The Potential for "LISA"-Type Nitrogen Use Adjustments in Mainstream U.S. Agriculture

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Abstract

Concern about environmental impacts of nitrogen fertilizer use is increasing. Mainstream agriculture is dependent on nitrogen fertilizer and use patterns are polluting water resources. A five cent tax on nitrogen fertilizer is shown to have three benefits. National nitrogen fertilizer use is estimated to decline about 10 percent. Use of legume-produced nitrogen increases and crop use of nitrogen declines only 5 percent. A reduction in wasted legume-produced nitrogen equal to 2.5 percent of nitrogen application in the baseline occurs due to more growing of legumes and other crops in rotation. The nitrogen tax is not without costs. Soil erosion and pesticide use are estimated to increase 2.2 and 1.7 percent, respectively, in response to the tax.

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1. Introduction

The research community and the public have expressed a growing concern over nonpoint source nitrogen pollution of water (6, 10, 14, 21). Farmers have greatly increased crop production capacity by use of manufactured nitrogen fertilizers (1, 15). Also, nitrogen fertilizer has often been applied beyond the levels removable by crop production. The result has been excess leachable nitrate in the root zone, contaminating water supplies (e.g., 8, 14, 17). Nitrogen contamination of water has been linked to human health risks, poisoning of livestock and salinity of soil (11). Various legislative bodies are considering policies for regulating nitrogen use (22).

There are several reasons farmers apply more nitrogen fertilizer than is removed in the crop. First, production practice, timing and application method may result in use of larger than required quantities of nitrogen to assure sufficient amounts in the right place at the right time for accelerated plant growth. Second, nitrogen fertilizer is relatively inexpensive, and farmers may apply excess amounts to insure against the income losses due to weather. Third, crop insurance may require high nitrogen fertilizer application as a best management practice. Fourth, nitrogen response research results and application recommendations may suggest unrealistic yield goals. Finally, crop-specific government commodity policies influence rotation choices, resulting in underutilization of legume-produced nitrogen.

Information to support analyses of potential nitrogen use policies is limited. Nitrogen sales data are available at the county level, however, data on the disposal or use of the nitrogen by crop and management technique by county are not generally available. Potential responses of producers to alternative nitrogen regulations are also not known. To fill this information gap, plant growth and economic interregional resource allocation/commodity production models can be combined to estimate nitrogen use. That is, use levels for nitrogen by crop, soil and management technique, and likely changes in response to a nitrogen use tax to alternative regulations can be estimated. Differential impacts of the nitrogen tax by region and producer type also can be estimated.

In this paper effects of a five cent nitrogen tax are estimated to show "low input sustainable agriculture" (LISA)-type management practice adjustments possible with the conventional production technology. The approach used is not new. During the 1970s when energy prices were increasing, similar evaluations were made to determine likely adjustments to nitrogen taxes or quotas (e.g., 9, 12, 17, 18, 19, 20). And, more theoretical papers have shown how a nitrogen tax could be derived to result in a closer matching of private and public interests (7, 23). Swanson (17) has summarized results of various studies of nitrogen use regulation by taxes and quotas.

2. The Models

The Agricultural Resources Interregional Modeling System (ARIMS) (2) was used for the analysis. ARIMS is a national-level interregional linear programming (LP) model with activities representing average producer technology by region (105 for crop production and 31 for marketing and livestock production), land quality and management practice. ARIMS was developed for the 1985 Resources Conservation Act (RCA) appraisal and is based on the large-scale LP modeling systems historically used by the Center for Agricultural and Rural Development (CARD) at Iowa State University. The solution of the model can be interpreted as estimating the equilibrium aggregate response of producers given sufficient adjustment time, fixed commodity demands and purchased inputs available at constant prices.

ARIMS estimates the overall nitrogen fertilization level for each crop, legume crop production and substitution of livestock manure for purchased nitrogen. Production activities require either purchased inputs or inputs from internal production (e.g., manufactured nitrogen fertilizer or manure from livestock). Also included are activities for livestock feeding and production, land conversion and land idling. Regional commodity demands can be met by local production or by transportation of commodities produced in other regions. Three market regions serve as trade links to international markets.

ARIMS results are conditioned by fixed commodity-demands, projected yield growth, the policy provisions of the current agricultural legislation, and estimated market outcomes for 1990. These conditioning factors are taken from FAPRI (4) and USDA statistics. Production technology and environmental impact information for cropping and land use in ARIMS are derived largely from the Erosion-Productivity Impact Calculator (EPIC) (13).

For an area, soil type, year and management technique, crop yields of each production activity are fixed, as are fertilizer requirements per unit of yield. Nitrogen use levels can change only as crop acreage and yields change as a result of changes in management technique. For each cropping activity, yields of crops are predetermined using FAPRI and USDA statistics and EPIC results (13). A Spillman-type yield function (5) was used to estimate nitrogen requirements given the predetermined yields. The Spillman function and its parameters are documented in Stoecker (16) and English et. al (3).

The five cent nitrogen tax was approximated by a price increase in each region. Yield and nitrogen levels were estimated from the 1990 baseline. Modifications in nitrogen use and yield implied by the Spillman estimates and the tax then were applied. In rotations including legume crops, the tax may lower the nitrogen use level to the point that legumes produce more nitrogen than is needed for the rotation. In that case, the application requirement is set to zero.

Regional prices for nitrogen vary in the United States. To illustrate the magnitude of the fertilizer price change from the five percent tax within ARIMS, a use-weighted nitrogen price was calculated. This weighted price increased from 22.5 to 27.5 cents per pound. On average, the approximate 25 percent increase in nitrogen price affected fertilizer use by about 5 percent (nitrogen application by 10 percent) and yields by 1 to 2 percent (Table 1). However, in aggregate, after the model accounted for possible interregional, crop rotation, and livestock production changes, the estimated aggregate percentage changes in yields were smaller.

3. Results

Aggregate results from the experiment are reported (more detailed results are available on request). The ARIMS results depend partly upon the specified market demand levels and rigid acreage allocations implied by commodity program parameters. These conditioning factors together with the aggregate nature of the model, may give adjustments different from those that would be expected for a single farm or region. In short, the policy impacts estimated by ARIMS are intended to be national and interregional indicators, and must be interpreted within the context of the model.

Fertilizer Use

In ARIMS, aggregate nitrogen use can adjust by: (1) changes in application level for an individual cropping activity, (2) changes in overall cropping mix (which must be reflected in livestock feed substitution since final demand composition is fixed), and (3) changes in management practices such as crop rotations. For example, legumes can be substituted for nonlegumes and crops with lower nitrogen requirements can be substituted in the overall crop mix. These changes can occur within and between regions. In particular, and important for the results to be presented, legumes can be grown in rotation with nonlegumes.

In ARIMS, animal-produced nitrogen is directly substitutable for purchased nitrogen. Thus, the substitution between produced and purchased nitrogen can result in avoiding the nitrogen tax with no implied change in total application. In some cases, the nitrogen available for leaching can be more than the reported application, when legumes produce more than the next crop in the rotation requires.

For the national five cent nitrogen tax compared to the baseline, total and per-acre nitrogen application (fertilizer and manure) by USDA production region declined between 4 and 13 percent (Table 2). However, legume-produced nitrogen use increased and plant use of nitrogen declined by only one-half the reduction in purchased nitrogen application. National production of legumes increased by only 2.5 percent (Table 3), indicating that about one-half of the substituted legume-produced nitrogen was already "in the system" but in rotations where it was not usable. These results can be seen by comparing plant nutrient application changes (columns one and three of Table 2) and noting that in ARIMS, crops are required to use nitrogen, phosphorous and potassium in fixed proportions. In summary, the use of nitrogen by crops was down about 5 percent, and there was an additional reduction of excess nitrogen in the system because of better utilization of legumes, equal to about one-half the decline in purchased nitrogen application.

The nitrogen tax increased cropped acreage and fertilizer use in the Northeast, likely due to transport costs and higher production costs for grain in other regions (Table 3). Total phosphorous and potassium changes for the Northeast were greater than for nitrogen while per-acre changes were lower, indicating a substantial shift to legume-produced nitrogen (Table 2 and 3). Appalachia had a shift to relatively more intensive cropping since per-acre nitrogen use dropped relatively less than total use (Table 2).

In the Southeast and the Delta, the tax had little impact on crop mix or management practice; all nutrients declined proportionately. The Corn Belt shifted to less intensive cropping because per-acre application declined more than total use, implying that more legumes were grown in rotation. The 10 percent decline in nitrogen use in this area was especially significant given the heavy level of use in the baseline (Table 2.)

The Lake States had a similar relative cropping intensity between the two ARIMS runs, in as much as per acre and total fertilizer applications changes were nearly equal. The largest decreases in nitrogen application (about 12 percent) occurred in the Plains, with little change in either crop mix, management, or cropping intensity; implied crop acreages were similar to the base (Table 3). The Mountain states also had a large decrease in nitrogen application (9 percent) along with a movement to less intensive cropping, since per acre quantities declined by more than the totals.

Nonnutrient Input Use

Different management practices involve alternative relative proportions of the inputs. The nitrogen tax affected the use of other factors of production (see Table 4). At the national level, the increased pesticide use (1.7 percent) was more than double the increased acreage (0.8 percent) and was one and one-half times the increase in machinery and labor (1.1 percent). In general, shifts to more intensive cropping with pesticides having a larger share of production costs in selected areas were implied.

The increase in input use, particularly pesticides (12.9 percent) was dramatic in the Northeast. This pesticide use increase accompanied by the nitrogen increase indicates an environmentally negative impact of the fertilizer tax, suggesting consideration of more specialized taxes. Only Appalachia and the Southeast experienced decreased pesticide use, and these decreases were exactly equal to cropped acreage declines. All other regions had higher rates of pesticide use per acre than before the nitrogen tax. Most regions had increased pesticide use relative to machinery and labor, implying for some land types a move away from what is commonly understood to be low-input sustainable agriculture.

Soil Erosion Impacts

The nitrogen tax resulted in increased soil erosion at the national level, both per acre (1.3 percent) and in total (2.2 percent) (Table 5). Lower yields, combined with fixed demands, imply more intensive cropping on more marginal lands. In all regions except the Southern Plains, Mountain, and Pacific, wind erosion was decreased by the tax. Water erosion was up in all regions except the Appalachian and the Southeast. These percentage changes are small in general compared to those reported for cropped land in Table 4 and fertilizer use in Table 2.

Regional Crop Production Patterns

Regional shifts in crop production due to the tax were large (see Table 3). At the national level, only commodities used as feed are allowed to change because final demands in ARIMS are fixed. But, regional distributions of crop production can change. For the nation, legume hay was substituted for nonlegume hay, soybeans increased by 0.2 percent and corn silage increased by 9.0 percent.

Barley was substituted for corn silage in the Appalachian (16.2 to 18.7 percent), in the Corn Belt (8.7 to -100.0 percent), and to lesser extent in the Lake States and Mountains. Corn silage was substituted for barley in the Northeast (95.7 to -6.9 percent) and at lower levels in the Southeast, Northern and Southern Plains and Pacific areas. These changes correlate to some extent with the livestock production changes shown in Table 6. The Northeast region showed the largest crop mix impacts. The Northern Plains and Mountains both had a decrease in total acreage in legumes; however, the nutrient requirement impacts (Table 2) indicate more legume-produced nitrogen. Thus, crop rotation changes occurred as a result of the tax.

Livestock Production Due to Nitrogen Tax

At the national level, there were no changes in livestock production because final demands were unchanged from the baseline (Table 6). Regional shifts in production were however quite large. A general shift of cattle and fed beef production to the Corn Belt from the Southern Plains was shown. The percentage changes shown in Table 6 are modest, but actual numbers are large since these regions had a major share of national production in the baseline.

Pork production shifted regionally the most, with percentage gains for the Northeast (19.9) and Lake States (27.3) and losses for the Appalachian region (-28.9), the Southern Plains (-91.8) and the Mountain

(-23.7) regions. Dairy production and grass-fed beef shifted among regions the least. Cattle (cow-calf) and grain fed beef production recorded major shifts.

Producer Cost and Income

Changes in producer cost and income due to the nitrogen tax were evaluated by comparing changes in total production cost with changes in estimated total imputed revenue (see Table 7). The baseline or base run was again the reference point. At the national level, crop producers gained at the expense of livestock producers. Total cost was only up 0.8 percent while total revenue increased 2.2 percent. For livestock producers, a -0.7 percent revenue decrease offset the small decrease in production costs. Crop producers gained 5.1 percent in imputed revenues while production costs increased by only 1.3 percent. The Appalachian region was negatively impacted the most as indicated by the balance of cost and revenue changes, while the Lake States, Northern Plains, Southern Plains, and Mountain regions all gained.

4. Conclusions

Results from the analysis with ARIMS indicate a nitrogen tax of "reasonable" size has an impact on fertilizer use even if opportunities for response were restricted to existing production technologies. Although the estimated impacts of the nitrogen tax from ARIMS were fairly small, they were larger than found in other studies (17). Still the results are in general agreement with the idea that with current production technology farmers are not likely to be highly responsive to price in fertilizer usage. However despite the limitations for substitution in nitrogen use in ARIMS, considerable flexibility in accommodating to the tax is indicated for mainstream U.S. agricultural technologies. The policy question is how to design measures that can take advantage of this potential flexibility.

Applied commercial fertilizer is shown by the ARIMS solution not to be the sole problem leading to current levels of water contamination. With present commodity policy, farmers are led to crop rotation sequences in which legume produced nitrogen is underutilized. According to the analysis with ARIMS, policies impacting rotation choices can have large impacts on nitrogen use. The fertilizer tax is one such policy, but is indicated to result in the substitution of other inputs, implying greater chemical use and in some cases increased erosion levels.

Estimated national impacts of the nitrogen tax experiment were relatively small. However, the impacts on individual farmers and regions may be large. For example, imposing a blanket national tax may unfairly penalize producers where water contamination problems are not severe and inadequately addresses significant problems elsewhere. Crop producers generally benefit from input taxes because final demands are relatively inelastic. Increases in marginal production costs exceed the increase in average costs, and revenue increases exceed cost increases. However this result is highly conditioned by the cost minimization structure implicit in the ARIMS specification. That is, with supported commodity prices, producers may in reality experience only the cost increases estimated by ARIMS, since increased market prices would in large part only reduce government costs.

Table 1 . Yield and nitrogen use elasticities associated with model coefficients[a]

	National level elasticities			
	Partial effects			Full Model effects[b]
Crop	Nitrogen use/ Price of Nitrogen	Yield/ Nitrogen Application	Yield/ Price of Nitrogen	Output/ Price of Nitrogen
Barley	-0.36	0.22	-0.08	-1.2
Corn grain	-0.59	0.21	-0.12	-2.6
Corn silage	-0.68	0.14	-0.10	-1.1
Cotton	-0.24	0.26	-0.06	-0.2
Legume hay	-0.15	0.00	-0.00	-0.4
Non-legume hay	-0.57	0.15	-0.09	-1.5
Oats	-0.47	0.20	-0.09	-0.7
Sorghum	-0.57	0.20	-0.11	-0.3
Sorghum silage	-1.08	0.07	-0.08	0.0
Soybeans	-0.13	0.04	-0.01	-0.1
Wheat	-0.36	0.21	-0.08	-0.4

[a]National averages for rainfed crops, the use weighted nitrogen price increased from 22.5 to 27.5 cents per pound.
[b]National average yield change in response to the nitrogen tax after all endogenous adjustments.

Table 2. Percent change in fertilizer application due to the nitrogen tax (percent from baseline)

Region/ National	Nitrogen		Phosphorous		Potassium	
	Total	/acre	Total	/acre	Total	/acre
Northeast	5.8	-3.7	11.8	1.7	11.6	1.5
Appalachian	-7.9	-7.4	-3.8	-3.3	-4.9	-4.4
Southeast	-4.3	-4.0	-4.0	-3.8	-3.1	-2.8
Delta	-7.2	-8.8	-5.4	-7.0	-5.4	-7.0
Corn Belt	-9.8	-10.8	-4.2	-5.2	-4.5	-5.5
Lake States	-8.4	-8.4	-3.6	-3.6	-6.7	-6.7
Northern Plains	-13.2	-13.2	-11.1	-11.1	-11.8	-11.8
Southern Plains	-11.9	-11.9	-11.1	-11.0	-9.9	-9.8
Mountains	-9.0	-9.3	-5.0	-5.3	-5.9	-6.2
Pacific	-5.4	-6.3	-2.2	-3.0	-2.2	-3.1
National	-9.4	-10.1	-3.4	-4.2	-5.9	-6.6
National baseline[a]	8040.0	50.0	4184.0	26.0	2829.0	18.0

[a]Baseline quantities are thousands of tons.

Table 3. Regional change in crop production due to the nitrogen tax (percent from baseline)

Region/ National	Crop								
	Barley	Corn Grain	Corn Sileage	Cotton	Sorghum	Soybeans	Wheat	Legume Hay	Nonleg. Hay
Northeast	-6.9	13.8	45.7	0.0	-50.4	28.9	2.4	18.8	-1.5
Appalachian	16.2	-1.4	-18.7	-2.2	-1.4	-2.6	-3.6	10.7	-8.9
Southeast	-3.6	-2.0	0.0	-3.6	-4.4	0.2	-2.1	-3.1	-2.3
Delta	0.0	-4.3	0.0	14.3	2.0	-2.1	-2.7	1.5	-2.5
Corn Belt	8.7	-0.4	-100.0	27.4	-5.7	0.1	1.2	3.8	-8.3
Lake States	2.0	-0.6	0.0	0.0	-1.6	-2.1	-3.4	3.5	-2.5
Northern Plains	-0.9	-4.7	0.0	0.0	4.4	-4.2	0.0	-23.9	2.1
Southern Plains	-2.1	15.7	0.0	-5.6	0.0	31.1	-0.8	-0.4	-5.0
Mountains	0.3	0.3	-1.0	8.5	-2.0	-2.9	-0.4	-0.0	-3.2
Pacific	-2.1	-10.3	9.8	-3.8	-4.0	0.0	3.3	0.6	-1.7
National	0.0	-0.0	9.0	0.0	0.0	0.2	0.0	2.4	-2.6

Table 4. Percent changes in non-nutrient input use resulting from the nitrogen tax (percent from baseline)

Region/ National	Cropped Acres	Pesticides[a]	Machinery[a]	Labor[a]
Northeast	10.0	12.9	11.6	11.6
Appalachian	-0.5	-0.5	-0.1	0.2
Southeast	-0.3	-0.3	-0.5	-0.4
Delta	1.8	6.8	4.3	3.0
Corn Belt	1.1	1.5	1.4	1.2
Lake States	0.0	0.1	-0.1	0.2
Northern Plains	0.0	0.4	-0.3	-0.2
Southern Plains	-0.1	0.5	0.2	0.2
Mountains	0.3	1.1	0.5	0.7
Pacific	0.7	2.3	0.6	0.2
National	0.8	1.7	1.1	1.1

[a]Expenditure changes.

Table 5. Soil erosion impacts resulting from the nitrogen tax (percent from baseline)

Region/ National	Per acre			Total		
	Water	Wind	Total	Water	Wind	Total
Northeast	16.3	-9.5	15.0	29.4	-0.7	27.8
Appalachian	0.0	-0.7	-0.0	-0.5	-1.3	-0.6
Southeast	-0.5	-0.9	-0.5	-0.9	-1.2	-0.9
Delta	0.7	-1.0	0.5	2.8	1.1	2.6
Corn Belt	2.9	-1.2	2.2	4.0	-0.1	3.3
Lake States	1.6	-0.7	0.6	1.6	-0.6	0.7
Northern Plains	2.7	-1.1	0.2	2.7	-1.2	0.1
Southern Plains	2.1	2.9	2.7	2.0	2.8	2.6
Mountains	0.2	0.2	0.2	0.6	0.6	0.6
Pacific	3.2	1.0	2.1	4.5	2.3	3.4
National	3.0	-0.3	1.3	3.9	0.6	2.2

Table 6. Regional changes in livestock production due to the nitrogen tax (percent from baseline)

Region/ National	Livestock				
				Beef	
	Pork	Dairy	Cattle	Grain	Grass
Northeast	19.9	0.3	0.3	241.5	0.2
Appalachian	-28.9	0.2	8.1	241.5	2.2
Southeast	0.0	-0.0	-0.4	0.0	-2.1
Delta	0.1	0.0	0.2	-1.0	0.8
Corn Belt	-0.5	0.8	5.5	1.4	3.1
Lake States	27.3	-2.1	-0.8	1.3	-1.8
Northern Plains	1.0	-3.5	1.7	-4.3	2.7
Southern Plains	-91.8	0.1	-6.5	-4.6	-2.9
Mountains	-23.7	2.3	0.4	-1.7	0.6
Pacific	0.0	0.0	0.5	1.3	0.5
National	-0.0	-0.0	-0.0	0.0	0.0

Table 7. Percentage change in producer costs and returns due to the nitrogen tax (percent from baseline)

	Crops		Livestock		Total	
	Cost	Returns	Cost	Returns	Cost	Returns
Northeast	13.1	18.3	0.8	0.5	6.0	6.3
Appalachian	-0.1	1.5	0.6	-2.7	0.2	-0.4
Southeast	-0.7	0.9	-0.3	-0.9	-0.5	-0.2
Delta	3.6	5.0	0.0	-1.6	2.1	2.1
Corn Belt	0.9	3.9	0.8	-0.2	0.9	1.9
Lake States	1.6	5.3	4.0	2.4	1.6	3.7
Northern Plains	-0.0	5.4	0.2	-1.9	0.0	2.7
Southern Plains	1.3	4.3	-5.1	-4.0	-1.8	2.5
Mountain	0.9	7.9	0.0	-1.8	0.6	2.7
Pacific	0.5	6.5	0.4	0.0	0.4	2.0
National	1.3	5.1	-0.0	-0.7	0.8	2.2

References

1. Delwiche, C. C. "The Nitrogen Cycle." In The Biosphere, pages 71-80. San Francisco: W. H. Freeman and Company, 1970.

2. English, Burton C., Elwin G. Smith, Jay D. Atwood, George Oamek and Stanley R. Johnson. 1989. Resource Conservation Act Analysis: An Overview of the CARD Agricultural Resource Interregional Modeling System. CARD Technical Report 89-TR11, Center for Agricultural and Rural Development, Iowa State University, Ames.

3. English, Burton C., Klaus F. Alt, and Earl O. Heady. 1982. A Documentation of the Resources Conservation Act's Assessment Model of Regional Agricultural Production, Land and Water Use, and Soil Loss. CARD Report 107T. Center for Agricultural and Rural Development. Iowa State University, Ames.

4. FAPRI. 1988. FAPRI Ten-Year International Agricultural Outlook. Summary and Tables, March. Food and Agricultural Policy Research Institute, Center for Agricultural and Rural Development, Iowa State University, Ames.

5. Griffin, Ronald C., John M. Montgomery and M. Edward Rister. 1987. "Selecting Functional Form in Production Function Analysis." West. J. Agr. Econ. Vol. 12, No. 2:216-227.

6. Hargrove, W. L. 1988. Cropping Strategies for Efficient Use of Water and Nitrogen. Proceedings of a Symposium sponsored by the Soil Science Society of America, Crop Science Society of America and the American Society of Agronomy in Atlanta, GA November 30 and December 1 of 1987. ASA Special Publication No. 51.

7. Horner, Gerald L. 1975. "Internalizing Agricultural Nitrogen Pollution Externalities: A Case Study." Am. J. Agr. Econ. February, pp. 33-39.

8. Keeney, D. R. "Transformations and Transport of Nitrogen." In Agricultural Management and Groundwater Quality, pp. 48-64. Editors: Frank W. Schaller and George W. Bailey. Ames, Iowa: Iowa State University Press, 1983.

9. Kramer, Randall A., William T. McSweeney, Waldon R. Kerns, and Robert W. Stavros. 1984. "An Evaluation of Alternative Policies for Controlling Agricultural Nonpoint Source Pollution." Water Resources Bulletin. Vol. 20, No. 6(December):841-846.

10. Nielsen, Donald R. and J. G. MacDonald. 1978. Nitrogen in the Environment. Includes two volumes. New York: Academic Press.

22. Wise, Sherry and Stanley R. Johnson. 1989. "A Comparative Analysis of State Regulations for the Use of Agriculture Chemicals." In Commodity and Resource Policies in Agricultural Systems, Editors: Richard Just and Nancy Bockstael. Berlin: Springer-Verlag.

23. Feinerman, Eli, E. Kwan Choi and Stanley R. Johnson. 1990. "Uncertainty and Split Nitrogen Application in Corn Production." American Journal of Agricultural Economics, (forthcoming 1990).

References

1. Delwiche, C. C. "The Nitrogen Cycle." In The Biosphere, pages 71-80. San Francisco: W. H. Freeman and Company, 1970.

2. English, Burton C., Elwin G. Smith, Jay D. Atwood, George Oamek and Stanley R. Johnson. 1989. Resource Conservation Act Analysis: An Overview of the CARD Agricultural Resource Interregional Modeling System. CARD Technical Report 89-TR11, Center for Agricultural and Rural Development, Iowa State University, Ames.

3. English, Burton C., Klaus F. Alt, and Earl O. Heady. 1982. A Documentation of the Resources Conservation Act's Assessment Model of Regional Agricultural Production, Land and Water Use, and Soil Loss. CARD Report 107T. Center for Agricultural and Rural Development. Iowa State University, Ames.

4. FAPRI. 1988. FAPRI Ten-Year International Agricultural Outlook. Summary and Tables, March. Food and Agricultural Policy Research Institute, Center for Agricultural and Rural Development, Iowa State University, Ames.

5. Griffin, Ronald C., John M. Montgomery and M. Edward Rister. 1987. "Selecting Functional Form in Production Function Analysis." West. J. Agr. Econ. Vol. 12, No. 2:216-227.

6. Hargrove, W. L. 1988. Cropping Strategies for Efficient Use of Water and Nitrogen. Proceedings of a Symposium sponsored by the Soil Science Society of America, Crop Science Society of America and the American Society of Agronomy in Atlanta, GA November 30 and December 1 of 1987. ASA Special Publication No. 51.

7. Horner, Gerald L. 1975. "Internalizing Agricultural Nitrogen Pollution Externalities: A Case Study." Am. J. Agr. Econ. February, pp. 33-39.

8. Keeney, D. R. "Transformations and Transport of Nitrogen." In Agricultural Management and Groundwater Quality, pp. 48-64. Editors: Frank W. Schaller and George W. Bailey. Ames, Iowa: Iowa State University Press, 1983.

9. Kramer, Randall A., William T. McSweeney, Waldon R. Kerns, and Robert W. Stavros. 1984. "An Evaluation of Alternative Policies for Controlling Agricultural Nonpoint Source Pollution." Water Resources Bulletin. Vol. 20, No. 6(December):841-846.

10. Nielsen, Donald R. and J. G. MacDonald. 1978. Nitrogen in the Environment. Includes two volumes. New York: Academic Press.

11. Nielsen, Elizabeth B. and Linda K. Lee. 1987. The Magnitude and Costs of Groundwater Contamination From Agricultural Chemicals: A National Perspective. USDA, Economic Research Service, Resources and Technology Division. Agricultural Economics Report No. 576.

12. Palmini, Dennis J. 1982. "The Secondary Impact of Nonpoint-Pollution Controls: A Linear Programming-Input/Output Analysis." J. Environ. Econ. and Man. Vol. 9:263-278.

13. Putman, John W. and Paul T. Dyke. 1987. The Erosion-Productivity Impact Calculator as Formulated for the Resource Conservation Act Appraisal. USDA, ERS, Natural Resource Economics Division Staff Report No. AGES861204.

14. Schaller, Frank W. and George W. Bailey. 1983. Agricultural Management and Water Quality. Ames, Iowa: Iowa State University Press.

15. Sprent, Janet I. 1987. The Ecology of the Nitrogen Cycle. New York: Cambridge University Press.

16. Stoecker, Art. 1974. A Quadratic Programming Model of U.S. Agriculture in 1980. Theory and Application. Unpublished dissertation, Iowa State University, Ames.

17. Swanson, E. R. 1982. "Economic Implications of Controls on Nitrogen Fertilizer Use." In Nitrogen in Agricultural Soils, Agronomy Monograph No. 22, pp. 773-90.

18. Taylor, C. Robert and Klaus K. Frohberg. 1977. "The Welfare Effects of Erosion Controls, Banning Pesticides, and Limiting Fertilizer Application in the Corn Belt." Am. J. Agr. Econ. 59:25-36.

19. Thomas, Dennis L. and Earl O. Heady. 1977. American Agriculture in 1980 Under a Fertilizer Allocation System. Misc. Report. Center for Agri. and Rural Dev. Iowa State University, Ames.

20. Walker, M. E., Jr. and E. R. Swanson. 1974. "Economic Effects of a Total Farm Nitrogen Balance Approach to Reduction of Potential Nitrate Pollution." Illinois Agricultural Economics, July, pp. 21-27.

21. Wilson, J. R. 1987. Advances in Nitrogen Cycling in Agricultural Ecosystems. Proceedings of the Symposium on Advances in Nitrogen Cycling in Agri. Ecosystems, Brisbane Australia, 11-15th of May, 1987.

22. Wise, Sherry and Stanley R. Johnson. 1989. "A Comparative Analysis of State Regulations for the Use of Agriculture Chemicals." In Commodity and Resource Policies in Agricultural Systems, Editors: Richard Just and Nancy Bockstael. Berlin: Springer-Verlag.

23. Feinerman, Eli, E. Kwan Choi and Stanley R. Johnson. 1990. "Uncertainty and Split Nitrogen Application in Corn Production." American Journal of Agricultural Economics, (forthcoming 1990).