# When the !%$? Hits the Land: Implications for US Agriculture and Environment when Land Application of Manure is Constrained

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**Abstract**

Confined animal production in the U.S. and its associated discharge of manure nutrients into area waters is considered a leading contributor to current water quality impairments. A common option to mitigate these impairments is to limit land application of manure. This paper evaluates the implications of alternative land application constraints for U.S. agriculture and the environment at the regional and sector level. The results suggest that when these constraints are particularly binding, due to minimal acceptance of manure as a substitute for commercial fertilizer, potentially large and unanticipated changes in returns to agricultural production and water quality may occur. Furthermore, we find that some of the cost of meeting the land application constraints will be passed on to consumers through higher prices and to a portion of rural economies through lower production rates and labor expenditures.

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## Introduction

Agricultural production in the United States annually produces large amounts of potential ground and surface water pollutants. Current production of manure nutrients on individual farms sometimes exceeds the nutrient requirements of the surrounding cropland available for manure spreading, thereby increasing the potential nutrient discharge into surrounding waters (Kellogg et al; Gollehon et al). The U.S. Environmental Protection Agency (EPA) estimates that nutrients from crop and animal production are found in 50% of impaired lakes and 20% of impaired rivers in the U.S. (EPA 2002a). Growing public concern over nutrient-related pollution from agricultural production is evident in recent state and federal legislation enacted to regulate livestock and poultry production (Metcalfe; USDA-EPA) and in new government funding intended to help livestock and poultry producers comply with water quality regulations (NRCS 2002a). One proposed option to reduce the potential of manure-nutrient water impairments is to require the adoption of manure 'best management practices.' This is generally agreed to be the agronomic application of manure nutrients on cropland (i.e., manure generated at confined animal feeding operations (AFOs) is applied to cropland and pastureland at no greater than agronomic rates, thereby minimizing nutrient runoff from the fields (USDA-EPA)).

Land application constraints on manure nutrient use could potentially lower aggregate production of livestock and poultry commodities at the national level, resulting in increased prices. Potential changes in aggregate crop production will depend on the derived demand for cropland for spreading manure and the demand for crops as feed ration inputs. In any event, the production changes at the national level will affect regional economies and their environments differently because economic and environmental conditions vary across regions. With such large-scale changes to consider, both a regional and a sector-wide assessment of economic adjustments is appropriate (Berck and Hoffman).

An abundance of literature discusses the merits of judiciously applying manure nutrients to crops (see for example, Brenneman; Fleming, Babcock, and Wang; Lazarus and Koehler). Innes extends this literature in providing a comprehensive, albeit theoretical, treatment of the spatial and environmental issues of manure generation, management, and regulation. Recent empirical applications have examined the impact and effectiveness of restricting land-based applications of manure nutrients to achieve water quality goals at the farm level (Ribaudo, Gollehon and Agapoff; Roe, Irwin and Sharp) and national level (NRCS 2002b; EPA 2001; FAPRI). However, for different reasons these applications do not completely adhere to the comprehensive approach suggested by Innes.  The farm-level papers mentioned above consider only the swine industry. The FAPRI study does not evaluate the potential changes in costs and benefits to rural economies, the environment, or to consumers. The NRCS and EPA studies do not incorporate equilibrium price effects, nor does the EPA study account for manure production in excess of land availability.

The objective of this research is to evaluate how manure-nutrient application constraints (henceforth, nutrient constraints) will influence animal and crop production decisions, rural agricultural economies, and consumer and producer welfare throughout the U.S. agricultural sector. In addition, we assess the corresponding environmental consequences when nutrient constraints are imposed. Our analysis of nutrient constraints departs from and builds upon the recent empirical literature by focusing on regional and sector economic adjustments, as suggested by Innes, and Berck and Hoffman. Following Ribaudo, Gollehon and Agapoff, and Fleming, Babcock and Wang, we allow the share of cropland utilizing manure nutrients to vary.

Crop producers may be reluctant to accept manure as a substitute for inorganic fertilizers given that manure nutrients are not packaged as uniformly as commercial fertilizers, may contain pathogens, and are generally more difficult to handle (Risse et al).

The next section provides a sector model that illustrates the potential changes in production and prices given the imposition of land application constraints for manure nutrients. The third section describes the empirical analysis used to evaluate the economic and environmental implications of these constraints and is followed by a discussion of the policy simulation results, detailing the potential changes in the livestock and poultry sectors, crop sectors, consumers, and the environment. The paper closes with a summary of findings and potential implications for regulating the environmental impacts of animal production.

**Empirical Analysis**

Nutrient constraints essentially force animal production and crop production within a geographic area to be in balance, likely reducing the quantity of manure nutrients that reach U.S. ground and surface waters. We assume that when an operation meets nutrient constraints, the manure generated from that operation is applied to cropland at no greater than agronomic rates. This could increase the cost of production for AFOs as they seek available cropland for manure spreading,[1] incur higher hauling costs, and invest in associated nutrient management services. Furthermore, if a region has more manure nutrients than can be assimilated by available cropland, it is out of balance. Of the several changes that can occur to allow a region to achieve a balanced state, we consider endogenous changes in cropping and animal composition, technologies, and production levels.

The imposition of nutrient constraints on CAFOs and thus manure management costs are transmitted throughout the entire agricultural sector, across animal and crop sectors, and across regions because animal and crop production is intricately linked through the agricultural input and output markets. For instance, crop producers supply feed grains to the animal sectors. If animal production declines due to the increased cost of production ,the demand for feed grains will shift downward, affecting the feed grain markets. Cross-sector shifts in demand and supply will continue throughout the agricultural economy as the markets adjust to changes in relatively prices for complement and substitute goods. To gauge the responsiveness of the U.S. agricultural sector to nutrient constraints, we focus attention on the availability of agricultural cropland for spreading manure, which in turn depends on crop producers' willingness to substitute manure for commercial fertilizer.[2]

With the sector model in mind, we consider the case where only concentrated AFOs (CAFOs) meet nutrient constraints.[3] These facilities represent 4.47% of the total AFOs in the U.S. However, the quantity of manure generated by CAFOs exceeds 200 million tons, more than 46% of the U.S. total from confined operations. Regional differences are also notable (Table 1). The percentage of animal operations categorized as CAFOs in the Southeast and Pacific regions is significantly higher than in other regions. In the Northern Plains, Appalachia, Mountain, and Pacific regions CAFOs generate more than 60% of the manure from all confined operations. Furthermore, these large facilities will soon be required to meet nutrient constraints under new

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[1] We consider cropland used in the production of corn, soybeans, sorghum, oats, wheat, rice, hay, and silage is available for the spreading of manure. We do not consider potential applications of manure to rangeland, vegetable, horticulture, sugar, peanut, or silviculture operations.

[2] New technological innovations that might allow animal producers alternative means by which to curtail manure nutrient generation are not considered. Examples of these might include supplements to livestock and poultry feed and alternative manure storage and treatment options that would serve to diminish the nutrient content of animal manure.

[3] CAFO is an AFO with more than 1,000 animal units. USEPA defines an animal unit as 700 dairy cows, 1,000 beef cows, 4,000 swine, 250,000 broilers for example (Gollehon et al.).

National Permit Discharge Elimination System (NPDES) rules (EPA 2002b). Table 1 illustrates the regions where meeting nutrient constraints might be more difficult than others. Appalachia, Southeast, and Pacific regions have greater manure production per acre of cropland than do other regions. This indicates that possible changes in economic performance throughout these regions could be more severe than in other regions. That said, we might also see greater environmental improvement in these regions.

**Table 1. Operations with confined livestock and manure distribution**

| USDA Farm Production Region | Operations | | Manure (Million Tons) | | CAFO Manure Concentration* (Tons/Acre) |
|---|---|---|---|---|---|
| | Total AFO | % CAFO | Total AFO | % CAFO | |
| Northeast | 31,350 | 1.59 | 39 | 15.42 | 0.42 |
| Lake | 52,498 | 1.64 | 59 | 25.10 | 0.39 |
| Corn Belt | 71,252 | 3.18 | 73 | 39.55 | 0.29 |
| Northern Plains | 26,087 | 4.77 | 65 | 64.01 | 0.57 |
| Appalachia | 22,776 | 7.46 | 66 | 62.29 | 2.25 |
| Southeast | 12,635 | 10.79 | 23 | 43.31 | 1.33 |
| Delta | 12,252 | 7.48 | 19 | 39.04 | 0.42 |
| Southern Plains | 10,500 | 7.00 | 46 | 38.22 | 0.56 |
| Mountain | 7,780 | 8.43 | 33 | 69.31 | 0.80 |
| Pacific | 7,654 | 14.85 | 40 | 60.55 | 2.43 |
| Totals | 254,784 | 4.47 | 462 | 46.36 | 0.64 |

*Tons of manure and acres of cropland are measured at the regional level.
Source: 1997 U.S. Census of Agriculture (USDA-NASS, 1997). Northeast = CT, DE, MA, MD, ME, NH, NJ, NY, PN, RI, VT; Lake = MI, MN, WI; Corn Belt = IA, IL, IN, MO, OH; Northern Plains = KS, ND, NE, SD; Appalachia = KY, NC, TN, VA, WV; Southeast = AL, FL, GA, SC; DELTA = AR, LA, MS; Southern Plains = OK, TX; Mountain = AZ, CO, ID, MT, NM, NV, UT, WY; Pacific = CA, OR, WA.

Next, we select a range of substitution rates over which to conduct our experiments. We define the willingness to substitute manure nutrients (*substitute*) as the percentage of a region's agronomic demand for nitrogen and phosphorus (based upon crop requirements in that region) met by manure nutrients. Currently 17% of corn producers and 9% of soybean producers supplement commercial fertilizer with manure as part of their crop fertilization regime (USDA 2000). It is unclear to what extent substitution rates might change as CAFOs adopt nutrient constraints, but it is not unrealistic to assume that this rate will increase, especially in regions facing binding nutrient constraints.[4] We allow this rate to vary between 20 and 40% (i.e., *substitute* ? (0.2, 0.3, 0.4)) to reflect a feasible range of possible substitution rates.

To evaluate the implications of meeting nutrient constraints we simulate a constrained partial equilibrium, regional optimization model, which seeks to maximize profits from livestock and cropping enterprises,

(1a) $$\max_{xact_{rj}, xact_{ri}} \sum_j (P_j xact_{rj} - VC_{rj} - TC_{rj} - FC_r) + \sum_i (P_i xact_{ri} - VC_{ri}) - AVC_r ,$$

subject to nutrient constraints

(1b) $$\sum_j (q_{jr} \times man\_nut_{jrf}(xact_{rj})) \leq substitute \times Ag\_nut_{rf}(xact_{ri}), \forall r, f \ .$$

Here $xact_{rj}$ represents regional production of livestock and poultry species *j* in region *r*; $xact_{ri}$ represents regional acres planted under cropping enterprise *i* (crop rotation and tillage regime) in region *r;* $P_j$ and $VC_j$ are equilibrium prices and variable costs for livestock and poultry products; $P_i$ and $VC_i$ are equilibrium prices and variable costs for crops. We also include the fixed costs (*FC*) essential to meeting a nutrient constraint, transportation costs (*TC*) associated with manure spreading, and additional variable costs (*AVC*) for soil testing and savings.[5]

Transportation costs are a function of the distance traveled and the quantity and type of manure transported. We use conventional estimates of base (*Base*) commercial hauling charges (*Mileage*) for tons of manure produced (*Ton*) by animal species within each region:

[4] We note that in the most recent USDA survey of corn producers from 2001 (USDA-NASS, 2003) approximately 26 percent of respondents report using manure on their fields.

[5] These fixed costs include per operation manure testing and management plan development of $200 and $400 respectively (NRCS 2002b). Soil testing cost estimates are taken from the NRCS Cost and Capabilities Analysis and range between $0.08 to $0.40 per acre per year across regions based on soil type (NRCS 2002b). Commercial fertilizer savings when manure nutrients are substituted for commercial fertilizer amount to $0.185 per pound of nitrogen and $0.30 per pound of phosphorus (Ribaudo, Gollehon and Agapoff).

(2a) $$TC_r = \sum_j Ton_{jr} \times (Base_{jr} + Dis_r \times Mileage_{jr}),$$

where *Dis* is the average distance greater than a mile traveled by a CAFO to spread manure. To calculate the regional distance per affected AFO, we modify the Fleming, Babcock, and Wang methodology for search acreage:

(2b) $$Dis_r = \sqrt{\frac{Ac_r}{(1-g_r)\times TO_r \times 640}} - 1,$$

where $Ac_r$ is the total acres available for spreading manure, which is a function of the nutrient constraints and the endogenous crop acreage choice ($xact_{ri}$), $g \in (0,1]$ describes the regional share of production from CAFOs, and *TO* is the total number of AFOs in that region. Here, *g* approaches one as the number of CAFOs within a region increases, effectively centralizing the location of affected operations towards the middle of the region, thereby allowing the search algorithm to capture the greater distance needed to spread manure from a few highly concentrated operations.[6]

The nutrient constraints (eq. 1b) require the sum of each manure nutrient generated by livestock and poultry activity *j*, within region *r* ($man\_nut_{jrf}$) to be less than or equal to the product of the regional substitution rate and agronomic crop nutrient demand ($Ag\_nut_{rf}$), where *f* indexes *nitrogen* and *phosphorus*, respectively.[7] $q_{jr}$ represents the CAFO portion of available manure generation for each region and species. Note that $man\_nut_{jrf}$ and $Ag\_nut_{rf}$ are endogenously determined given optimal levels of animal and crop production. This constraint

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[6] Because the farm production regions are already large (incorporating from two to eleven states), we assume that transportation of manure only occurs within a region.

[7] Estimates of available manure nutrients by animal type are net the losses attributable to prevailing storage and handling technology (Kellogg et al.). Agronomic demand is calculated using crop uptake values for nitrogen and phosphorus, accounting for losses due to denitrification, subsurface flow, runoff, and leaching.

(eq. 1b) explicitly requires the regional agricultural sector to maintain nutrient balance through altering animal and crop production.

We simulate this constrained optimization problem using the U.S. Regional Agricultural Sector Mathematical Programming Model (USMP). This is a comparative-static, spatial and market equilibrium model that incorporates agricultural commodity, supply, demand, environmental impacts, and policy measures (House et al.). This model has been applied to various issues, such as climate change mitigation (Peters et al.), water quality policy (Ribaudo et al.), wetlands policy (Claassen et al.), and sustainable agriculture policy (Faeth). In the model, the agricultural sector adjusts to the nutrient constraints by substituting across production activities, and cropping and tillage practices with varying input requirements. This substitution is facilitated by nested constant elasticity of transformation functions that allow for interior solutions across activities and technologies.

Crop and animal production choices are linked to edge-of-field environmental variables using the Environmental Policy Integrated Climate Model (EPIC), which uses a daily time step to simulate weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, crop management and growth, and pesticide and nutrient movements with water and sediment (Mitchell et al). The movement of nutrients, pesticides, and sediment across the landscape is then calibrated to USGS estimates of regional pollutant loads (Smith, Schwartz, and Alexander).

Estimates of CAFO and AFO spreading practices on swine operations taken from Ribaudo, Gollehon and Agapoff allow us to account for prior land application of manure in the simulations. On average, CAFOs currently spread manure on the 155 nearest acres to their operation and the smaller AFOs currently spread manure on the 90 nearest acres. While these numbers do not reflect the wide variety of animal operations across the U.S., they are reasonable for initial estimates of the environmental effects of excess manure utilization at the Farm Production Region scale. Because many livestock facilities have little or no land on which to dispose of manure, the above levels provide a lower bound on our estimated benefits to meeting nutrient constraints. Given the acres currently receiving manure nutrients, we calculate the quantity of manure nutrient in excess of the crop requirements on those acres. These excess nutrients are available for potential leaching into ground waters and/or transport across the landscape into surface waters.

**Results**

By simulating various manure nutrient substitution rates for commercial fertilizers, we obtain results portraying a potential range of national and regional changes in the U.S. agricultural sector following the adoption of nutrient standards by CAFOs. In general, production decreases for livestock and poultry commodities and increases for crop commodities, while their respective prices move in the opposite direction. At the regional level, large decreases in animal production are noted in the Southeast, Appalachia, and Pacific regions as expected. Correspondingly, increases in production are predicted for the Northeast, Lake, Corn Belt, and Delta regions. However, due to price changes, net returns increase in many sectors and regions throughout the U.S. These general results are now discussed in more detail.

*Prices & Quantities*

Overall, livestock and poultry quantities decrease and prices increase (Table 2).[8] At greater levels of manure substitution, the policy scenarios become less binding and the magnitude of production decreases and price increases declines across the livestock and poultry sectors. When

CAFOs adopt nutrient constraints and the willingness to substitute manure remains near current levels (i.e., 20%), the largest quantity and price changes occur in the poultry sector. Production decreases are largest for broilers and turkeys (7.8% and 7.5%, respectively). The corresponding price for leading poultry products could increase by approximately 3.1% for broilers, 6.2% for eggs and 5.2% for turkey. Egg production declines by only 0.35%, perhaps due to the low price elasticity of demand for eggs. Price changes for dairy products are also noticeable. Given current or near current levels of manure substitution, butter and milk prices may possibly increase by as much as 4% and 2.3%, respectively. These results suggest that consumers of these commodities will bear some of the cost associated with the imposition of nutrient constraints.

**Table 2. Percent Change in Prices and Quantities by Manure Substitution Rate**

| | *Prices* | | | *Quantities* | | |
|---|---|---|---|---|---|---|
| Commodity | 40% | 30% | 20% | 40% | 30% | 20% |
| Eggs (Dozen) | -0.04 | 1.65 | 6.17 | 0.00 | -0.09 | -0.35 |
| Broilers (Carcass lbs.) | 0.15 | 0.89 | 3.13 | -0.37 | -2.23 | -7.87 |
| Turkey (Carcass lbs.) | 0.20 | 1.37 | 5.17 | -0.28 | -1.97 | -7.47 |
| Manufactured Milk (Cwt) | 0.60 | 1.10 | 2.33 | -0.18 | -0.34 | -0.71 |
| Butter (Lbs.) | 1.05 | 1.91 | 4.04 | -0.30 | -0.54 | -1.14 |
| American Cheese (Lbs.) | 0.50 | 0.91 | 1.92 | -0.18 | -0.33 | -0.70 |
| Fed Beef (Cwt) | 0.42 | 0.45 | 0.55 | -1.70 | -1.83 | -2.20 |
| Pork (Cwt) | 0.01 | 0.00 | 0.73 | -0.02 | -0.01 | -1.56 |
| Corn (Bu) | -0.15 | -0.38 | -1.27 | -0.15 | -0.27 | -0.64 |
| Sorghum (Bu) | -0.12 | -0.16 | -0.50 | -0.31 | -0.16 | -0.01 |
| Barley (Bu) | -0.07 | -0.12 | -0.28 | -0.21 | 0.02 | -0.37 |
| Oats (Bu) | -0.83 | -0.81 | -3.77 | -0.43 | -0.48 | -2.38 |
| Wheat (Bu) | -0.02 | -0.03 | -0.15 | 0.04 | 0.09 | 0.40 |
| Rice (Cwt) | 0.00 | -0.14 | -0.34 | -0.03 | 1.36 | 3.35 |
| Soybeans (Bu) | -0.03 | -0.17 | -0.88 | -0.04 | 0.06 | 0.80 |
| Cotton (Bale) | 0.00 | -0.06 | -0.19 | 0.00 | 0.07 | 0.26 |

The accompanying quantity and price changes in the crop sector are not as general as are those for the livestock sectors. This is in part due to the dual role of cropland as a sink for manure nutrients and a source of feed grains for livestock and poultry operations. This sink role creates

[8] These changes are in reference to the USDA baseline projections for the year 2010 (USDA, WAOB 2001).

an incentive to plant crops that require relatively high quantities of phosphorus (assuming that the phosphorus constraint is more binding than the nitrogen constraint). For example, the quantity of corn produced falls, as does its price. This occurs because the derived demand for corn as an ingredient in feed rations decreases more than the increase in demand for corn acreage as a means of disposal, thus lowering the price. This may be explained by the large decrease in poultry production, a major user of corn in its feed rations, and by the fact that corn production occurs in regions with relatively low poultry concentrations. In contrast, even though the price of hay and wheat could fall, their production increases. One explanation for this result is that these crops are relatively high consumers of (i.e., sinks for) phosphorus, which outweighs the reduction in derived demand for livestock and poultry feed.

*Regional Response*

At the regional scale we see how different the impacts of nutrient constraints will be on the number of animal units produced, the number of cropland acres planted, and regional agricultural labor expenditures (Table 3). The most noticeable changes in the U.S. agricultural sector occur when substitution rates remain at or near current levels. At a substitution rate of 40%, only minor changes occur because most areas have sufficient cropland for spreading manure. At the 20% percent level, we can readily observe spatial shifts in production. Given the assumption that crop producers currently utilizing manure nutrients continue to do so and that there is no significant increase in manure acceptance (i.e.; manure substitution rates remain at or near current levels), U.S. livestock and poultry production could fall by approximately 2.23%. However, production falls by more than 20% in the Appalachia, Southeast, and Pacific regions. Conversely, livestock and poultry production increases in the Northeast (6.2%), Lake (5.9%), Corn Belt (7.1%), Delta (7.4%), and Southern Plains (1.6%) regions. This greater dispersion of animal production, however, may not result in a decrease in the size of operations, which largely occur because of economies of scale within the industry (Martinez).

Crop acreage changes less than one percent across most scenarios, although there are significant increases in crop acreage in the Appalachia, Southeast, and Pacific regions (Table 3); i.e., those regions with the most binding constraints on manure nutrient production, reflecting the high cost of meeting nutrient constraints. These acreage increases provide additional sinks for manure nutrients and potentially lessen any livestock and poultry production cuts that otherwise might have been required to meet the nutrient constraints, particularly in the Appalachia, Southeast, and Pacific regions. Other regions, with a general abundance of land for spreading manure nutrients, do not experience significant changes in cropped acreage.

**Table 3. Regional Change in Animal Units, Crop Acreage and Labor Expenditure by Manure Substitution Rate**

| | *Animal Units* (%) | | | *Crop Acreage* (%) | | | *Labor Expenditure* (*$Million*) | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | 40% | 30% | 20% | 40% | 30% | 20% | 40% | 30% | 20% |
| Northeast | 0.45 | 1.35 | 6.24 | -0.10 | -0.17 | -0.48 | 3.0 | 6.4 | 16.4 |
| Lake | -0.31 | 0.33 | 5.85 | -0.13 | -0.24 | -0.75 | -0.3 | 2.3 | 13.8 |
| Corn Belt | -0.61 | -0.18 | 7.11 | -0.05 | -0.12 | -0.41 | -7.1 | -4.8 | 16.7 |
| Northern Plains | -3.03 | -2.73 | -0.37 | -0.08 | -0.14 | -0.42 | -19.1 | -16.4 | -4.2 |
| Appalachia | 0.50 | 0.91 | -20.53 | -0.14 | -0.28 | 6.17 | 1.0 | 3.2 | -46.3 |
| Southeast | 0.65 | -7.39 | -26.52 | -0.08 | 4.65 | 12.66 | 1.9 | 5.9 | 10.8 |
| Delta | -0.22 | 0.67 | 7.40 | -0.07 | -0.16 | -0.49 | -0.2 | 0.0 | 1.8 |
| Southern Plains | 0.95 | 1.36 | 1.62 | -0.03 | -0.05 | 0.29 | 5.5 | 15.8 | 20.9 |
| Mountain | -3.50 | -3.11 | -1.55 | -0.07 | -0.13 | -0.27 | 3.9 | 11.7 | 28.0 |
| Pacific | -0.95 | -8.22 | -22.72 | -0.05 | 2.66 | 6.05 | -11.8 | -41.6 | -109.0 |
| United States | -1.06 | -1.13 | -2.23 | -0.08 | 0.04 | 0.46 | -23.1 | -17.5 | -51.0 |

These potential changes in regional production patterns trickle down through rural agricultural economies, creating a relationship between nutrient constraints and agricultural labor expenditures (Table 4). Under all substitution rate scenarios the amount paid to agricultural labor falls nationally, indicating that rural agricultural economies may face decreasing purchasing power. However, a closer look at the regional heterogeneity reveals that most of this decrease will be faced by agricultural labor in the Northern Plains, Appalachia and Pacific regions. Conversely, the remaining regions increase expenditures on agricultural labor, particularly when manure substitution rates are at or near 20 %, with the greatest increases in the Southern Plains and Mountain regions.

*Sector Responses*

Table 4 shows the changes in net returns to livestock, poultry and crop sectors at the national and regional levels. Essentially, when net returns to the livestock and poultry sectors increase due to prevailing elasticities and the stringency of the nutrient constraints, net returns to the crop sectors decrease. Conversely, when net returns to the livestock and poultry sectors fall, net returns to the crop sectors rise. While we can generalize these effects at the national level, the sectors experience a range of changes across regions depending on the extent to which crop producers are willing to substitute manure nutrients for commercial fertilizer.

Specifically, under the 20% manure substitution rate there is an overall positive effect on the livestock and poultry sectors due to secondary price effects. National increases in net returns to livestock production do not imply that all sectors in all regions benefit, and do not imply that despite increasing returns at the regional level, all individual operators will benefit. In addition, as substitution rates increase, the livestock and poultry sectors see increasing losses, because the cost of meeting nutrient constraints is not offset by a fully compensating increase in prices. On the other hand, the crop sectors benefit from increasing returns under higher substitution rates, due primarily to foregone commercial fertilizer expenditures.

Regionally, when the manure substitution rate is at or near current levels (20%) we see that net returns increase for the livestock and poultry sector in all regions except in the Northern Plains, Southeast and Pacific. The lack of suitable cropland for spreading manure in these regions implies that the cost effect will be too large for the corresponding national price increase to compensate, thus resulting in declining returns. As the substitution rate increases and the national price falls for livestock and poultry products, we see an additional region (the Mountain region) experience net returns below pre-constraint levels. If the substitution rate were to grow to 40%, then the bulk of the manure management cost fall on CAFOs, given little to no change in the national price level, and net returns will fall below pre-constraint levels for all regions.

**Table 4. Regional Change in Net Returns to Livestock and Poultry Sector and Crop Sector by Manure Substitution Rate**

| | *Livestock and Poultry* (*$Million*) | | | *Crops* (*$Million*) | | |
|---|---|---|---|---|---|---|
| | 40% | 30% | 20% | 40% | 30% | 20% |
| Northeast | 18.4 | 120.8 | 427.9 | 1.9 | -1.9 | -17.2 |
| Lake | -41.2 | 50.1 | 369.5 | 1.8 | -11.1 | -65.2 |
| Corn Belt | -104.2 | 4.7 | 526.4 | -9 | -73.7 | -350.5 |
| Northern Plains | -306.3 | -245 | -1 | 0.8 | -19.1 | -97 |
| Appalachia | -68 | 25.1 | 105.5 | 13.4 | 6.1 | -21 |
| Southeast | -44.8 | -221.9 | -743.3 | 8.6 | 16 | 16.6 |
| Delta | -36.2 | 45.2 | 310.2 | -0.1 | -1.9 | -17.6 |
| Southern Plains | -2 | 88.8 | 267.9 | 0.2 | -1.2 | -5.9 |
| Mountain | -70.1 | -10.4 | 132.3 | 0.3 | -0.9 | -5.7 |
| Pacific | -175.6 | -497.2 | -1110.9 | 0.9 | 7 | 12 |
| United States | -830.1 | -639.8 | 284.8 | 18.8 | -80.8 | -551.6 |

For the crop sector, we see changes in net returns primarily driven by changes in the corn and soybean sectors. In general, the changes in crop production and prices are smaller than for livestock and poultry. The corresponding changes in net returns to the crop sector are also smaller in magnitude. When the substitution rate is 20%, the crop sector overall sees decreases in net returns associated with a large decrease in animal production and thus the demand for feed grains such as corn and soybeans. With greater substitution rates, we see that the losses to the crop sector decline. This can be explained by the corresponding growth in livestock and poultry production, and thus feed grain demand, as the substitution rate increases. These results suggest that overall, the decrease in demand for feed grains outweighs the increase in demand for crop acreage as a sink for manure nutrients.

A different story emerges at the regional level. When the substitution rate is 20%, the Pacific region illustrates how the demand for crop acreage as a sink can offset the decline in demand for feed grains, resulting in an increase in net returns for the crop sector in that region. Other regions face the opposite situation where net returns to the crop sector fall due to declining demand for feed grains and thus decreases in both the quantity sold and the price received for crops. This is most noticeable in the Corn Belt, where net returns fall by as much as $350 million. As the substitution rate increases and livestock and poultry production return to pre-constraint levels we see net returns begin to increase across the regions. When the substitution rate reaches 40%, the crop sector enjoys greater net returns due primarily to the savings from substituting manure nutrients for commercial fertilizer.

*Environmental Impacts*

The use of USMP and EPIC allow us to examine the environmental implications resulting from our policy scenarios. In particular, we estimate the quantity of phosphorus discharged into surface water and the quantity of nitrogen discharged into surface and ground waters (Table 5). We find that under all nutrient constraint scenarios the nitrogen and phosphorus discharged to surface waters (from crop and livestock production) falls by approximately 400 and 100 million pounds, respectively. These declines correspond to significant overall reductions in nitrogen and phosphorus discharge, 10% and 29% respectively. However, it appears as though the quantity of nitrogen leached to groundwater will actually increase at low substitution rates, due to induced cropping and livestock production changes.

Phosphorus reductions across the regions range from as little as 9% in the Northeast region when substitution remains at or near current levels to as much as 70% in the Pacific region at the higher levels of substitution. The greatest reductions in pounds of phosphorous occur in Appalachia and the Corn Belt regions. Under all scenarios the nitrogen discharged to surface water falls when CAFOs meet nutrient constraints. These reductions range from as little as 2% in the Corn Belt (40 million pounds) to more than 40% (80 million pounds) in the Pacific region. The amount of nitrogen leached to groundwater increases in some scenarios and decreases in others. At low manure acceptance rates the amount of nitrogen leached to groundwater generally increases by 2.6%, or 45 million pounds. Increased nitrogen leaching is particularly evident in the Appalachia (5.8%), Southeast (10.5%), and Pacific (32%) regions. As substitution rates increase nitrogen leaching falls in all regions, indicative of less severe changes in regional agricultural production.

One factor leading to the somewhat unanticipated results for nitrogen leaching is that when the nutrient constraint becomes more binding, an incentive exists to increase cropland acres and to grow crops that consume relatively more nutrients and leach more nitrogen on those acres. Because the phosphorus constraint binds sooner than the nitrogen constraint, cropland producers will have to supplement the new crop composition and acreage planted with additional commercial nitrogen fertilizer, which in effect serves to undermine the reductions in manure production (at least vis-à-vis nitrogen leaching).

For example, if we take a closer look at the potential adjustments occurring in the Pacific region (essentially Washington, Oregon, and California) we see that there is a general increase in corn and hay production. Both of these crops exhibit relatively high levels of nitrogen leaching. Furthermore, in certain areas of California potential increases in cropland devoted to cotton-rice-barley rotations, which have very high levels of nitrogen leaching per acre, may occur even when nitrogen is applied at agronomic rates. Nevertheless, the nitrogen prevented from reaching surface waters is of a greater magnitude than the relatively small increases in nitrogen leaching in all regions and scenarios.

**Table 5. Reduction of Phosphorus and Nitrogen Discharged (Million Pounds) by Manure Substitution Rate**

| | *Phosphorus to Surface Water* | | | *Nitrogen to Surface Water* | | | *Nitrogen to Ground Water* | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | 40% | 30% | 20% | 40% | 30% | 20% | 40% | 30% | 20% |
| Northeast | 4.1 | 3.5 | 1.6 | 20.7 | 20.9 | 21.4 | 0.3 | 0.4 | 1.1 |
| Lake | 8.9 | 8.5 | 5.1 | 33.5 | 34.1 | 36.7 | 1.8 | 3.4 | 10.1 |
| Corn Belt | 23.1 | 23.1 | 19.5 | 38.6 | 39.8 | 44.8 | 0.6 | 0.7 | 1.2 |
| Northern Plains | 10.9 | 10.9 | 10.3 | 33.5 | 34.1 | 37.3 | 0.5 | 0.6 | 1.1 |
| Appalachia | 21.1 | 20.2 | 20.8 | 55.8 | 56.2 | 43.5 | 1.5 | 2.2 | -23.3 |
| Southeast | 11.1 | 11.8 | 14.1 | 63.4 | 62.1 | 53.2 | 0.5 | -6.8 | -19.2 |
| Delta | 4.4 | 4.0 | 2.6 | 16.2 | 16.4 | 12.7 | 0.4 | 0.8 | 2.0 |
| Southern Plains | 6.6 | 6.3 | 5.6 | 17.8 | 16.6 | 13.2 | 0.2 | 0.2 | -0.3 |
| Mountain | 11.7 | 11.6 | 11.2 | 43.2 | 43.3 | 43.5 | 0.1 | 0.1 | 0.1 |
| Pacific | 11.0 | 11.6 | 12.9 | 81.2 | 79.5 | 77.3 | 0.2 | -7.4 | -17.6 |
| United States | 112.8 | 111.5 | 103.7 | 403.9 | 402.9 | 383.5 | 6.0 | -5.8 | -44.9 |

**Summary of National-Level Analysis**

Efforts are underway at the local, state, and federal level to reduce the discharge of manure nutrients into U.S. ground and surface waters. Recently the EPA promulgated its final rule for Concentrated Animal Feeding Operations (EPA, 2002b). These regulations, slated for implementation in 2006, will require CAFOs to meet nutrient constraints. Furthermore, the USDA provides funding under the Environmental Quality Incentive Program (EQIP) to assist livestock producers implement manure management practices, such as nutrient standards. Many possible outcomes of these and other policies affecting the location and production decisions of U.S. agricultural producers may occur. We consider potential economic and environmental implications for a case when only the largest animal facilities, CAFOs, meet nutrient constraints. These operations account for nearly 50% of confined livestock and poultry production. And, because the impact of nutrient constraints are dependent upon the acres available for spreading manure nutrients, we have allowed the percentage of crop producers that are willing to substitute manure nutrients for commercial fertilizer to vary. Furthermore, because we allow the production decisions of both livestock and crop producers to respond to secondary price effects, we add to the body of literature attempting to quantify the costs and benefits of such nationwide agri-environmental policies.

However, this analysis cannot reveal how individual operations would benefit or suffer due to the application constraints. If only the largest animal feeding operations meet nutrient constraints, the costs of compliance would potentially fall most heavily on the CAFOs and the benefits from secondary price effects will accrue to the smaller AFOs. We see that when crop producers' substitution rates for manure nutrients remain at or near current levels, the secondary price effects are sufficient to compensate most livestock and poultry sectors for the costs of meeting nutrient standards. However, at higher acceptance rates the costs of transporting manure, manure testing, soil testing, and developing a manure management plan outweigh compensating price effects and foregone commercial fertilizer purchases, resulting in reduced net returns for the animal and crop sectors. At most, these losses could approach $830 million (1.6% of baseline returns), when 40% of agronomic nutrient requirements are met with manure nitrogen and phosphorus. These losses are less than the projected annual EQIP budget for 2004-2007 (ERS

2002), which is potentially available to offset the cost of manure management. We also note that the costs we have included in our analysis (namely transportation costs, manure testing costs, soil testing costs, and nutrient management plan development) do not include all the costs livestock and poultry producers face as they adjust to meet nutrient standards. Additional costs might include relocation costs, and investments in new manure storage and handling infrastructure.

In addition to the costs and benefits borne by agricultural producers in meeting nutrient constraints, we have also predicted the higher food prices paid by consumers under the various policy scenarios. In particular, prices for poultry and dairy products could increase when substitution rates remain low. Due to reductions in livestock production under all scenarios, labor expenditures are likely to decrease between $17.5 million and $51 million. As with the sector performances, these impacts on the labor market are heterogeneous across regions and scenarios.

Motivating many of the agri-environmental policies aimed at reducing discharge of manure nutrients into U.S. surface and ground water has been a realization of the adverse ecological effects attributed to these pollutants. We illustrate that however well intentioned policies are, potentially undesirable secondary effects could arise from shifting market equilibria. Studies that have looked at the potential benefits to restricting land applications of manure nutrients have until now ignored secondary price effects on production choices and subsequent environmental ramifications.

We show that under modest assumptions (i.e., when crop producers' willingness to substitute manure nutrients for commercial fertilizer remains at or near current levels) nitrogen leached to ground water may increase, especially in the Appalachia, Southeast, Southern Plains and Pacific regions. However, as intended, in all regions phosphorus discharged to surface waters and net nitrogen discharged (surface plus ground water) to the environment falls significantly across all scenarios.

In sum, the potential for unanticipated impacts in certain areas exists due to heterogeneous economic and environmental conditions. In some regions, these impacts may be positive, such as increasing net returns to livestock and poultry producers; in others they may be undesirable, such as increased nitrogen leaching in the Pacific region. Such variable effects illustrate the need to perform regional and sector-wide analyses when evaluating such far-reaching policies, as argued by Berck and Hoffman.

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