. The average compliance cost for farms in the second group was a gain and relatively small, about $0.03, ranging from zero to $0.21 under both restriction scenarios.

Marginal Costs (shadow prices) of manure

Information on the marginal cost (shadow price) for the farm to utilize the last 1000 gallons of manure could help the operator improve the dairy operation's efficiency. It could help the operator, for example, to determine the proper size of the dairy operation to efficiently use manure to improve net income, assess the economic feasibility of adopting alternative manure technologies to process manure, and to move manure off the farm by paying hauling fees.

The average marginal cost of slurry manure for surveyed dairy farms increased substantially from $9.55 under the baseline scenario to $35.36 under the N-restriction scenario and to $28.71 under the P-restriction scenario (Table 10). The average marginal cost of lagoon liquid manure was $7.98, ranging from $6.58 to $11.58 under the baseline scenario (Table 10). Both N-and P-restriction restrictions caused relatively small decreases in this cost. For those farms with large marginal costs under the restrictions, off-site disposal of their cow manure can be a viable option to reduce this cost when the hauling fees are less than the marginal cost.

CONCLUSIONS

In response to public concerns about the environmental effects of large concentrated livestock feeding operations and their associated waste management, EPA has proposed several changes to current permit regulations. The changes include redefining concentrated animal feeding operations (CAFOs), and specifying permit requirements for land application of manure. As a result, more dairy farms will face increased restrictions on how they apply manure to land. This study assessed the economic impacts of these changes on dairy farms surveyed by 2000 ARMS in the cold-and-cool humid regions, which includes states in the Cornbelt, Upper-Midwest, and Northeast sections of the United States.

In 2000, more than 84 percent of dairy farms in the United States were located in these regions and most of them had less than 200 cows. About 2.7 percent of these farms were large and would be subject to regulation under the proposed new definition of CAFO.

Of the 18 dairy farms analyzed in this study, the proposed phosphorous (P)-based nutrient management plan, which restricts manure application rate based on a plant's need of P, had no impact on those CAFO farms storing manure in lagoons and spreading liquid manure on crop and pastureland. The current nitrogen (N)-based plan, which restricts manure application based on crop's need of N, also had no impact for the 18 dairy farms analyzed in this study. Farms in this group had adequate cropland to comply with both plans and some farms in this group could slightly improve their farm income by apply manure nutrients to the plant's needs.

However, the proposed P-based or the current N-based plans would have substantial impacts on most CAFO farms storing manure in underground or above-ground slurry tanks and spreading slurry manure on crop and pastureland. About 40 percent of farms in this group would have to lease additional land to comply with the P-restriction and about 57 percent of farms with the N-restriction. Farms in this group, on average, would have to lease 236 acres under the P-restriction, and 328 acres under the N-restriction.

The cost to comply with the P-restriction, on average, was $37,217 and the cost to comply with the N-restriction was $41,536. The compliance cost per cwt of milk sold, on average, was $0.37 under the P-restriction and $0.51 under the N-restriction.

The shadow price per 1000 gallons of manure increased from the current (baseline) $9.55 to $28.32 under the P-restriction and to $35.14 under the N-restriction.

Inferences made in this study apply only to the sub-sample of 18 surveyed dairy farms. For these dairy farms, EPA's proposed P-based nutrient management plan might cause excess N nutrient on the cropland where farms comply with the P-restriction.

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Appendix. Definition of parameters and variables used in the model

The subscripts (sets) considered in the model are as follows:

i	crop grown; corn grain, corn silage, sorghum grain, sorghum silage, soybeans wheat, alfalfa hay, other hays.
j	fertilizer nutrient; N, P, K.
m	manured land.
n	non-manured land
s	land for sale crops
f	land for feed crops.
v	animal nutrients; net energy (v=1), crude protein (v=2), crude fiber (v=3).

The parameters considered in the model are as follow:

p_i	market price for crop *i*.
mp	milk market price per cwt.
$\boldsymbol{y_i}$	crop yields, bushels (tons) per acre, for crop *i*.
0_i	other production costs for crop *i*.
f_j	cost for fertilizer *j*.
r	land rent for leased acres.
Lo	land current owned and leased by the operator.
Lp	pastureland.
u_j	pounds of *j* nutrient in 1000 gallons of manure.
d_{ij}	pounds of *j* nutrient needed to produce one bushel (ton) of crop *i*.
au	number of animal units. One animal unit is 1000 pounds of animal weight.
w	gallons of manure produced per au.
mq	quantity of milk (cwt) produced per au.
Me	minimum amount of net energy (Mcal) required for one animal unit.
Mp	minimum amount of crude protein required for one animal unit.
Md	maximum daily amount of roughage per lb of animal.
n_v	purchase prices for one unit of net energy (Mcal) (v=1), one pound of crude protein (v=2), and one pound of crude fiber (v=3).
h_v	lbs of dry matter for one (Mcal), one pound of crude protein, and one pound of crude fiber.
Ma	total volume (1000 gallons) of manure applied. ***Ma = w au.***
Bc	base charge ($) for hauling 1000 gallons of manure.
Mc	manure transportation cost ($) per 1000 gallon per mile.
a_i	amount of net energy (Mcals) in one bushel (ton) of crop *i*.
b_i	amount of crude protein (lbs) in one bushel (ton) of crop *i*.
g_i	amount of dry matter (lbs) in one bushel (ton) of crop *i*.

The variables considered in the model are as follows:

Ls	additional acres leased.
C_{ims}	manured acres produced crop *i* sold to the market.
C_{imf}	manured acres produced crop *i* for feed.
C_{ins}	non-manured acres produced crop *i* sold to the market.
C_{inf}	non-manured acres produced Crop *i* for feed.

F_{ij} pounds of *j* nutrient applied to crop *i*.

A_i amount (1000 gallons) of manure applied on crop *i*.

MAC cost to transport and spread manure on crops.

FDC cost for purchased feeds.

S_{ij} the amount of surplus manure nutrient *j* applied to crop *i* but not utilized by the crop.

N_v purchased amounts of net energy (Mcals), crude protein (lbs), and crude fiber (lbs).

Figure 1. Four dairy producing regions in U.S.

Table 1. Distribution of dairy farms by facility size of operation and by region, 2000

Regions	Milk cows < 200	200 ≥ milk cows < 700	Milk cows ≥ 700
	Number of dairy farms (percent of farms in the nation)		
Warm and hot arid region	1,434 (2.0%)	2,087 (2.9%)	761 (1.1%)
Cool and cold arid region	1,417 (2.0%)	436 (0.6%)	212 (0.3%)
Warm and hot humid region	3,701 (5.2%)	553 (0.8%)	56 (< 0.1%)
Cold and cool humid region	58,836 (82.5%)	1,653 (2.3%)	185 (0.2%)
Subtotal	65,388 (91.7%)	4,729 (6.6%)	1,214 (1.7%)

Table 2. Nutrient contents in dairy manure[a]

	Manure produced	N	P2O5	K2O	
Solid manure	Tons/yr				
Cow (per manure cow)	14.0	126	49	91	
Heifer (per heifer capacity)	6.5	63	24	44	
Calf (per calf capacity)	1.5	14	5	8	
Bull					
Herd (per milk cow)	20.1	185	72	132	
Semi-solid liquid	Pounds/yr				
Cow (per milk cow)	6,000	186	90	114	
Heifer (per heifer capacity)	3,000	96	42	84	
Calf (per calf capacity)	700	19	10	16	
Bull					
Herd (per milk cow)	8,816	276	129	193	
Lagoon liquid	Pounds/yr				
Cow (per milk cow)	11,000	46	19	33	
Heifer (per heifer capacity)	6,000	26	12	18	
Calf (per calf capacity)	1,200	4	1	3	
Bull					
Herd (per milk cow)	16,616	70	30	50	

[a] As manure leaves storage for land application.

Source: Sutton A.L.,D.D. Jones, B.C. Joern and D.M. Huber. Animal Manure as a Plant Nutrient Resource. Purdue University Cooperative Extension Service, 1994

Table 3. Amount of nutrients needed by selected crops

Crops \ Nutrients	N	P2O5	K2O
Corn grain (lbs/bushel)	1.23	0.38	0.46
Corn silage (lbs/ton)	9.33	4.33	12
Sorghum silage (lbs/ton)	9.33	4.33	12
Soybeans (lbs/bushel)	0.54	1.00	1.90
Wheat (lbs/bushel)	1.0	1.42	0.7
Alfalfa hay (lbs/ton)	56.00	26.00	64.00
Other hays (lbs/ton)	46.66	33.33	20

Source: Sutton A.L.,D.D. Jones, B.C. Joern and D.M. Huber. Animal Manure as a Plant Nutrient Resource. Purdue University Cooperative Extension Service, 1994.

Table 4. Dairy daily nutrient requirements on dry matter basis

	Net energy (Mcal per lb of body weight)	Crude protein (lbs/ per lb of body weight)	Minimum crude fiber (percent of total dry matter fed)	Minimum forage (hay-equivalent) (percent of body weight)	Maximum dry matter (percent of body weight)
Cow lactating for 10 months plus gestating for 2 months.	0.0074[a]	0.00037[b]	17	1.5	3
Growing Heifer	0.0097 [c]	0.0011[d]	17	1.5	3
Mature bull	0.0073 [e]	0.00051[f]	15	1.5	3
Milk production (per lb of milk)	0.31 [h]	0.037[I]			

[a] Maintaining 1320 lbs. of a mature cow lactating 10 month and plus last two months of gestation: [9.70 (Mcal/day) /(2.2*600(kg/cow))] = 0.0074 (Mcal) per lb. This number will be increased by 5% for activity allowance.
[b] 0.489 (kg) /(2.2*600(kg/cow)) =0.00037 (lbs) per lb.
[c] The assumed average weight of heifer calves is 300 kg. NE_m and NE_g for a growing heifer: (5.55 +1.36) (Mcal/kg)/(2.2*300(kg/heifer)) = 0.0105 (Mcal) per lb.
[d] 0.713 (kg /(2.2*300(kg/heifer)) = 0.0011(lbs) per lb.
[e] The assumed average weight a mature bull is 2000 lbs. NE_m to for maintaining a bull: 14.55 Mcal/2000 lbs = 0.0073 (Mcal) per lb.
[f] 1.017 kg/2000 lbs = 0.00051 (kg) per lb.
[h] Assuming 3.5 % of milk fat, 0.69 (Mcal/Kg)/ (2.2(lbs/kg)) = 0.31 (Mcal) per lb.
[I] Assuming 3.5 % of milk fat, 0.082 (kg)/(2.2(lbs/kg)) = 0.037 (lbs) per lb.

Source: Source: National Academy of Sciences. Nutrient Requirements of Daily Cattle, 5[th] revised edition, 1978. National Academy of Sciences, Washington, D.C. 1978.

Table 5. Nutrient supplied by harvested crops.

Nutrient\Crop [Reference Number]	Corn grain (bushel) [4-21-018]	Corn silage (ton) [3-02-887]	Sorghum silage (ton) [3-04-323]	Soybeans (bushel) [5-04-610]	Alfalfa hay (ton) [1-00-071]	Orchard grass hays (ton) [1-03-428]
Dry matter (%)	89	35	29	90	91	88
Dry-matter basis						
Net energy (NE_l) (Mcal)[a]	52	1,445	1118	59	1,045	1,000
Net energy (NE_m) (Mcal)	54	1,400	1063	66	1,009	973
Net energy (NE_g) (Mcal)	36	880	436	42	327	255
Crude protein (Lbs) [b]	6	160	75	25	270	168
Crude fiber (Lbs) [c]	1	480	520	4	740	740
Dry matter (Lbs) [d]	50	700	580	54	1,820	1,760
As-fed basis [e]						
Net energy (NE_l) (Mcal)	46	506	324	53	951	880
Net energy (NE_m) (Mcal)	48	490	308	59	918	856
Net energy (NE_g) (Mcal)	32	308	126	38	298	224
Crude protein (Lbs)	5.3	56	22	23	246	148
Crude fiber (Lbs)	0.9	168	68	3.6	673	651

[a] Net energy (NE_l) from corn : 2.03(Mcal/kg) / 2.2 (lb/kg) * 56 (lb/bu) = 52 Mcal/bu.
[b] Crude protein from corn:10 (%) *56(lb/bu) = 5.4 lbs/bu.
[c] Crude fiber from corn: 2 (%) * 56 (lbs/bu) =1.0 lbs/ton.
[d] Dry matter: 89 (%) * 56 (lbs/bu) = 49.8 lbs/bu.
[e] As-fed estimates = dry-matter estimates * percent of dry matter .

Source: National Academy of Sciences. Nutrient Requirements of Daily Cattle, 5th revised edition, 1978. National Academy of Sciences, Washington, D.C. 1978.

Table 6. Average costs and returns to large dairy farms (200 + cows) spreading slurry manure on Cropland in cool and cold humid regions.

	Baseline	N-restriction	P-restriction
Number of farms	905		
Animal units per farm	1032		
Manure produced (1000 gals)	4679		
Acres owned	567		
Own acres received manure	366	546	547
Manured total acres	366	847	754
N-fertilizer purchased (lbs)	4,560	4,560	5,364
P2O5-fertilizer purchased (lbs)	3,561	5,993	3,674
K2O-fertilizer purchased (lbs)	8,616	80,226	75,424
Fertilizer value of manure utilized by crops ($)	24,504	67,405	64,620
Net energy from home-grown crops (Mcal)	3,760,297	5,435,448	4,899,307
Crude protein from home-grown crops (lbs)	419,374	602,806	543,470
Crude fiber from home-grown crops (lbs)	1,256,638	1,806,934	1,628,926
Dry matter from home-grown crops (lbs)	1,848,009	2,650,524	2,390,926
Net energy purchased (Mcal)	1,926,693	269,255	805,396
Crude protein purchased (lbs)	97,277	3,772	62,046
Crude fiber used (lbs)	0	0	0
Fertilizer purchase costs ($)	15,814	13,339	12,155
Feeds purchase costs ($)	67,637	8,147	31,113
Land lease cost($)	0	32,833	23,552
Manure application costs ($)	52,206	76,055	74,068
Other crop production costs ($)[1]	122,983	222,503	212,539
Returns from milk sale ($)	1,098,158	1,098,158	1,098,158
Returns from crop sale ($)	21,531	174,229	79,100
Net returns ($/)	861,048	819,512	823,830

1. Other crop production costs include all costs excluding costs of commercial fertilizer and leased land and manure applications.

Source: Results of individual whole farm modeling.

Table 7. Average costs and returns to large dairy farms (200 + cows) spreading lagoon liquid manure on cropland in cool and cold humid regions.

	Baseline	N-restriction	P-restriction
Number of farms	731		
Animal units per farm	642		
Manure produced (1000 gals)	5,487		
Acres owned	821		
Own acres received manure	441	441	441
Manured total acres	441	479	479
N-fertilizer purchased (lbs)	42,894	48,620	48,620
P2O5-fertilizer purchased (lbs)	24,110	26,866	26,866
K2O-fertilizer purchased (lbs)	50,183	57,823	57,823
Fertilizer value of manure used by crops ($)	28,176	30,919	30,919
Net energy from home-grown crops (Mcal)	2,378,293	2,700,565	2,700,565
Crude protein from home-grown crops (lbs)	306,202	342,114	342,114
Crude fiber from home-grown crops (lbs)	967,128	1,075,872	1,075,872
Dry matter from home-grown crops (lbs)	1,722,397	1,83,896	1,83,896
Net energy purchased (Mcal)	1,697,224	1,365,813	1,365,813
Crude protein purchased (lbs)	101,076	64,398	64,398
Crude fiber purchased (lbs)	0	0	0
Fertilizer purchase costs ($)	20,070	23,800	23,800
Feeds purchase costs ($)	61,624	47,341	47,341
Land lease cost ($)	0	0	0
Manure application costs ($)	50,810	51,926	51,926
Other crop production costs ($)[1]	86,441	95,501	95,501
Returns from milk sale ($)	920,137	920,137	920,137
Returns from crop sale ($)	10,609	10,609	10,609
Net returns ($)	710,720	712,177	712,177

1. Other crop production costs include all costs excluding costs of commercial fertilizer and leased land and manure applications.

Source: Results of individual whole farm modeling.

Table 8. Additional leased acres needed by farms to comply with restrictions on land application of manure for crop production.

	N-restriction	P-restriction
Acres (percent of surveyed farms in the group)		
Dairy farms with slurry manure		
Average	328 (57%)	236 (40%)
Maximum	720	720
Minimum	0	0
Dairy farms with lagoon liquid manure		
Average	0 (0%)	0 (0%)
Maximum	0	0
Minimum	0	0

Source: Results of individual whole farm modeling.

Table 9. Costs to comply with restrictions on land application of manure for crop production.

A. Cost per farm

	N-restriction	P-restriction
Dairy farms with slurry manure	$/farm (percent of surveyed farms in group) [a]	
Average	41,536 (57%)	37,217 (57%)
Maximum	101,953	104,362
Minimum	(6,079)[a]	(6,389)
Dairy farms with lagoon liquid manure		
Average	-1,455 (46%)	-1,455 (46%)
Maximum	(12,865)	(12,865)
Minimum	0	0

B. Cost per cwt of milk sold

	N-restriction	P-restriction
Dairy farms with slurry manure	$/cwt	
Average	0.51	0.37
Maximum	2.73	1.35
Minimum	(0.09)[a]	(0.10)
Dairy farms with lagoon liquid manure		
Average	(0.03)	(0.03)
Maximum	(0.21)	(0.21)
Minimum	0	0

[a] Percent of farms in the group have positive costs
[b] Number in the parenthesis is the income gain.

Source: Results of individual whole farm modeling.

Table 10. Marginal costs of manure (shadow prices) under various application scenarios.

	Baseline	N-restriction	P-restriction
		$/1000 gallons	
Dairy farms with slurry manure			
Average	9.55	35.14	28.32
Maximum	11.21	67.94	46.03
Minimum	3.38	3.38	3.38
Dairy farms with lagoon liquid manure			
Average	7.98	7.88	7.88
Maximum	11.58	11.58	11.58
Minimum	6.58	6.71	6.71

Source: Results of individual whole farm modeling.