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Macro Level Economic Evaluation of Manure Application Rates Using CEEOT-MMS

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Abstract

Alternative manure application rates represent an integral part of current nutrient management efforts on animal feeding operations (AFOs). Previous studies have indicated that lower manure application rates tend to increase farm production costs. In this study, the Comprehensive Economic and Environmental Optimization Tool – Macro Modeling System (CEEOT-MMS) was used to evaluate the farm-level economic implications of alternative manure application rates for all AFOs in the 48 contiguous states of the U.S. Representative farms derived through statistical disaggregation of national databases and K-means clustering were simulated within the the Farm-level Economic Model (FEM) to determine the economic impacts of four manure application rates.

The highest manure application rate scenario investigated here (two times the N rate, or 2N) resulted in the highest net farm returns to AFOs. Similarly, the lowest manure application rate scenario considered in this study (the Half P rate), is projected to cost AFO operators the most, about $4,300 relative to the standard N rate scenario. Results of the study show that the larger AFOs would be required to haul out a much greater portion of on-farm manure than the smallest AFOs. Furthermore, the largest AFOs incur the highest per farm and per animal unit costs when manure application rates are reduced to rates below the P rate. However, under the Half P scenario all farm size groups would be required to haul out significant portions of manure generated on the farm. The total annual cost of the Half P scenario tops $1 billion dollars for AFOs in the 48 contiguous states.

Keywords: FEM, CEEOT-MMS, animal feeding operations, clustering, costs, manure, phosphorus

Introduction

As livestock production in the U.S. continues to be concentrated in fewer and larger sized operations, manure production and its management have received greater attention in recent decades. Concerns over the environmental implications of livestock waste have been well documented (Osei and Keplinger 2008; Sharpley et al. 1994; Khuder et al. 2007). Manure is a source of useful crop nutrients, but nutrient pollution from improperly managed manure applications is a source of concern. Manure is also a source of pathogens, which have been listed as a leading cause of impairments in rivers and streams. Recent U.S. water quality inventories indicate that pathogens from livestock operations as well as nutrients (primarily nitrogen (N) and phosphorus (P)) from livestock manure and other related agricultural activities are major causes of impairment of downstream waters (USEPA, 2007).

Whereas appropriate manure management is at the center of federal and local efforts to improve water quality (USDA and USEPA, 1999), livestock manure is still perceived as a leading cause of water quality problems in a number of watersheds across the nation. Livestock producer and government efforts to control nutrient losses from fields receiving manure have focused considerable attention on reduced manure application rates and judicious use of commercial fertilizer. Various studies have shown that reducing manure application rates to supply no more than crop agronomic requirements will lead to a reduction in nutrient losses, though this often comes at a cost to livestock producers (Osei et al. 2008; Feinerman, Bosch, and Pease 2004; Kaplan, Johansson, and Peters 2004; Osei et al. 2000; Schmit and Knoblauch, 1995; Massey and Krishna, 1994). In most cases applying manure at crop agronomic rates implies that manure applications are calculated to supply no more than crop P requirements since the N:P ratio of land applied manure nutrients is often lower than that of crop nutrient requirements.

Reduced manure application rates also imply that manure needs to be applied over greater land areas. Furthermore, under current regulations in most States (Metcalfe, 2000) for concentrated animal feeding operations (CAFOs), some fields previously receiving manure cannot be used for nutrient applications for many years due to the fact that a considerable period of time is required after cessation of nutrient applications for P levels in those fields to be restored to acceptable levels (Sharpley and Rekolainen, 1997). Thus soil P buildup further exacerbates the problem of finding appropriate land for manure application within an economically viable hauling distance from the livestock operation.

Previous research documented the economic implications of reduced manure application rates on animal feeding operations (AFOs) in Texas (Osei et al. 2008). In that study representative AFOs were defined using the statistical and data disaggregation procedures of the Comprehensive Economic and Environmental Optimization Tool – Macro Modeling System (CEEOT-MMS). In the present study, the economic implications of alternative manure application rate scenarios are estimated for AFOs in the 48 contiguous states of the U.S., using statistically derived representative farms. Four scenarios representing twice the N rate, the N rate, the P rate, and half the P rate of manure application were simulated for each representative farm using the Farm-level Economic Model (FEM; Osei et al. 1995; Osei, Gassman, and Saleh 2000), a whole-farm annual economic simulation model.

Overview of the modeling system

Overview of CEEOT-MMS

CEEOT-MMS was designed for large scale evaluation of water quality and other environmental policy issues (Osei et al. 2003; 2008). CEEOT-MMS consists of a farm-level economic model, an edge-of-field environmental simulation model, a national database on farm types and practices and other related data, and a central interface that includes various statistical clustering and mathematical routines.

CEEOT-MMS is used to evaluate large scale practices or policies through micro simulation of statistically derived representative farms and aggregation of simulation results across the study area using weights that reflect the number of individual farms represented by the simulated representative farm. Recent applications of CEEOT-MMS include evaluation of alternative manure application rates for Texas AFOs (Osei et al. 2008), evaluation of comprehensive nutrient management plans for AFOs in the Ohio River basin (Osei et al. 2006a), development of metamodels to capture the impacts of alternative nutrient management policies (Keplinger and Osei 2005), and risk and uncertainty analysis of manure nutrient characteristics (Osei et al. 2006b). The present study is limited to evaluation of economic impacts. Thus FEM is the only simulation model used and the field scale environmental model of CEEOT-MMS was not employed in this study.

Overview of FEM

FEM is a whole farm annual economic simulation model that estimates the impacts of a wide range of scenarios on farm-level economic indicators. FEM was developed primarily for environmental policy assessment (Osei, Gassman and Saleh 2000), but has been expanded to account for a broader range of policies related to agriculture. Key components within FEM include cropping systems (crop yields, field operations, nutrient requirements, input and output prices, etc.), livestock systems (livestock types, nutrient requirements, livestock operations, manure production characteristics, etc.), manure handling (manure storage and handling options, impacts of storage and handling on manure characteristics, etc.), land areas and uses (land areas available to the farm, crop land cover, characteristics of fields, etc.), structures and facilities, machinery and equipment, and exogenous parameters (biophysical characteristics of the farm, government policy variables, market conditions, etc.).

FEM includes special FORTRAN routines for estimating costs and returns of a farm operation based on user defined or default data about farm characteristics. Optimizations required for FEM simulations are handled within a General Algebraic Modeling System (GAMS; Brooke, Kendrick and Meeraus 1992) submodule that is linked to several model routines for transfer of relevant decision and exogenous variables.

Costs of field operations are computed in FEM by using agricultural machinery management specifications in ASAE EP496.1 (ASAE 1995a) and ASAE D497.1 (ASAE 1995b). Fixed costs of machinery and structures are computed using standard financial accounting formulas (Brigham and Gapenski, 1994). The time in hours required to complete a field operation on an acre of land is given by:

$$h = [wse\theta]^{-1}, \tag{1}$$

where h is the hours required per acre of land, w is the width of the implement, s is the field travel speed of the implement, e is the implement field efficiency, and θ is a unit conversion constant equal to 8.25. Given the hours of use h_{jit} for operation i in year t, using machinery j, repair and maintenance costs are given by:

$$C_{jit} = \frac{h_{jit}}{h_{jt}} RF1_j P_j \left[\left(\frac{H_{jt}}{1000} \right)^{RF2_j} - \left(\frac{H_{jt-1}}{1000} \right)^{RF2_j} \right], \tag{2}$$

where C_{jit} is the repair and maintenance expense for machinery j used in field operation i in year t,

h_{jit} is the number of hours machinery j was used in field operation i in year t,

h_{jt} is the number of hours machinery j was used in all field operations in year t,

$RF1_j$ and $RF2_j$ are ASAE repair and maintenance factors,

P_j is the purchase price of machinery j, and

H_{jt} is the cumulative hours of use of machinery j through the end of year t.

For manure application rate scenarios, special FORTRAN routines in FEM were used to determine the sizes of land areas that would receive manure given the expected behavior of farm operators under each application rate scenario. Further information on FEM is given in Osei, Gassman and Saleh (2000).

Derivation of AFO Distributions and Representative Farms

Derivation of AFO Distribution

For CEEOT-MMS simulations, AFOs are derived by applying statistical disaggregation and mathematical programming tools to extant national databases and other state data sources. The major databases employed in this effort are the Agricultural Census, National Resources Inventory (NRI), crop production databases, cropping practices surveys, as well as other USDA data sources. More information on data generation and statistical clustering procedures used are provided in Osei et al. (2003). For this study, data from the 1997 Agricultural Census were used as the key determinants of farm types and sizes.

Using statistical disaggregation procedures a set of hypothetical farms was derived that mimics the distribution of actual farms in the U.S. at the state and county levels. To determine which hypothetical farms should be categorized as AFOs, several criteria were used in a manner similar to the criteria used in a recent USDA study on the cost of implementing CNMPs on AFOs across the United States (USDA-NRCS, 2003). In particular, most of the farms classified as AFOs in USDA-NRCS (2003) either had at least 35 AU or consisted predominantly of confined livestock types. In this study, only farms with at least 35 AU were categorized as AFOs. Furthermore, an operation with over 35 AU was not considered an AFO if it was a sheep or beef cattle operation that had enough pasture biomass to provide adequate forage for the livestock on the farm. It was assumed for this study that if a sheep or beef cattle operation had at least an acre of pasture land per AU, it was not an AFO.

As an indication of how the statistically derived set of hypothetical AFOs compares with the list of AFOs produced by USDA, Table 1 shows the total number of AFOs of each major farm type as reported in USDA-NRCS (2003) and the number of hypothetical AFOs of the same farm types that were obtained using the disaggregation procedure within CEEOT-MMS. The numbers in the table indicate that the hypothetical set of AFOs is a reasonable approximation of the actual AFOs. Since USDA-NRCS (2003) included some smaller farms in their definition of AFOs (farms with less than 35 AU), the hypothetical set of AFOs is actually closer to the actual AFO distribution than is indicated in Table 1.

Derivation of representative AFOs

Given the set of AFOs in the 48 contiguous states, statistical clustering procedures were employed to determine representative farms for FEM simulations. In CEEOT-MMS, K-means clustering is used in a two-step clustering procedure to first divide the study area into ecological subregions and then determine representative farms for each subregion. With K-means clustering the criterion function is the average squared distance of the data items $\boldsymbol{X_k}$ from their nearest cluster centroids, $\boldsymbol{m}_{c(X_k)}$.

$$\mathbf{E}_k = \sum_k \left\| \boldsymbol{X}_k - \boldsymbol{m}_{c(X_k)} \right\|^2 \tag{3.2}$$

where $c(\boldsymbol{X}_k)$ is the index of the centroid that is closest to $\boldsymbol{X}_k$. One possible algorithm for minimizing E_k begins by initializing a set of K cluster centroids denoted by $\boldsymbol{m}_i$, i = 1, 2, 3, . . ., K. The positions of the $\boldsymbol{m}_i$'s are then adjusted iteratively by first assigning the data samples to the nearest clusters and then recomputing the centroids. The iteration is stopped when **E** does not change markedly any more. For CEEOT-MMS applications, the K-means clustering approach was employed using the FASTCLUS procedure of SAS (SAS Institute, 1999).

To determine the optimal number of clusters a procedure combining two empirical criteria was used. The Cubic Clustering Criterion (CCC; SAS Institute, 1983; 1999) and the Pseudo-F statistic were both considered. The optimal number of clusters was chosen as the number of clusters that yielded high CCC and Pseudo-F values and also represented distinct improvements over other partitions with almost the same number of clusters. Using this procedure, 7 subregions were delineated during the first-stage clustering process.

In the second-stage of clustering, all AFOs in each subregion were clustered to obtain farm clusters within each subregion. Representative farms were then obtained as the farm(s) closest to the centroid of each farm cluster. The K-means partitional clustering method was also used for second-stage clustering. Farm attributes used for the second-stage clustering are shown in Table 2. The second-stage clustering process was performed for each combination of the nine farm types and five farm sizes represented in each subregion. The two-step clustering process yielded a set of 1,050 representative farms, representing the distribution of farms by size and type in each ecological subregion. Figure 1 shows the spatial distribution of representative farms by farm size and by farm type across the 7 subregions.

The hypothetical farm data obtained from the Agricultural Census was augmented with management practice and other farm and economic data from other sources. Field operations performed on cropland and pasture were obtained from a Crop Operations Library, which was developed from the USDA Cropping Practices Survey (USDA, 1995) and state-level crop enterprise budget information. The Crop Operations Library contains field operations typical of the major cropping systems for each state.

Crop yields were obtained from USDA crop production databases. Crop agronomic rates were obtained by multiplying crop yields by crop agronomic uptake ratios. Agronomic uptake ratios for N, P, and potassium (K), were obtained from the Potash and Phosphate Institute (PPI, 2002) and Kellogg et al. (2000). Prices farmers receive for feed/grain sales as well as fertilizer and other input prices were obtained from the annual USDA Agricultural Prices publications (USDA-NASS, 2006).

Several other assumptions pertaining to manure production and handling were established for each farm type and size category. For this study, there were a total of nine main farm types based on predominant livestock species (dairy, beef, swine, broiler, layer, sheep, goat, turkey and horse operations) and five farm size categories based on total animal units (AU) on the farm (very small – less than 200 AU, small – 200 to 400 AU, medium – 400 to 1000 AU, large – 1000 to 2000 AU, and very large – over 2000 AU). Farm types were further subdivided into subcategories based on production systems and housing styles, yielding a total of 140 potential farm types.

Manure production data were obtained from ASAE (1995c) per unit of liveweight for each livestock species. Total manure production for each farm was then calculated as a summation across all livestock species, weighted by their respective liveweights, number on the farm, and duration in the herd. Manure handling systems in place were based on the manure management systems distribution used in Kellogg et al. (2000). Manure nutrient loss prior to land application was based on assumptions widely used in nutrient management plans in various states.

Manure Application Rate Scenarios

Four alternative manure application rate scenarios were investigated in this study for all AFOs in the 48 contiguous states of the U.S. Manure application rates were investigated because recent studies indicate that nutrient management on fields receiving manure remains one of the most relevant practices for water quality enhancement (Osei et al. 2000), particularly in livestock impacted areas. The four manure application rate scenarios included in this study relate to the N or P agronomic rate of receiving crops, as defined below.

The N Rate scenario:

The N rate scenario was also assumed to be the baseline or status quo scenario for purposes of comparison. Under this scenario, AFOs apply manure on crop fields and pastures at rates calculated to supply all of crop N needs, taking into account all applicable losses and unavailable portions of nutrients. Any remaining cropland or pasture on the farm was assumed to receive commercial fertilizer nutrients at recommended crop agronomic rates. It was also assumed that for all scenarios, farmers would continue to apply some amounts of inorganic fertilizer on fields receiving manure. Thus the simulations implicitly assume partial accounting for manure nutrients. If the land farmed by this representative AFO was not adequate for manure applications, the remaining manure was hauled to a nearby landowner's premise and applied there at the N agronomic rate. The representative AFO was assumed to bear all manure hauling and application expenses.

The 2N Rate scenario:

The 2N rate scenario entails manure application at twice the N agronomic rate. All other specifications used for the N rate scenario were used for the 2N scenario as well. The 2N scenario implies manure application over smaller land areas, which means that the proportion of manure hauled off the AFOs would be less under this scenario than the N rate scenario.

The P Rate scenario:

The P rate scenario provides improved manure P management by specifying manure application at a rate that is more in line with crop agronomic requirements. The P rate scenario calls for manure application at such rate that manure total P supplies all crop P requirements. Generally, manure application at a P-based rate also necessitates commercial fertilizer N supplementation on these fields because of the disparity between the manure N/P ratio and the N/P ratio of nutrients needed for most crops. Thus additional commercial fertilizer N levels were simulated if current inorganic fertilizer N rates were inadequate.

The Half P Rate scenario:

The Half P scenario entails manure application at a rate that is half what would be used under the the P rate scenario specified above. In a number of states, manure application rates are adjusted based on soil P levels or a more comprehensive indicator known as the P index. In such situations manure application rates are reduced to rates lower than the P agronomic rate if soil P levels are higher than a predefined threshold. The Half P rate scenario reflects the situation where AFO operators need to apply manure at rates lower than the P rate because of soil P buildup caused by high manure and/or fertilizer P application rates in previous years. As mentioned previously prevailing fertilizer application rates are maintained on fields receiving manure, as well as on other fields farmed by the livestock operator. Thus while manure nutrient rates are reduced, just as with the other scenarios, the Half P scenario also assumes that AFO operators are not fully accounting for manure nutrients. Model assumptions used for the Half P scenario were the same as used for the P rate scenario, except for the manure application rate. In practice, it is expected that manure application rates would increase as soil P levels are restored to the acceptable range.

Other baseline and scenario specifications

The application rates specified for all four scenarios were simulated for both liquid and solid manure fields. All scenarios were simulated for a 30-year period in order to account for the complete cycle of different cropping patterns on the farms. Since P application rates are lower than N rates for most cases solid manure also needs to be applied over greater acreage under the P-rate scenarios. Furthermore, commercial fertilizer use would change from one scenario to another. For each scenario, manure was applied at the same frequency and timing that commercial fertilizer applications are made on receiving land areas.

Some AFOs do not have enough land on their farms to utilize manure for crop needs. On these farms, manure remaining after appropriate land application is hauled to the closest available landowner who is willing and has adequate land to receive the manure. Hauling costs accruing to the AFO operator are in direct proportion to the distance to the receiving land owner. For this study, it was assumed that the average hauling distance is 5 miles and that manure hauling expenses would average about $2/ton for the first mile and $0.15 per ton-mile for each additional mile, based on data collected recently and adjusted for increases in fuel costs.

On some AFOs, such as open lot and freestall dairies, some portion of manure is handled in liquid form and collected in lagoons or waste storage ponds. The effluent from these lagoons or ponds is then irrigated on liquid manure application fields. In addition to assuming an N agronomic rate for manure applications in the baseline, it was also assumed that irrigation facilities for liquid manure handling were sized to apply lagoon effluent on just the amount of land area required to receive the effluent at the N agronomic rate. Thus, under the P rate scenarios, irrigation facilities on these farms would be expanded. This expansion generally constitutes a great portion of the cost of moving from an N to a P agronomic rate on farms that irrigate wastewater on manure application fields.

It was assumed that AFO operators would not purchase or lease additional land for solid manure application. However, in situations where additional acreage is needed for liquid manure application, it was assumed that AFO owners would purchase additional land for that purpose and that they would harvest the grain or forage grown on the leased area. In the latter case, additional grain or forage harvested from the leased land area would have impact on livestock feed costs and grain or forage sales. These impacts were determined within the livestock nutrition module of FEM. The livestock nutrition module incorporates an optimization process similar to the procedure used by nutritionists to determine livestock rations based on nutrient requirements, livestock inventories, feed prices and other feed characteristics.

Results and discussions

All four scenarios defined above were simulated using FEM. The results presented here are aggregate summaries across all AFOs within each subregion, each farm size category, or the entire simulation region. Aggregate impacts were calculated as weighted averages across all representative farms in the respective categories, as explained earlier. For instance, aggregate results by subregion were obtained as weighted averages across all representative farms within each subregion. The weights refer to the number of farms each simulated (representative) farm represents, as determined from the statistical clustering process.

The economic impacts of the three alternative application rates are shown in Table 3 by subregion and for all 48 contiguous states as compared to the baseline. The table shows the average values of net farm returns, net farm returns per AU, depreciation and interest, fertilizer and other crop inputs, manure spreading and other crop operating expenses, manure hauling cost, and percent of manure hauled off the farm for the entire study area. The first line of values shown are baseline values obtained as weighted averages across all farms simulated. Net farm returns values reported here are the result of deducting all explicit and implicit costs from total revenues.

The results from FEM simulations indicate that almost 23% of solid manure is hauled off the average AFO in the U.S. when manure is applied at the N agronomic rate of receiving crops.

Under the baseline, net farm returns is about $81,000 per farm per year, fixed costs of farm facilities and equipment (depreciation and interest) average almost $120,000, fertilizer and other crop input expenses are over $40,000, and other crop operating expenses, including manure spreading, also averaged over $40,000 per farm per year.

The first set of scenario impacts shown in Table 3 are for the 2N scenario. The impacts are shown as the change in costs ($/farm) for each indicator, except for percent of manure hauled off, which is expressed as the simple difference in percent of manure hauled off between the baseline and the alternative scenario. On average, the 2N rate scenario is projected to save farmers about $300 per farm, with average savings by subregion ranging from under $100 to over $4,000 per farm annually. The 2N scenario represents cost savings because of lower manure application costs and lower manure hauling costs. Percent of manure hauled out of AFOs decreases by less than 1%, though the decrease in subregion 7 is over 12%. In aggregate, the 2N scenario saves farmers over $70 million dollars annually.

The next set of numbers in the table show the impacts of the P application rate scenario on the selected economic indicators. The P application rate is projected to cost the average farm almost $1,620 per year relative to manure application at the N agronomic rate. Depreciation and interest expenses are projected to increase by about $250 per farm, manure spreading and other crop operating expenses are projected to increase by almost $500 per farm per year, and fertilizer expenses are projected to increase by close to $190 per farm per year. The impacts of the P rate scenario are much lower than the impacts reported for Texas AFOs in a recent study (Osei et al. 2008), which suggests that some farms in these regions are likely to gain from lower manure application rates and judicious use of commercial fertilizer.

Under the P rate scenario the percent of manure hauled off the typical AFO is projected to increase by about 5%, though this would range from less than 1% in subregion 1 to over 30% in subregion 7. In terms of overall costs, subregions 2, 3, 4, and 7 are projected to experience the highest per farm costs relative to the N agronomic rate scenario. However, due to the greater number of AFOs in other subregions, higher aggregate costs are incurred by AFOs in subregion 6 than in subregion 7. In aggregate, the P rate scenario is projected to cost AFOs in the contiguous states over $380 million dollars annually.

The last set of numbers in the table show the impacts of the Half P application rate scenario on the selected economic indicators. The Half P application rate is projected to cost the average farm almost $4,400 per year relative to manure application at the N agronomic rate. The sizable difference between the P rate scenario and the Half P rate scenario suggests that in areas where soil P buildup requires farm operators to apply manure at rates below the P agronomic rate, significant cost implications are likely. Depreciation and interest expenses are projected to increase by over $1,200 per farm, manure spreading and other crop operating expenses are projected to increase by almost $1,000 per farm per year, and fertilizer expenses are projected to increase by close to $500 per farm per year. The percent of manure hauled off the typical AFO is projected to increase by almost 10%, though this would range from about 3% in subregion 1 to over 40% in subregion 7. In terms of overall costs, subregions 2, 3, and 6 account for the greatest share of the total cost incurred under the Half P manure application rate, with each of these regions incurring a cost increase of between $200 million and $310 million annually. The total cost of the Half P rate to AFOs is projected to top $1 billion dollars annually, which is about 3 times the cost of the P rate scenario.

It is important to note here that the Half P scenario assumes manure application at half the P agronomic rate for all farms. In reality, such a low manure application rate would be applicable only to a few farms where soil P levels are very high or other local conditions dictate the low manure application rates. The costs of the P rate scenarios would also be lower if existing commercial fertilizer applications that are not needed by the crop had been eliminated.

The economic impacts of the scenarios are shown by farm size category in Table 4. As expected, the average economic impacts of all scenarios per farm are greater for larger AFOs than smaller ones (Table 4). Financial gains from the 2N scenario are greatest for the very large AFOs ($14,825/farm) and smallest for the small AFOs ($48/farm). The impacts on net farm returns per AU are also greatest with the very large AFOs and smallest with the small sized AFOs. All farm sizes are projected to experience a reduction in the percentage of manure hauled off the farm, with the large and very large AFOs experiencing the greatest reduction in percentage of manure hauled off, as expected.

The economic impacts of the P rate scenario are also largest for the very large AFOs. The annual cost per farm (reduction in net farm returns) is estimated at over $45,000 for very large AFOs and only about $360 for the very small AFOs. Percent of manure hauled off the AFOs is also largest for the larger AFOs, about 37% and 38% for the very large and large AFOs respectively. On the contrary, very small AFOs are projected to see a very small increase in the percentage of manure hauled off their farms, about 2%. Of the $380 million total annual cost of the P rate scenario relative to the N rate, very large AFOs are projected to incur about $100 million and very small AFOs are projected to incur $48 million.

The last set of results in Table 4 show the impacts of the Half P rate scenario. While the Half P rate entails a manure application rate that is half of the P rate, the economic impacts are disproportionately higher. A key factor behind the disproportionate increase in cost is the fact that disproportionately greater proportions of manure need to be hauled off the farms and manure and commercial fertilizer application costs are also higher. While small AFOs would haul off an additional 5% of their manure under the P rate scenario, they are projected to haul off over 14% more of their manure under the Half P scenario. Similarly, very small AFOs are projected to see an increase in percent of manure hauled off under the Half P rate of over 4% relative to the N rate, as compared to about 2% under the P rate scenario. Large and very large AFOs are estimated to haul off over 40% of their manure when application rates are based on half of the P agronomic rate.

Of the roughly $1 billion total annual cost of the Half P rate, only large AFOs incur a share of less than $100 million. About $270 million is incurred by AFOs in each of the two smallest size categories because of their sheer numbers, and also because unlike the other scenarios, the smallest AFOs also experience significant costs under the Half P rate scenario. Per farm costs of the Half P rate scenario range from about $2,000 for the very small AFOs to almost $90,000 for the very large AFOs.

Summary and conclusions

A macro modeling system developed for the purpose of evaluating large-scale policies and practices related to agriculture and the environment was applied to evaluate the economic impacts of manure application rates on AFOs. Representative farms derived using statistical clustering and data disaggregation routines within CEEOT-MMS were simulated in FEM to evaluate the impacts of manure applications at the N rate, twice the N rate, the P rate, and half the P rate on net farm returns and other farm-level economic indicators. While all simulations were performed for a 30-period, it is unlikely that farmers would actually apply manure at the Half P rate for so many years.

Simulation results indicate that the Half P rate scenario is disproportionately costly to AFOs. Total annual cost of the Half P rate scenario to AFOs is projected to exceed $1 billion annually, whereas the total annual cost of the P rate scenario is about $380 million. The cost increases related to the P and Half P manure application rate scenarios as compared to the N rate scenario are due to the increased manure application costs, increased crop operating expenses, and increased manure hauling costs. These costs, particularly for the Half P rate, would be lower if farmers fully accounted for all manure nutrients and reduced inorganic fertilizer applications accordingly.

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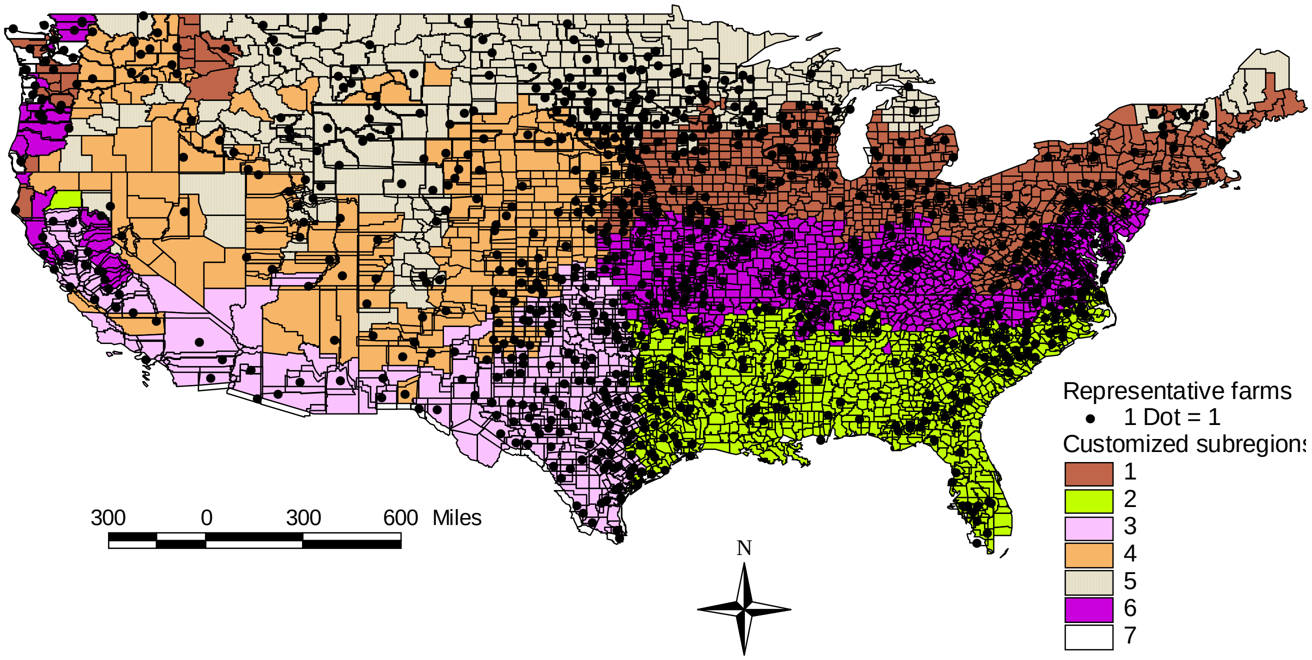

Figure 1: Distribution of representative farms by size and type across subregions.

Table 1. Comparison of number of AFOs: USDA versus statistically disaggregated data

Farm type	USDA	Hypothetical
Dairies	79,318	70,056
Swine	32,955	36,953
Broilers	16,251	14,193
Layers	5,326	5,764
Turkeys	3,213	1,350
Other	120,138	106,716
Total	257,201	235,032

Table 2: Farm attributes used in second-stage clustering

Farm Attribute	Dairy	Beef	Swine	Broilers	Layers	Sheep	Goats	Turkeys	Horses
Total cropland (acres)	X	X	X	X	X	X	X	X	X
Harvested cropland (acres)	X	X	X	X	X	X	X	X	X
Cropland used for pasture or grazing only (acres)	X	X	X	X	X	X	X	X	X
Pastureland and rangeland other than cropland and woodland pastured (acres)	X	X	X	X	X	X	X	X	X
Corn for grain or seed (acres)	X	X	X	X	X	X	X	X	X
Corn for silage or green chop (acres)	X	X	X	X	X	X	X	X	X
Sorghum for grain or seed (acres)	X	X	X	X	X	X	X	X	X
Wheat for grain (acres)	X	X	X	X	X	X	X	X	X
Cotton (acres)	X	X	X	X	X	X	X	X	X
Soybeans for beans (acres)	X	X	X	X	X	X	X	X	X
All hay (acres)	X	X	X	X	X	X	X	X	X
Beef cows		X							
Milk cows	X								
Heifers and heifer calves		X							
Steers, steer calves, bulls, and bull calves		X							
Cattle fattened on grain and concentrates		X							
Hogs and pigs inventory			X						
Sheep and lambs of all ages inventory						X			
Layers and pullets: 13 weeks old and older inventory					X				
Broilers and other meat-type chickens sold				X					
Goats, inventory							X		
Turkeys, inventory								X	
Horses, inventory									X

Table 3: Simulated average annual economic impacts of scenarios by subregion.

Subregion	Net farm returns	Net farm returns per AU	Depreciation and interest	Fertilizer and other crop inputs	Manure spreading and other crop operating expenses	Manure hauling cost	% Hauled off	Aggregate net returns
	$/farm	$/AU	---------------------------$/farm------------------------				%	Million $
Baseline	81,359	361	119,707	41,724	41,735	1,568	22.9	19,122.1
		Impacts of 2N, P, and Half P scenarios: changes from baseline scenario						
2N Impact								
48 States	305	1.4	-20	0.0	-43	-216	-0.6	71.7
1	88	0.5	-20	0.0	-12	-41	-0.2	6.6
2	291	1.0	-22	0.0	-46	-207	-1.1	10.2
3	1,684	5.2	-47	0.0	-166	-1,374	-1.5	27.4
4	320	1.1	15	0.0	-104	-214	-0.3	7.5
5	222	1.3	-83	0.0	-31	-68	-0.2	7.5
6	212	1.1	16	0.0	-25	-188	-0.8	10.8
7	4,013	13.3	-274	0.0	-56	-3,116	-12.4	1.6
P Impact								
48 States	-1,618	-7.2	246	188.8	494	512	5.0	-380.2
1	-466	-2.4	64	10.2	195	117	0.7	-34.8
2	-2,614	-8.6	410	518.3	722	832	13.3	-91.5
3	-4,720	-14.6	545	135.2	1,397	1,800	6.8	-76.7
4	-2,823	-10.0	400	274.5	1,224	785	4.2	-66.4
5	-783	-4.6	104	13.5	323	292	4.6	-26.6
6	-1,556	-7.7	319	318.3	259	442	5.4	-79.3
7	-11,639	-38.7	1,344	271.2	1,389	5,383	32.7	-4.8
Half P Impact								
48 States	-4,383	-19.5	1,213	470.9	986	850	10.6	-1030.2
1	-1,300	-6.8	344	31.3	376	257	3.6	-97.3
2	-6,669	-22.0	2,182	822.8	1,592	1,186	20.3	-233.6
3	-12,706	-39.3	2,516	853.8	2,512	3,032	22.0	-206.4
4	-6,181	-21.9	1,438	671.7	2,192	1,258	7.9	-145.5
5	-901	-5.3	-235	74.8	716	433	6.4	-30.6
6	-6,041	-30.0	2,258	911.1	583	838	14.4	-308.0
11	-21,533	-71.5	2,882	2,055.6	3,283	6,335	42.7	-8.8

Table 4: Simulated average annual economic impacts of scenarios by farm size categories.

Subregion	Net farm returns	Net farm returns per AU	Depreciation and interest	Fertilizer and other crop inputs	Manure spreading and other crop operating expenses	Manure hauling cost	% Hauled off	Aggregate net returns
	$/farm	$/AU	--------------------------$/farm-----------------------				%	Million $
	Impacts of 2N, P, and Half P scenarios: changes from baseline scenario							
2N Impact								
Very Small	111	1.7	-32	0.0	-12	-53	-0.3	14.9
Small	48	0.2	16	0.0	-50	-8	-0.1	4.0
Medium	369	0.6	-30	0.0	-118	-191	-1.1	5.1
Large	4,516	2.7	-221	0.0	-241	-3,841	-14.8	15.1
Very Large	14,825	3.7	-333	0.0	-877	-12,550	-14.2	32.6
P Impact								
Very Small	-360	-5.4	74	8.3	122	105	2.0	-48.1
Small	-1,182	-4.9	225	224.7	472	169	5.5	-97.0
Medium	-6,026	-9.2	620	1,489.7	1,664	1,733	18.3	-83.4
Large	-15,492	-9.4	2,226	465.7	4,446	7,196	38.3	-51.7
Very Large	-45,422	-11.4	6,102	1,198.9	10,559	20,132	37.0	-100.0
Half P Impact								
Very Small	-2,006	-29.9	1,015	39.9	234	182	4.3	-267.9
Small	-3,402	-14.1	955	647.9	881	436	14.2	-279.2
Medium	-14,658	-22.3	1,802	2,144.4	3,465	4,022	36.0	-202.9
Large	-25,188	-15.3	3,192	1,606.7	9,294	9,076	48.4	-84.1
Very Large	-89,065	-22.3	16,168	7,775.0	22,262	24,379	44.7	-196.1