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Economic Impacts of EPA's Manure Application Regulations on Dairy Farms with Lagoon Liquid Systems in the Southwest Region

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EPA's new restrictions on land application of manure nutrients by concentrated animal feeding operations (CAFOs) could decrease the net return of 6–17% of the medium and large dairy farms with lagoon systems in the southwestern United States. Many of the other dairy CAFOs in the region could achieve higher net income under the restrictions if they reduce feed costs by better utilizing manure and expanding homegrown feed production.

Key Words: CAFO, dairy farms, land application, manure regulations, nutrient management

JEL Classifications: C61, Q12, Q52, Q58

U.S. livestock industries have undergone dramatic structural change in recent years. Technical innovations, changes in production systems, and specialization have led to expanded numbers of large concentrated livestock operations (Short). The environmental effects of waste management practices on those large concentrated livestock feeding operations are an increasing source of public concern (Innes; Kaplan, Johansson, and Peters; Litke; McSweeney and Shortle; Metcalfe; USGS). In response to this concern, the Environmental Protection Agency (EPA) (USEPA 1999) proposed changes to the current National Pollutant Discharge Elimination System (NPDES) permit regulations and to the Effluent Limitation Guidelines (ELG). These changes include redefining the concentrated animal feeding operations (CAFOs) subject to NPDES permit regulation, and respecifying ELG for animal confinement, manure storage areas, land application, and off-site transfer of manure. After reviewing public comments, the EPA, on December 15, 2002, announced the final CAFO rule (USEPA 2002a).

The EPA's final rule defines three types of dairy CAFOs that must obtain NPDES permits: (1) a large CAFO if the number of mature dairy cows is 700 or more; (2) a medium-size CAFO if it has between 200 and 699 dairy cows and if it meets either of the following two conditions: a man-made ditch or pipe that carries manure or wastewater into surface waters (the man-made ditch condition), or animal contact with surface waters running through their confinement area (the direct con-

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tact condition); (3) a designated CAFO if the permitting authority inspects the operation and finds that it is polluting surface waters, regardless of its operation size. All large CAFOs are subject to the ELG, which specifies broad permit requirements, including a nutrient management plan that addresses land application areas and is based on the most limiting nutrient (the one of greatest environmental concern). Although some medium-size and designated CAFOs are not subject to the ELG, they also will need to develop and implement nutrient management plans. The plan will either be phosphorous (P) based or nitrogen (N) based, depending on whether P or N limits the amount of manure to be applied to the field. For example, in areas of high P in soil, CAFOs must follow a P-based plan that restricts manure application to the amount of P needed by crops. In areas of low P in soil, CAFOs must follow an N-based plan that restricts manure application to the amount of N needed by crops (NRCS 2001).

How will these changes in regulations affect dairy farms and their economic well-being and competitiveness? Clearly more dairy farms will come under regulation, and the new rule requiring a P- or N-based plan could increase manure application costs and reduce the profitability of dairy CAFOs. Utilizing data from the United States Department of Agriculture's (USDA's) Agricultural Resources Management Survey (ARMS), the analysis reported in this paper addresses the issue of economic impact for a major U.S. dairy region.

Study Coverage and Objectives

This paper assesses the economic impacts of the EPA's manure application regulations on medium and large dairy farms in the Southwest region, which includes the states of California, Arizona, New Mexico, Texas, and Oklahoma. ARMS data for 2000 included a total of 137 dairy farms in these states, representing 4,282 dairy farms when expanded by survey weights. About 2,087 medium-size (200–699 cows) and 761 large dairies (700 cows and over) were in these states. These states had 48% of medium and large dairy farms in the United States, which together produced 28% of U.S. milk.

Many medium-size dairy farms will be affected by the new manure application regulations. Previous EPA regulations (1976) required only large farms to obtain a NPDES permit, whereas the new CAFO definition (USEPA 2002a) continues to affect large farms; it also requires that certain medium-size farms obtain a permit under the man-made ditch and the direct-contact conditions (USEPA 2002b). EPA estimates that in the Southwest region about 18% (376) of the medium-size dairy farms may be classified as CAFOs and become regulated. Since we could not identify these 376 CAFO farms from among the medium-size farms in our survey, we assumed that the survey data representing medium-size farms in the region would be generally applicable.

This study addresses several questions: What percentage of regulated farms would have to arrange for additional land to properly disperse manure under the new restrictions and what acreage would be needed? What percentage of regulated farms could experience a reduction in net returns and what would be the size of the reductions? And what would be the marginal cost to the regulated farm of applying the last 1,000-gallons of manure?

Marginal cost provides a reference point for comparing the costs of alternative methods for manure disposal. For example, if the marginal cost of land application exceeded that of new on-farm technologies for reducing nutrients in the manure or that of hauling manure off the farm, a dairy farm would be economically better off by adopting one of the alternatives with a lower marginal cost.

Assessment Models

Mathematical programming models and spreadsheet analyses have been useful tools for investigating the economic impacts of manure management on dairy farms (Ashraf, Christensen, and Frick; Bosch and Pease; Diebel et al.; Good et al.; Heimlich; Leatham et al.; Pratt, Jones, and Jones; Schmit and Knoblauch). In our study we used Heimlich's modeling framework, which specially included herd-feeding activities, to design a linear programming whole-farm model for assessing the impact of the EPA regulations on individual dairy farms. Including herd-feeding activities in the model provides a better estimation of the economic impacts of a farm expanding manured acres and, in turn, the supply of homegrown feed. Recommended levels of dairy feed rations (roughage and concentrates) grown on-farm or purchased off-farm are used to model the herd-feeding operation. Modeling of individual dairy farms recognizes the heterogeneity of the dairy operations in terms of herd size and composition, crops grown and yields, feed purchase, cropland acreage owned and leased, and manure management system.

Several key modeling assumptions were: (1) land application of manure was the only compliance option; (2) the operation maintained the same herd size, type of dairy operation, and manure storage and application system regardless of manure application restrictions; (3) the farm leased additional land adjacent to the farm at year-2000 cash rent when necessary to comply with the restrictions; and (4) no adjustment costs occurred because of changes in farm equipment, feed storage, irrigation systems, and other facilities related to crop production. These assumptions seem generally reasonable and help us simplify the modeling. Exceptions certainly exist that a more extensive analysis might consider. For example, if adjacent land is not available for applying manure, such as may be the case with many large dairy farms in California (surrounded by urban development), the farm will incur higher transportation costs or higher contractor costs to haul away the manure.

The model is described next. Appendix A contains more detail on the model's parameters and variables.

Objective Function

We assumed that the dairy farm operator would maximize net return, Z, given the availability of manure produced on the farm and the crop acreage operated by the farm on which to spread the manure. Net return was defined as the residual return to management, land ownership, and capital investment (excluding fixed costs for crop production). The objective function representing the net return was specified as:

(1) Maximize

$$Z = [\mathbf{mp}\ \mathbf{mq}\ \mathbf{au}] + \left[\sum_i p_i \mathbf{y}_i (C_{ims} + C_{ins})\right] - \left\{\sum_i \sum_j f_j F_{ij}(C_{ims} + C_{inf}) + \sum_i \sum_j f_j d_{ij} \mathbf{y}_i (C_{ins} + C_{inf}) - \left[\sum_i o_i (C_{ims} + C_{imf} + C_{ins} + C_{imf})\right]\right\}.$$

On the right-hand side of Equation (1), the terms in brackets define the return from milk sales (first bracket), the returns from the sale of crops produced on acres treated with and without manure (second bracket), the cost of fertilizer purchased for both manured and nonmanured acres (third bracket), and other production costs to produce crops (fourth bracket). The latter includes fixed and variable crop production costs, excluding fertilizer and land ownership costs. The terms in the last bracket include manure application cost (*MAC*), and the cost for leased land and the cost for the purchased feeds. The bold parameters in Equation (1) and in the equations that follow were obtained or estimated from each farm's survey data. The optimization was subject to a variety of constraints.

Acreage Restriction

This constraint ensured that the sum of acres used to grow the different crops was less than or equal to the total number of acres ($\mathbf{L}_o$) available on the farm and on additional land (L_s) leased for manure application:

$$(2)\quad \sum_i (C_{inf} + C_{ins}) + Am \leq \mathbf{L}_o$$

$$(3)\quad \sum_i (C_{imf} + C_{ims}) = Am + L_s.$$

Equation (3) states that the farm leased additional land only for the purpose of spreading manure.

Manure Use Restriction

This constraint ensured that all manure produced on the farm was spread on crops grown either on owned or rented land:

$$(4) \quad \sum_i A_i(C_{imf} + C_{ims}) = \boldsymbol{w\, au}.$$

Per-Acre Nutrients Required by Crops

A crop uses nutrients (N, P, and K) to produce the expected yield. The constraint required that the applied amount of each nutrient per acre from manure ($\boldsymbol{u}_j A_i$) and supplemental commercial fertilizer (F_{ij}) met the amount ($d_{ij}\boldsymbol{y}_i$) needed by the crop:

$$(5) \quad F_{ij} + \boldsymbol{u}_j A_i - d_{ij}\boldsymbol{y}_i \geq 0 \quad \text{for } i \text{ and } j.$$

Nutrient Application Restrictions

The EPA's final rule restricts the per-acre amount of P or N in applied manure to that needed by the crop. This restriction was represented mathematically as:

$$(6) \quad F_{ij} + \boldsymbol{u}_j A_i - d_{ij}\boldsymbol{y}_i + S_{ij} \leq 0 \quad \text{for } i \text{ and } j,$$

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 (restriction [5]). For example, surplus P can occur when the manure application rate is restricted by N because one unit of manure generally supplies more P than N.

The following rule can be used to determine which of the two restrictions needs more acres for manure application: If r1 > r2, more acres are needed to comply with N standard. If r1 ≤ r2, equal or more acres are needed to comply with P standard, where r1 = (quantity of N)/(quantity of P_2O_5) in one unit of manure, and r2 = (quantity of N removed)/(quantity of P_2O_5 removed) in one unit of harvested crop.

Manure Application Cost(MAC)

Manure application costs for a dairy farm in the Southwest region included the irrigation cost to spray lagoon liquid and the field application and hauling costs to spread solid manure. These costs covered only manure applied to the land on the farm and not disposed of by alternative means:

$$(7) \quad MAC = (1 - \boldsymbol{mv}) \times \{(ac)(\boldsymbol{lq}) + [(bc)(\boldsymbol{sm})] + [(mc)(\boldsymbol{sm})TD]\},$$

where $\boldsymbol{mv}$ is the percentage of manure removed from the farm, ac is the manure field application cost (in dollars per 1,000 gallons) adjusted for the field application method, $\boldsymbol{lq}$ is the amount of lagoon liquid manure (in 1,000 gallons) and $\boldsymbol{sm}$ is the amount of solid manure (in tons) produced on the farm, bc is the field application cost (in dollars per ton), and mc is the manure transportation cost (in dollars per ton per mile). The manure travel distance (TD) is: $TD = (0.25)(Tm)/160)(1 + [Tm/160 - 1]/2)$, where Tm is total manured acres (C_{imf} + C_{ims}).[1]

Feed Requirements

The ration fed to the dairy herd provides the recommended daily minimum nutrient requirements for milk production and herd maintenance, including net energy, crude pro-

[1] The derivation of TD assumes that each one square mile (640 acres) of cropland can be divided into four 160-acre rectangular blocks, with each block being 0.25 mile by 1 mile. Blocks are lined up contiguously. For the first block, the manure travel distance is 1 × 0.25 miles; for the second block, the manure travel distance is 2 × 0.25 miles (the distance across the first and the second block); for the third block, the manure travel distance is 3 × 0.25 (the distance across the first, the second, and the third blocks); and so on; for the n block, the manure travel distance is n × 0.25, where n is Tm (total manured acres)/160. The total travel distance TD is $1 \times 0.25 + 2 \times 0.25 + 3 \times 0.25 + \cdots + n \times 0.25$, which is $0.25 \times (Tm/160)\ (Tm/160 + 1)/2$.

tein, and crude fiber.[2] The nutrients come from homegrown crops or purchased feed. The following constraints ensure that annual feeding requirements are met for net energy, crude protein, and crude fiber.

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

$$(8) \quad N_1 + \sum_i a_i[\boldsymbol{y}_i(C_{imf} + C_{inf})] \geq \boldsymbol{nen\ au}.$$

The supply of crude protein from homegrown crops and purchased feeds is equal to or greater than that required by the herd:

$$(9) \quad N_2 + \sum_i b_i\boldsymbol{y}_i(C_{imf} + C_{inf}) \geq \boldsymbol{cpr\ au}.$$

The daily supply of dry matter in the ration from purchased feeds and homegrown crops is less than 3% of animal weight:

$$(10) \quad \sum_v h_v N_v + \sum_i g_i\boldsymbol{y}_i(C_{imf} + C_{inf}) \leq 0.03(1000 \times 365\boldsymbol{au}).$$

The supply of crude fiber is at least 17% of dry matter in the ration:

$$(11) \quad N_3 + \sum_i c_i\boldsymbol{y}_i(C_{imf} + C_{inf}) \geq 0.17\left[\sum_v h_v N_v + \sum_i g_i\boldsymbol{y}_i(C_{inf} + C_{inf})\right].$$

Data and Data Procedures

Data used to estimate key parameters for the individual farm models came from USDA's 2000 ARMS (NASS 2000). The parameters for each surveyed dairy farm include crop yields, crop acres owned, number of cows in animal units (au) in the farm (where 1 au is assumed to be 1,000 pounds of live weight), quantity and price of milk produced, nutrient composition of 1,000 gallons of manure, amount of manure produced, percentage of manure removed from the farm, minimum required amount of net energy, crude protein, crude fiber, and maximum amount of roughage per au.

The state's average cash rent paid for leasing land was used when the actual rent was not reported in the survey (NASS 2001a). 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 on the leased land. The same yields and production practices were assumed for crops grown on both owned and leased land. Also, the same yields were assumed for crops grown on both manured and nonmanured acres. All farms using a similar manure system were assumed to have the same coefficients for nutrient content of manure, amount of nutrients needed by crops, daily nutrient requirements of the herd, and nutrients in feed supplied by crops.

The composition of the herd (number of calves, lactating and dry cows, replacement heifers, and bulls) on each farm determined the amount of manure that the farm must spread on cropland annually and the amount of N and P in that manure available for crop use (Table A in Appendix B). The nutrient availability estimates excluded nutrient losses before entering storage, deposited in the lagoon sludge, and nitrogen volatilization occurring under various methods (i.e., incorporation or irrigation) used to spread manure on the field (Table B in Appendix B). The estimates also excluded N and P losses in sediment and solution runoffs. Under actual conditions, not all manure nutrients applied in soil are immediately available for plant uptake. A mineralization process must take place over time to convert all organic manure nutrients to inorganic form for crop uptake. In this study, we assumed all nutrients applied after adjustment for field losses would be available for plant uptake, assuming available mineralized nutrients in the soil reach a steady state. A steady state assumes that the inventory of min-

[2] Feeding operations and requirements were based on a 1978 National Academy of Sciences study and on consultation with Keith Hummel, Agricultural Research Service, Beltsville, Maryland, and with Thomas Overton, Cornell University, Ithaca, New York.

eralized nutrients accumulated from the current and the past nutrients available for plant uptake reaches a constant level if the same amount of manure is applied on the land annually.

The determination of the amounts of nutrients needed by a given crop was based on the average crop yield reported and plant uptake of nutrients by crop (Table C in Appendix B).

The determination of the annual amount of net energy, crude protein, minimum crude fiber, and maximum dry matter per au for each farm was based on the herd composition and the quantity of milk produced (Appendix C). Nutrients supplied by various harvested crops are shown in Appendix D. The amount of dry matter for one Mcal (million calories) purchased was 0.96 lbs., based on purchased corn grains (NAS 1978). The determination of the annual amount of net energy, crude protein, minimum crude fiber, and maximum dry matter per au for each farm was based on the herd composition and the quantity of milk produced (Appendix C). Nutrients supplied by the harvested crops are shown in Appendix D.

Manure application costs included irrigation to spread lagoon liquid and hauling and spreading solid manure. An irrigation cost of $0.30 per 1,000 gallons was assumed, on the basis of a 140-acre central pivot spray-irrigation system (Dorn; O'Brien et al.). The field application of solid manure included loading manure from storage and spreading manure on the field. Average hauling cost from the storage to the application field was assumed to be $1 per ton per mile (DeBoom pers. commun.; Feenstra, pers. commun.) and field application cost was assumed to be $4.80 per ton (Outlaw, Purvis, and Miller).

Market prices in 2000 for the Southwest region were $2.54/bu. for wheat (NASS 2001b). Corn silage, sorghum silage, alfalfa, and coastal Bermuda grass were produced only for feed use on the farm. Fertilizer nutrient prices, which included field application costs, were $0.15/lb. for nitrogen, $0.29/lb. for phosphate, and $0.15/lb. for potash based on April 2000 prices (USDA 2001). These fertilizer nutrient prices included field application costs.

Crop production costs, excluding fertilizer and land ownership, were $107/acre for wheat in 2000 (ERS 2001), $10/ton for corn silage, $38/ton for alfalfa hay, and $45/acre for Bermuda-grass hay (Texas A&M).

The costs for purchased feeds were based on the estimated nutrient prices of feeds. The estimated prices were $0.032/Mcal for net energy, $0.137/lb. for crude protein, and $0.0675/lb. for crude fiber. These values were estimated by a regression analysis using feed purchase data from the 2000 ARMS and feed nutrient composition data from the National Academy of Science.[3]

Analysis and Scenarios

Two sets of analyses were used to estimate the impacts of the restrictions.

Short-run Analyses Compared Farms before and after the New Restrictions:

Short-run before restriction scenario simulated the actual operation of each dairy farm before implementing the new restrictions. Simulation was based on data reported in the 2000 ARMS. *Manure was applied unrestricted, but limited to the same number of manured acres reported in the survey* (no leasing of additional land allowed).

Short-run after restriction scenarios simulated each farm just meeting the minimum requirements of the regulations for N or P. Manure application was restricted to not exceed the N or P needs of the crops being grown. Farms with inadequate land to comply with the restrictions were allowed to *lease the minimum additional acres needed and to maximize returns under this constraint.*

[3] A linear regression was used to estimate the prices for net energy, crude protein, and crude fiber. The dependent variable was the unit price of purchased feed and the explanatory variables were the quantity of feed purchased, region, quantities of net energy, crude protein, and crude fiber in the feed. The number of observations used was 105. The estimated prices for net energy and crude protein were statistically significant at the 0.05 level and the adjusted $R^2 = 0.83$.

Long-Run Analyses Compared Farms Optimizing with and without the New Restrictions:

Long-run without restriction scenario simulated the optimal net returns each farm could achieve over time (as opposed to what it actually was doing in the short run) in the absence of N or P restriction. Also, in contrast to the short-run before restriction scenario, *the farm was allowed to lease additional land for manure application (although not required to do so) if it contributed to higher returns.*

Long-run with restriction scenarios simulated each farm achieving the maximum net returns possible while complying with the N or P restriction. In contrast to the short-run after restriction scenarios, *leasing of additional land for manure application was permitted beyond the minimal acres needed to come into compliance.*

The two analyses complement each other. The results of the short-run analysis indicate how dairy operations would change from the actual 2000 observed state of operation (which may be nonoptimal) to a regulation state in which they only make the minimum adjustments required in land and manure use. The short-run analysis provides the best estimates of the number of farms having to lease additional land or having to improve manure use without leasing land, to comply with the restrictions. In contrast, the results of long-run analysis indicate how dairy operations without any land constraints would change from an optimal no-regulation state (based on optimal behavior rather than observed) to an optimal regulation state. This analysis provides better estimates of the effects of the regulation itself apart from the effects of farms moving from nonoptimal to optimal levels of operation.

Surveyed dairy farms in the Southwest region included 51 medium-size farms and 29 large farms. Of these, only 26 medium farms and 13 large farms were used in the analysis. Three of the excluded farms used slurry manure storage systems, too few to analyze as a separate category (all other farms used lagoon-liquid systems). The other farms excluded from the analysis were those having most (more than 90%) of their manure hauled away from the farm for use elsewhere. Table 1 provides a summary of the production characteristics of the dairy farms included in this study in these two operation-size groups. Although both size groups of farms averaged long-run production losses (as indicated by the value of production less operating and overhead costs), the average loss for large farms was much smaller. This indicates that a strong incentive likely exists in the region to increase size of operation.

Results of the Analyses of Farms with Lagoon Systems

Affected Farms

The short-run analysis indicates that in 2000 the majority of medium (56–60%) and large (69–93%) dairy farms with lagoon systems in the region were already in compliance with the new restrictions (i.e., had adequate land and were already applying less manure nutrients per acre than the maximum amounts allowed, Table 2). The balance of the analyzed medium (40–44%) and large (7–31%) dairy farms all needed to both lease additional land and to change nutrient management to come into compliance with the new restrictions.

The economic impacts of coming into compliance were negative, positive, or neutral, depending on how the income gained from the additional leased land (in terms of expanded crop production and reduced feed purchases or increased crop sales) compared with the increased costs of leasing the land, hauling and spreading manure, and other crop production activities. The simulations indicated that relatively few of the affected farms would experience lower returns. For example, although 33% of medium-size farms with lagoon systems leased additional land to comply with the N restriction, only 6% overall had income losses compared with 27% with income gains.

One might then ask why have not the 27% of dairy farms with lagoon systems already taken steps to achieve the higher returns? Various explanations are:

Table 1. Production Characteristics of CAFO Dairy Farms with Lagoon Systems in the Southwest Region[a]

	Medium-Size Farms (200–699 Cows)	Large Farms (700 Cows and Over)
Number of Surveyed Farms Analyzed	26	13
Estimated Number of Farms Represented	642	499
Avg. Animal Units per Farm (au)[b]	620	1,654
Avg. Acres Owned	212	549
Avg. Acres to Which Manure Was Applied	146	372
Avg. Acres Owned/au[b]	0.34	0.33
Avg. Manure Produced (1,000 gals/yr)[c]	5,025	8,006
Crops Grown	Corn silage, sorghum silage, alfalfa, and coastal Bermuda grass	Corn silage, sorghum silage, alfalfa, wheat, coastal Bermuda grass
Manure Type	Solid and lagoon liquid manure	Solid and lagoon liquid manure
Milk Produced (cwt/au per yr)	91	100
Milk Prices ($/cwt)	12.50	12.22
Value of Production Less Operating Costs ($/cwt)	2.60	2.93
Value of Production Less Operating and Overhead Costs ($/cwt)	−6.64	−0.33

Source: Agricultural Resource Management Survey, 2000.
[a] Except for number of farms analyzed, all other numbers are based on data from the analyzed farms expanded by survey weights.
[b] Animal units (au) were the estimated live weight of lactating and dry cows, heifers, calves, and bulls on the farm. One au is equal to 1,000 pounds of live weight.
[c] Dry manure was converted to gallons of lagoon liquid manure at 14 tons for 11,000 gallons (Sutton et al.).

- Operators in 2000 may not have been aware that they could improve returns by acquiring additional land, or had not yet been able to complete the acquisition.
- Operators may have had different criteria for the optimal operation because of financial and capital limitations, and other factors.
- Operators of these farms may have had a

Table 2. Short-Run Analysis: Percentage of Dairy Farms with Lagoon Systems Affected by New Restrictions on Land Application of Manure, Southwest Region

	Medium-Size Farms		Large Farms	
Farm Group	N Restriction	P Restriction	N Restriction	P Restriction
	%			
1. Farms Already in Compliance (Had Adequate Land and Were Applying Less Manure than Maximum Allowed).	60	56	69	93
2. Farms That Changed Nutrient Management Only (Had Adequate Land).	0	0	0	0
3. Farms That Changed Nutrient Management and Leased Additional Land:				
Net Income Increased	34	32	24	0
Net Returns Decreased	6	12	7	7
Subtotal	40	44	31	7
Total Dairy Farms	100	100	100	100

Source: Results of individual whole farm modeling expanded by survey weights.

higher yield expectation than the reported yields used in the model, and thus did not perceive that manure nutrients could be better utilized.[4]

- Operators may have faced a higher land leasing cost and a high management cost of leasing added land.
- Operators may have faced a higher manure hauling cost (no nearby land available) than those we used in the model.
- Production equipment and feed storage may have been inadequate to support greater on-farm feed production.
- Because of weather and yield variations, homegrown feeds may not have provided a reliable supply of feed for a large dairy operation.

In the long-run analysis, none of the analyzed farms with lagoon systems experienced income gains from compliance with the restrictions on N or P. The principal reason was that the farms were allowed to reach optimality in the without-restriction scenario, as well as in the restriction scenarios, so the farms moved from one optimal situation to another, with only the restriction added on manure use. Some farms in the without-restriction scenario leased additional land to maximize net returns. As a result, some of them already had adequate land for manure application and did not need to lease more to come into compliance with the restrictions.

Additional Acres Needed

In the short-run analysis, 40% of the medium-size dairy farms with lagoon systems in the Southwest region leased additional land to comply with the N restriction and 44% to comply with the P restriction (Table 3).[5] Additional leased land in the region totaled 36,000 acres under the N restriction and 41,000 acres under the P restriction. The affected farms leased, on average, 141 acres to comply with the N restriction and 145 acres to comply with the P restriction.

Of the region's large dairy farms with lagoon systems, 31% leased additional land under the N restriction and, surprisingly, only 7% under the P restriction. The small percentage under the P restriction resulted from farms needing less acreage to spread manure to grow corn silage or sorghum silage under the P restriction than under the N restriction.[6] Even though fewer large farms leased land under the P than N restriction, those fewer farms leased more land, 800 acres on average, compared to 162 under the N restriction. The large acreage increase came mainly from those farms growing Bermuda grass hay instead of corn or sorghum silage and experiencing relatively low hay yield. In total, large farms in the region leased 25,000 additional acres under the N restriction, compared with 26,000 acres under the P restriction.

In the long-run analysis, about 9% of medium-size dairy farms with lagoon systems leased additional land to comply with the N

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[4] A farm experiencing low crop yields would need more acres to comply with the restriction than a farm with high crop yields. Low crop yields reduce nutrient uptakes by crops and limit the amount of manure that can be applied to the field. Therefore, for a fixed amount of manure, a lower crop yield would require a larger acreage to comply with restrictions on manure application.

[5] To screen out those farms with adequate land to comply with the restriction, an artificially large rent was imposed for a leased acre when running the model to estimate additional acres needed for manure application. The estimated additional acres were the number of acres needed by those farms with inadequate land to make the solution of the model feasible. We then rerun the model for each of those farms with the estimated additional leased acres and actual cash rent specified in the model to estimate the regulation costs and the marginal costs.

[6] In this study, we found that growing corn silage would need more acres under the N restriction than that under the P restriction. Using the data from Sutton et al. (Table A and C in Appendix B) for lagoon liquid dairy manure, $r1 = 2.42(46/19)$, (or $r1 = 2.57$ [126/49] for solid manure). For corn silage, $r2 = 2.15$. Because $r1 > r2$, more acres are needed to comply with N restriction. Most of crops, however, have $r1 \leq r2$. For example, for corn grain, $r2 = 3.2$ (160/50) and for Bermuda grass, $r2 = 4.41(75/17)$. Because $r1 < r2$, more acres are needed to comply with P restriction than with N restriction when these two crops are planted.

Table 3. Impacts of Complying with the Restrictions on Land Application of Manure, Dairy Farms in the Southwest Region

Short-Run Analysis	N Restriction	P Restriction
Medium-Size Farms (200–699 Cows)		
Regional additional acres leased to comply	36,409	41,036
Percent of farms leasing additional land	40%	44%
Average additional acres leased/farm (range)[a]	141 (26–936)	145 (10–993)
Average additional lease cost (range) $/farm (range)	13,507 (719–25,290)	7,865 (263–26,819)
Large Farms (700 Cows and Over)		
Regional additional acres leased to comply	24,995	25,805
Percent of farms leasing additional land	31%	7%
Average additional acres leased/farm (range)	162 (33–786)	800 (581–1,009)
Average additional lease cost (range) $/farm (range)	6,225 (1,453–69,207)	25,805 (18,167–52,286)
Regional total acre leased	61,404	66,841
Long-run Analysis	**N Restriction**	**P Restriction**
Medium-Size Farms (200–699 Cows)		
Regional additional acres leased to comply	20,432	30,194
Percent of farms leasing additional land	9%	15%
Average additional acres leased/farm (range)	343 (1–936)	309 (14–993)
Average additional lease cost (range) $/farm (range)	10,871 (242–25,290)	911 (395–26,814)
Large Farms (700 Cows and Over)		
Regional additional acres leased to comply	15,432	24,671
Percent of farms leasing additional land	7%	7%
Average additional acres leased/farm (range)	428 (49–783)	685 (49–1.009)
Average additional lease cost (range) /farm (range)	10,591 (1,339–21,157)	14,931 (1,339–19,007)
Regional Total (Medium and Large Farms) (Acres)	31,023	54,865

Source: Results of individual whole-farm modeling expanded by survey weights.

[a] Average acres leased and average lease costs were based only on those farms leasing additional land to comply with the restrictions.

restriction and less than 15% with the P restriction (Table 3). Regionally, the additional acres totaled to around 20,000 under the N restriction, compared to over 30,000 under the P restriction. The additional acreage needed by the affected farms was 343 acres on average under the N restriction and 309 acres under the P restriction. The lower average acreage under the P than under N restrictions was mainly the result of a greater number of affected farms being used in computing the average. About 7% of the large dairy farms leased additional land to comply with the N or P restriction. Regionally, the additional acres totaled to 16,000 under the N restriction, and 25,000 acres under the P restriction. On a per-farm basis, the additional acres leased averaged 428 acres under the N restriction and 685 acres under the P restriction.

Compliance Cost

In the short-run analysis, the cost of complying with the restriction for each affected farm was the difference in net income between the before-restriction and restriction scenarios. Although the analysis indicated that a large percentage of medium-size and large dairy farms with a lagoon system in the region would have to lease additional land to comply with the restrictions, only 6% under the N and 12% under the P restriction would end up with lower net returns (Table 4). Many farms in this region would gain from expanded homegrown forage production on the leased acres and reduced feed purchase. The cost saving from reduced purchase of feed would exceed the added costs of growing the feed.

Regionally, the compliance cost for those negatively affected medium-size farms totaled to $909,000 under the N restriction, and to $1,347,000 under the P restriction. The average drop in net returns for those negatively affected medium-size farms was $25,000 per farm (a 4% reduction), $0.80 per cwt. of milk sold under the N restriction, $18,000 per farm (a 3% reduction), and $0.32 per cwt. of milk under the P restriction. The decline in average compliance cost under the P restriction was mainly due to the inclusion of more farms in computing the P-restriction average.

The restriction lowered the net returns for 7% of the large farms, totaling to $1,331,000 under the N restriction and $1,398,000 under the P restriction. The average drop in net returns for those negatively affected large farms was $36,970 per farm (a 2% reduction) under the N restriction, and $38,838 per farm (a 2% reduction) under the P restriction. The compliance cost per cwt. of milk sold increased from $0.16 to $0.24.

In the long-run analysis, 11–17% of medium-size dairy farms and 10–12% of large farms with lagoon systems incurred income losses, while the rest of the farms analyzed had no change in net incomes (Table 4). Regionally, the decrease in net returns for the affected medium-size farms totaled $965,000 under the N restriction, and $992,000 under the P restriction. The average cost of complying with the N restriction was $13,642 per farm (a 2% reduction in net income), or $0.55 per cwt of milk sold under the N restriction. Under the P restriction, the cost was $9,110 per farm (a 2% reduction in net income) or $0.31 per cwt. The number of affected large farms increased from 10% under the N restriction to 12% under the P restriction. Similarly, the regional aggregate compliance cost was $1,523,000 under the N restriction, compared to $1,535,000 under the P restriction. The average compliance cost for the large farms was smaller under the P restriction, but the average compliance cost per cwt. of milk sold increased from $0.13 to $0.16, because of lower average milk production from those farms affected by the P restriction. Overall, the compliance cost per cwt. of milk sold was much smaller for the large farms than for the medium-size farms. This occurred because the large surveyed farms had higher milk production per animal unit (Table 1).

The compliance cost estimates of this study are a 2–3% reduction in net returns for farms to comply with the P restriction and lower than Pratt, Jones, and Jones' estimates of 6–14% for both large and medium-size dairy farms in the upper North Bosque River Watershed of Texas. Although some differences in assumptions exist between our analysis and their analysis, our lower estimates can be attributed to reduced purchase of feed resulting from expanded homegrown feed production on the additional acres leased to comply with the regulation. Our analysis, based on farms surveyed in 2000, complements their analysis based on representative farms in 1997. Interestingly, both studies indicate that larger farms will experience relatively lower reductions in net income than smaller farms.

Note that the regional compliance costs were higher under the long-run analysis than under the short-run analysis. In the no-restriction (baseline) analysis, the farm's long-run net return was higher than the farm's short-run net return because the farm in the long-run analysis was allowed to lease additional acres to reach the optimal state. However, in the restriction analysis, the farm's long-run net return was not much different from the farm's short-run net return. Thus, the loss of net income from complying with restriction is higher under the long-run analysis.

Marginal Costs (Shadow Prices) of Manure

The marginal cost provides a reference point for comparing the costs of alternative methods

Table 4. Cost of Complying with the Restrictions on Land Application of Manure, Dairy Farms with Lagoon Systems in the Southwest Region

Short-Run Analysis Compliance Cost per Farm[a]	N Restriction	P Restriction
Medium-Size arms (200–699 Cows)		
Regional decrease in net returns ($)	909,036	1,346,840
Percent of farms having income reduction	6%	12%
Average decrease in net return/farm (range) $	25,042 (8,977–46,422)	17,787 (347–35,941)
% decrease in average net returns	4	3
Large Farms (700 Cows and Over)		
Regional decrease in net returns ($)	1,330,575	1,397,808
Percent of farms having income reduction	7%	7%
Average decrease in return/farm (range) $	36,970 (8,359–89,496)	38,838 (21,653–60,142)
% decrease in average net returns	2	2
Regional Total Decrease in Net Return ($)	2,239,611	2,744,648
Compliance Cost per Cwt. of Milk		
Medium-size farms (200–699 Cows)		
Percent of farms having income reduction	6%	12%
Average decrease in net returns (range) $	0.80 (0.18–1.89)	0.32 (0.01–0.85)
Large Farms (700 Cows and Over)		
Percent of farms having income reduction	7%	7%
Average decrease in net returns (range) $	0.16 (0.06–1.68)	0.24 (0.06–1.29)
Long-run analysis Compliance Cost Per Farm	N Restriction	P Restriction
Medium-Size Farms (200—699 Cows)		
Regional decrease in net returns ($)	964,552	1,364,896
Percent of farms having income reduction	11%	17%
Average decrease in net return/farm (range) $	13,642 (2–46,422)	12,533 (2–51,204)
% decrease in average net returns	2	2
Large Farms (700 Cows and Over)	1,523,009	1,535,727
Regional decrease in net returns ($)	10%	12%
Percent of farms having income reduction	30,357 (1,184–117,113)	26,408 (0–60,144)
Average decrease in return/farm (range) $	1	1
% decrease in average net returns		
Regional Total Decrease in Net Return ($)	2,487,561	2,900,623
Compliance Cost per Cwt. of Milk		
Medium-Size Farms (200–699 Cows)		
Percent of farms having income reduction	11%	17%
Average decrease in net returns (range) $	0.55 (0.01–2.77)	0.31 (0–1.73)
Large Farms (700 Cows and Over)		
Percent of farms having income reduction	10%	12%
Average decrease in net returns (range) $	0.13 (0.01–0.30)	0.16 (0.01–0.42)

Source: Results of individual whole-farm modeling expanded by survey weights.
[a] Average compliance cost based only on those farms experiencing a reduction in net returns from complying with the restrictions.

Table 5. Marginal Costs of Manure under Various Application Scenarios, Dairy Farms with Lagoon Systems in the Southwest Region

Short-Run Analysis	N Restriction	P Restriction
Medium-Size Farms (200–699 Cows)		
Percent of farms having positive marginal costs	6%	11%
Average marginal cost (range) $/1000 gallon	12.83	7.39
	(5.66–19.40)	(0.59–17.44)
Large Farms (700 Cows and Over)		
Percent of farms having positive marginal costs	7%	7%
Average marginal cost (range) $/1000 gallon	6.38	8.82
	(2.66–11.82)	(6.83–13.03)
Long-Run Analysis	**N Restriction**	**P Restriction**
Medium-Size Farms (200–699 Cows)		
Percent of farms having positive marginal costs	6%	11%
Average marginal cost (range) $/1000 gallon	12.54	7.40
	(5.66–19.14)	(0.56–17.44)
Large Farms (700 Cows and Over)		
Percent of farms having positive marginal costs	7%	7%
Average marginal cost (range) $/1000 gallon	6.39	8.82
	(2.66–11.82)	(5.83–13.63)

Source: Results of individual whole-farm modeling expanded by survey weights.

for manure disposal. On-farm or off-farm centralized composting, off-farm centralized manure digestion, and paying contractors to haul manure off the farm are three alternatives (Feenstra, pers. commun.; Pratt, Jones, and Jones). In the short-run analysis, the average marginal cost for medium-size farms with lagoon systems to apply the last 1,000 gallons of manure was $12.83 for the affected 6% of the farms under the N restriction and $7.39 for the affected 12% of the farms under the P restriction (Table 5). More large farms also were affected by the P restriction than the N restriction. For the affected group of large farms, the average marginal cost increased from $6.38 under the N restriction to $8.82 under the P restriction.

In the long-run analysis, the average marginal cost for the affected 6% of medium-size farms to apply the last 1,000 gallons of manure was $12.54 under the N restriction, compared with $7.40 for the affected 11% of the farms under the P restriction (Table 5). More large farms were also affected under the P than N restrictions. The average marginal cost for the affected 7% of large farms was $8.82 under the P restriction, compared with $6.39 for the same group of farms under the N restriction.

In a recent California study, the average cost was $18 per 1,000-gallon equivalence of manure for paying a contractor to remove manure from the farm for land application, $20 for central cocomposting, and $55 for central manure digestion (DeBoom, pers. commun.). These costs are generally higher than the largest marginal cost $19 we found for on-farm manure application on a particular surveyed farm (Table 5), indicating that these last two alternatives would be less preferable. Pratt, Jones, and Jones also reached a similar conclusion for on-farm and central composting alternatives in Texas.

Summary and Concluding Remarks

This study assessed the economic impacts of the EPA's new CAFO land application rule on U.S. dairy farms with lagoon systems in the Southwest region, which includes California, Arizona, New Mexico, Oklahoma, and Texas. The new rule could make 376 medium-size dairy farms in the region subject to the proposed new regulations, along with 761 large farms. Major findings of this study are:

(1) Our short-run analysis indicated that that the EPA's CAFO final rule on land application of manure could reduce the net return of only a few medium and large dairy farms with lagoon systems in the Southwest. Although a considerable number of farms would have to lease additional land to comply with the regulation, most of them could avoid income loss or even improve their net income by providing homegrown feed on their leased acres. The average compliance cost (reduction in net returns) for those negatively affected medium-size farms would be $18,000 to $25,000 per farm, or $0.30 to $0.80 per cwt. of milk, compared to $37,000 to $39,000 per farm, or $0.10 to $0.30 per cwt. of milk for those affected large farms. The average marginal cost (shadow prices) of manure was estimated to be $7.00 to $13.00 per 1,000 gallons of manure for those affected medium-size farms and $6.00 to $9.00 for those affected large farms.

(2) Our long-run analysis also indicated that the EPA's CAFO rule on land application of manure could reduce the return of only a few medium and large dairy farms with lagoon systems in the Southwest. A small percentage of them would have to lease additional acres to comply with the restrictions. The average compliance cost for those negatively affected medium-size farms would be around $13,000 to $14,000 per farm, or $0.30 to $0.60 per cwt. of milk. In comparison, the average compliance cost was around $26,000 to $31,000 per farm, or $0.10 to $0.20 per cwt. of milk for affected large farms. Similar to the result of the short-run analysis, the average marginal cost of manure could be $7.00 to $13.00 per 1,000 gallons of manure for those affected medium-size farms and $6.00 to $9.00 for those affected large farms.

Several options for the affected CAFOs to reduce the income impact of the new EPA rule include: (1) Improve crop yields or selection to increase crop nutrient uptake, lowering the number of acres needed for spreading manure and the need for leasing additional land; (2) reduce the number of animals on the farm and, hence, the amount of manure to be disposed; (3) adopt technologies to reduce the amount of nutrients in the manure; (4) adopt technologies that process excess manure for other uses; and (5) hire contractors to remove excess manure from the farm.

Our analysis indicates that, although the EPA's new regulation on land application of manure nutrients by CAFOs could have a large impact on a few dairy farms, it would have a relatively small impact on the region as a whole. It could affect 6–17% of the medium and large dairy farms in the southwestern United States, inducing dairy farms to lease 30,000 to 67,000 additional acres, and reducing net returns in the region by $2 to $ 3 million (Table 4), a small amount relative to billions of dollars of milk sales in the region. Because large CAFO dairy farms are more able to absorb the regulation cost than medium-size farms, the trend toward large operations in the region is likely to continue.

Finally, the results for the large dairy farms analyzed here are based on a relatively small sample. A future survey with a larger sample size of CAFOs could provide a better assessment. Also needing further study is the sensitivity of compliance cost to changes in manure application costs and crop yields.

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Appendix A. Definition of parameters and variables used in the model

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

- i crop grown; corn silage, sorghum silage, wheat, coastal Bermuda grass.
- j fertilizer nutrient; N, P, K
- k land treatment; manured ($k = m$) and non manured ($k = n$) land.
- l crop use; sold to the market ($l = s$) and crop used for feed ($l = f$)
- v animal nutrients; net energy ($v = 1$), crude protein ($v = 2$), and crude fiber ($v = 3$).

The parameters considered in the model are as follows:

- a_I amount of net energy (Mcals) in one bushel (ton) of crop i.
- ***au*** number of animal units of the farm. One animal unit is 1,000 pounds of animal weight.
- b_i amount of crude protein (lbs) in one bushel (ton) of crop i.
- bc base charge ($) for hauling 1,000 gallons of manure.
- c_i amount of crude fiber (lbs) in one bushel (ton) of crop i.
- ***cpr*** amount of crude protein required by one ***au***.
- d_{ij} pounds of j nutrient needed to produce one bushel (ton) of crop i.
- f_j cost for fertilizer nutrient j.
- g_i amount of dry matter (lbs) in one bushel (ton) of crop i.
- h_v lbs of dry matter for one Mcal from corn grain ($v = 1$), one pound of purchased crude protein ($v = 2$), and one pound of purchased crude fiber ($v = 3$).
- ***Lo*** land currently owned by the operator.
- ***ma*** total volume (1,000 gallons) of manure applied. ***ma*** = ***w au***.
- ***mc*** manure transportation cost ($) per 1,000 gallon per mile.
- ***Md*** maximum daily amount of roughage per pound of animal.
- ***Me*** minimum amount of net energy (Mcal) required per ***au***.
- ***mp*** milk market price per cwt.
- ***Mp*** minimum amount of crude protein required per ***au***.
- ***mq*** quantity of milk (cwt) produced per ***au***.
- n_v purchase prices for one unit of net energy (Mcal), one pound of crude protein, and one pound of crude fiber.
- ***nen*** amount of net energy required by one ***au***.
- o_I other production costs for crop i.
- p_i market price for crop i.
- ***r*** land rent for leased acres.
- $\boldsymbol{u}_j$ pound of j nutrient in 1,000 gallons of manure or in one ton of solid manure, which was determined by the amounts of the nutrient from lagoon liquid manure, and from dry manure. The amount was adjusted to account for losses due to field application methods.
- ***w*** gallons of manure produced per ***au***, which includes the amount of lagoon liquid manure and the equivalent amount of gallons converted from dry manure produced on the farm.
- $\boldsymbol{y}_i$ crop yield, bushels (tons) per acre, for crop i.

The variables considered in the model are as follows:

- A_i amount (1,000 gallons) of manure applied on one acre of crop i.
- Am Manured acres from owned cropland.
- C_{ikl} 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, and C_{inf} non manured acres produced crop i for feed.
- F_{ij} pounds of j nutrient applied to crop i.
- FDC cost for purchased feeds.
- Ls additional acres leased for the manure application.
- MAC cost to transport and spread manure on crops.
- N_v purchased amounts of net energy (Mcals), crude protein (lbs), and crude fiber (lbs).
- S_{ij} the amount of surplus manure nutrient j applied to crop i but not utilized by the crop.

Appendix B. Quantity and Nutrient Content of Dairy Manure, Application Losses, and Crop Nutrient Needs

Table A. Quantity and Nutrient Content of Manure[a]

	Manure Produced	*N*	P_2O_5	K_2O
Solid Manure	Tons/yr		Pounds/yr	
Cow (per mature cow)	14	126	49	91
Heifer (per heifer capacity)	6.5	63	24	44
Calf (per calf capacity)	1.5	14	5	8
Lagoon Liquid	Gallons/yr		Pounds/yr	
Cow (per mature cow)	11,000	46	19	33
Heifer (per heifer capacity)	6,000	26	12	18
Calf (per calf capacity)	1,200	4	1	3

Table B. Nitrogen Losses from Animal Manure to Air as Affected by Method of Application

Method of Application	Type of Manure	Nitrogen Loss %
Broadcast without Incorporation	Solid	15–30
	Liquid	20–25
Broadcast with Incorporation	Solid	1–5
	Liquid	1–5
Injection (Knifing)	Liquid	0–3
Irrigation	Liquid	30–40

Table C. Amount of Nutrients Needed by Selected Crops

Crops/Nutrients	N	P_2O_5	K_2O
Corn Silage (lbs/ton)	9.33	4.33	12
Sorghum Silage (lbs/ton)	9.33	4.33	12
Wheat (lbs/bushel)	1	1.42	0.7
Alfalfa Hay (lbs/ton)	56	26	64
Coastal Bermuda Grass (lbs/ton)	75	16.67	25

Source: Sutton, et al; Sweeten and Wolfe.

[a] As manure leaves storage for land application. The values were adjusted to account for losses due to the method of land application (Sutton et al.). The adjusted values then were assumed available for crop use in the analysis.

Appendix C. Daily Nutrient Requirements of Dairy Animals 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)	Maximum Dry Matter (Percent of Body Weight)
Cow Lactating for 10 mo plus Gestating for 2 mo	0.0074[a]	0.00082[b]	17	3
Growing Heifer	0.0097[c]	0.0024[d]	17	3
Mature Bull	0.0073[e]	0.0011[f]	15	3
Milk Production (per lb of Milk)	0.31[h]	0.037[i]		

Source: National Academy of Sciences, Overton.
[a] Maintaining 1,320 lbs. of a mature cow lactating 10 mo and plus last 2 mo 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(lbs/kg)/(2.2 × 600(kg/cow)) = 0.00082 (lbs) per lb of body weight.
[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 of body weight.
[d] 0.713 (kg × 2.2(lbs/kg)/(2.2 × 300(kg/heifer)) = 0.0024(lbs) per lb of body weight.
[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) × 2.2(lbs/kg)/2000 lbs = 0.0011 (lbs) per lb of body weight.
[h] Assuming 3.5% of milk fat, 0.69 (Mcal/kg)/(2.2(lbs/kg)) = 0.31 (Mcal) per lb of milk.
[i] Assuming 3.5% of milk fat, 0.082 (kg)/(2.2(lbs/kg)) = 0.037 (lbs) per lb of milk.

Appendix D. Animal Nutrients Supplied by Various Harvested Crops

Nutrient/Crop	Corn Silage (ton)	Sorghum Silage (ton)	Wheat (bushels)	Alfalfa Hay (ton)	Coastal Bermuda Grass (ton)
Dry-Matter Basis					
Dry Matter (%)	35	29	89	91	91
Net Energy (NE_l) (Mcal)[a]	1,445	1,118	55	1,045	954
Net Energy (NE_m) (Mcal)	1,400	1,063	59	1,009	936
Net Energy (NE_g) (Mcal)	880	436	39	327	173
Crude Protein (lbs)[b]	160	75	8	270	120
Crude Fiber (lbs)[c]	480	520	2	740	680
Dry Matter (lbs)[d]	700	580	53	1,820	1,820
As-Fed Basis[e]					
Net Energy (NE_l) (Mcal)	506	324	49	951	868
Net Energy (NE_m) (Mcal)	490	308	53	918	852
Net Energy (NE_g) (Mcal)	308	126	32	298	157
Crude Protein (lbs)	56	22	7.1	246	109
Crude Fiber (lbs)	168	68	1.8	673	618

Source: National Academy of Sciences.
[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 mater: 89 (%) × 56 (lbs/bu) = 49.8 lbs/bu.
[e] As-fed estimates = dry-matter estimates × percent of dry matter.