Farm-Level Evaluation of Alternative Policy Approaches to Reduce Nitrate Leaching from Midwest Agriculture

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Policies to reduce nitrate leaching are evaluated using a mixed integer linear programming model of a representative Michigan cash grain farm. At spring 1993 prices, elimination of the current deficiency payment program is found to be more efficient at reducing leaching than a nitrogen input tax, a tax credit on biologically fixed nitrogen, a rotation payment, or obligatory use of the Integrated Farm Management Program Option (IFMPO). However, elimination of the deficiency payment program would significantly reduce farm income. Modeling risk management and nitrate leaching dynamics are useful extensions of this research, as is estimating the benefits from averting nitrate leaching.

As policy makers plan for the next "farm bill" in 1995, a growing concern is how that legislation will affect incentives to limit groundwater contamination and to practice crop rotations that include resource-conserving crops. Conversations with farmers and publications in the popular press (Cramer) suggest growing disaffection with the current government deficiency payment program. Academic research bears out the belief that despite some innovation in the 1990 farm bill, the commodity price stabilization programs continue to discourage rotations including resource-conserving crops (RCC's) (Diebel and Williams, Williams and Diebel). While the federal farm commodity programs alone may lack enough leverage to transform husbandry practices (Doering), they clearly have a powerful incentive effect at the margin, even as the financial benefits they offer diminish.

Public concern about groundwater contamination from nitrate leaching has been raised by its status as the most widespread agriculturally-related chemical appearing in groundwater samples. In recent studies, more than 3% of wellwater samples tested exceeded maximum contaminant level (MCL) set by the U.S. Environmental Protection Agency (USGS) and many areas of the United States have high potential for nitrate leaching (Kellogg, Maizel and Goss). Nitrate ingestion has been associated with methemoglobinemia or "blue baby syndrome," but only at levels far exceeding the MCL of 10 parts per million (Fan, Willhite and Book). However, opinion research indicates that consumers are wary of unavoidable risks, especially those involving children (Winter and Sieber). These factors have combined to make agricultural nitrate management an issue in the upcoming policy debate.

This paper reviews some recent analyses of U.S. agricultural policy impacts on crop rotation adoption and on nitrate leaching into groundwater. It proceeds to examine a set of alternative policies in the context of a representative Michigan cash crop farm. These policies include the current (1990) farm program provisions, complete abandonment of the deficiency payment program, and variants of these which include a nitrogen input tax, a subsidy for biologically fixed nitrogen, and "quasi-deficiency" payments for resource-conserving rotational crops planted on base acreage.

Contemporary U.S. agricultural price and income stabilization policy has become increasingly complicated since its introduction in the Agricultural Adjustment Act of 1933. The overwhelming focus of the "farm bills" since 1933 has been to stabilize and support farm incomes. This has been done chiefly through price supports and supply control measures. The principal crops in the program have been wheat, corn, oats, barley, sorghum, rice, cotton, tobacco, and peanuts. Oilseeds such as soybean, canola, and sunflower have received more limited price supports in the form of loan rate price floors (discussed below).

The key program provisions allow farmers to be

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paid a "deficiency payment" equal to the difference between a "target price" and the market price for eligible crops. If the market price is below a lower bound level known as the "loan rate," then the deficiency payment is the difference between the target price and the loan rate, and participating farmers may obtain a non-recourse loan from the U.S. Commodity Credit Corporation secured by eligible grain stocks valued at the loan rate. Eligible crops are those grown on the historical "acreage base" land where they had been grown before the program came into being. That land was required to continue to produce program crops or permissible substitutes in order to remain in the eligible "base." Deficiency payments are based on county average or five-year historical average yields (which have not been adjusted since 1985). In order to manage the supply of wheat and feed grains, the government has required that some of the base acreage be "set aside" from the growing of program crops under the Acreage Reduction Program (ARP).

The Food Security Act of 1985 represented the first time environmental objectives entered significantly into the commodity programs. The environmental innovations in the 1985 bill focussed chiefly on conservation measures. The two principal environmental programs were the Conservation Reserve Program (CRP), which allowed putting highly erodible lands into longterm fallow, and the requirement that farmers develop "conservation compliance" plans for reducing soil erosion on these highly erodible lands if they wished to continue participating in the commodity programs. The bill introduced the opportunity to grow a non-program crop on designated flexible or "flex" acres without losing that part of the base acreage. It also created the 50/92 program, which allowed farmers to fallow program crop land on up to 50% of base acres still be paid 92% of the deficiency payments to which he or she would be entitled if the crop had been grown.

The latest bill, called the "Food, Agriculture, Conservation and Trade Act of 1990" (FACTA), and related legislation in the "Omnibus Budget Reconciliation Act of 1990" added to these provisions additional "optional flex" acreage, extended the 50/92 program to 100% of base acreage for some crops (ergo, the new "0/92" name), and a new program called the Integrated Farm Management Program Option (IFMPO). This last allows participating farmers to raise "resource-conserving crops" on at least 20% of their base acreage while receiving deficiency payments and retaining the associated base. Resource-conserving crops include hay and small grain crops. However, program crops such as wheat may not be harvested (although oat harvest has been allowed), and hay crops may not be harvested during five months of the summer season. In the three years since its inception, the IFMPO has been little used.

Resource-conserving Crops and the 1995 Farm Bill

The failure of the IFMPO is ironic, given its potential to reduce agricultural nonpoint source water pollution—both surface erosion and nitrate leaching into groundwater. This comes at the same time that congressional debate over reauthorization of the Clean Water Act has refocused public attention on nonpoint source pollution. Moreover, there is emerging scientific evidence that crop diversity—which is enhanced by rotations and cover crops—can reduce nonpoint water pollution by improving soil quality and tilth (Harwood). Improved soil quality leads to faster infiltration of rainwater into the soil, and more active soil microbial life. If properly managed, the latter has the potential to reduce necessary amendments of nitrogen fertilizer, with associated reductions in nitrate leaching.

Why is the IFMPO little used in spite of potential social benefits of resource-conserving crops? Diebel and Williams found that its restrictions on haying, grazing, and harvest for human consumption made it less profitable than optional flex production under northeastern Kansas conditions. Subsequent research by Williams and Diebel indicates that current programs discourage rotational cropping, even taking into account the agronomic value of nitrogen fixed by leguminous crops in rotation. A farmer wishing to begin a rotation including RCC's may find flex acres the most economical means to do so.

RCC'S under FACTA in Southeastern Michigan: Results from an LP Model

Since enterprise profitability and government program impacts vary considerably from one part of the country to another, the FACTA program was examined using mixed integer linear programming (MILP) for a representative cash grain farm in southern Michigan. MILP is helpful for capturing the indivisibility requirements inherent in some farm program provisions, and has been used previously for this purpose by Gillespie, Hatch and Duffy and by Mims, Duffy and Young. For simplicity, the present study assumes risk neutrality and static optimization, so expected prices are fixed and both all crop growth and nutrient movement occur in the same season.

The model was developed for a cash grain farm with 500 acres of crop land representative of sandy loam soils in southern Michigan. The farm operator's objective was assumed to be the maximization of farm gross margin, defined as returns to unpaid family labor, management, capital, and land. The farm, a modified version of one described in Clark, was assumed to have 250 acres of corn acreage base, to practice conventional tillage, and to have a labor force of one fulltime owner-operator with the opportunity to hire added occasional labor at $6.50 per hour. Farm workers were assumed to work 10-hour days on the mean number of days suitable for fieldwork on a sandy loam soil with weather typical of Bad Axe, Michigan (Rosenberg et al.). Enterprises included 1) monocrops of low-, medium- and high-yielding corn, wheat, soybeans, oats, and canola, for which prices, yields and variable costs are shown in Table 1; 2) two RCC's: oats followed by red clover and wheat followed by red clover, and 3) rotations of corn-corn-soybean-oat/clover, corn-wheat/clover-corn-oat/clover, and corn-corn-soybean-wheat/clover (CCSW/Cl) (all with high corn yields). The costs and yields of crop rotations were based on those in Table 1, weighted by the importance of each crop enterprise in the rotation. The cash grain farm was assumed to raise leguminous hay crops only as cover or green manure crops.

For the 250 acres in the corn program base, the model included commodity program rules for 1993, which call for 10% ARP set-aside acreage, 15% normal (mandatory) flexible acreage, up to 10% optional flexible acreage, and the rest corn acreage eligible for deficiency payments ("payment acreage"). The model was developed as a mixed integer model in order to accommodate the requirement that IFMPO participation include at least 20% of program acreage.

While the actual process of nitrate leaching is complex and affected by many uncontrolled, environmental factors (Follett, Kenney and Cruse), leaching was modeled here in a simplified fashion that is intended only to be illustrative of how policy and leaching may interact. Forty percent of applied mineral nitrogen fertilizer was assumed to leach in nitrate form. Biologically fixed nitrogen was assumed not to leach and all leaching was assumed to occur in the year of fertilizer application.

Market prices per bushel assumed in the model were $2.03 for corn, $2.95 for wheat, $1.30 for oats, $5.60 for soybean, and $5.10 for canola (Gardner et al.), as shown in Table 1. Because the assumed corn price exceeds the 1993 loan rate of $1.72, the latter value did not enter into deficiency payment calculations. While these commodity prices are low relative to inflation-adjusted historic values, their relative magnitudes are close to historic ratios (e.g., corn-soybean price ratio in Huang and Uri). Variable costs and yield data were obtained from Nott et al., while average enterprise labor requirements for a highly mechanized farm were obtained from Hinton (except for canola, which was treated like wheat except for planting by mid-September). Costs modeled included dry (100%) nitrogen fertilizer at $0.19/pound, anhydrous ammonia (82% nitrogen) at $0.13/pound, corn drying at $0.03/bushel, and other variable costs that do not change with fertility management practices.

A condensed version of the 27 row by 66 column programming matrix is displayed in Table 2. Plus signs denote positive values, while minus signs denote negative ones. A similar, but much simpler model with no integer constraints was used to evaluate elimination of the commodity programs.

Under FACTA, the optimal solution included the maximum amount of high-yield corn permitted on base acres (187.5 acres) with soybeans on the 37.5 normal flex acres and 25 acres of set-aside (ARP) land. Soybeans were grown on all non-base acres, as shown in the first column of Table 3. The total gross margin was $69,112, including $16,200 in deficiency payments. Total projected nitrate leaching was 10,906 pounds.

As in Williams and Diebel's results, it would be costly to introduce rotations. The least expensive way to introduce a rotation would be to grow corn-corn-soybean-wheat/clover, planting high-yield corn on corn base payment acres at a private marginal cost of $11.67 per acre. Using IFMPO would cost far more, since it would displace high-yield corn income at a marginal cost of $63.25 per acre for oats followed by clover (with oats harvested). This might more accurately be viewed as an incre-

Table 1. Crop Prices, Yields, and Variable Costs Assumed for the Representative Farm Model

Crop	Price ($/Bushel)	Yield (Bushels/Acre)	Variable Cost ($/Acre)
Canola	5.10	36	89
Corn	2.03	120*	123
Oats	1.30	70	65
Soybean	5.60	40	90
Wheat	2.95	60	85

*Corn enterprises with yields of 80 and 100 bushels/acre were also included.

Table 2. Condensed Tableau for the Mixed Integer Linear Programming Model of a Michigan Cash Grain Farm Under 1993 Commodity Programs

	Crop																	
	Base[a]	Non Base	Normal Flex	Opt. Flex	0/92[b]	IFMPO Crops	Set Aside	Buy N	Hire Seas. Labor	IFMPO	Def. Pay't	Sell Crop	Leaching	N Credit	N Tax	Rot'n Credit		RHS
Return	–	–	–	–		–	−10	–	−6.5		.72	+		(+)[a]	(−)[a]	(+)[a]		
Integer min.										1								
Land	1	1	1	1	1	1											≤	500
Corn base	1				1	1											≤	250
Setaside	.111[c]		.111[c]	.111[c]	.111[c]	.111[c]	−1										≤	0
Normal Flex	−.177[c]		1			−.177[c]											≥	0
Opt. Flex	−.333[c]			1		−.333[c]											≤	0
Gov. Corn	–											1					≤	0
Def. yield	–				−.92x						1						≤	0
Oth. crops		–	–	–		–[g]						1					≤	0
N required	+	+	+	+		+		−1									=	0
Leaching	+	+	+	+		+							−1				=	0
Leach tfr.													1				≤	M[d]
N used	+	+	+	+		+									−1		=	0
Seasonal labor	+	+	+	+		+	+		−1								≤	+
IFMPO acres						1				−50							≥	0
Min. IFMPO										1							≥	0
N credit[e]	–													1			=	0
Rot'n pay	–[f]															1	=	0

[a]Parentheses denote scenarios which varied across model runs.
[b]Fallow or canola. 0/92 canola column contains corresponding costs and yields.
[c]Coefficients prorated for rotations including non-base acreage.
[d]A very large number such that constraint is never limiting.
[e]Nitrogen credit applies only to crop rotations where nitrogen-fixing legumes and nitrogen-retaining small grams are included.
[f]Applies to rotations only; coefficient is equal to proportion of rotation not in corn.
[g]IFMPO wheat not allowed to be sold under current program regulations; oats, however, may be sold.

mental opportunity cost of $3,162, since IFMPO requires that a minimum 20% of base acres be planted to resource-conserving crops. Under this IFMPO enterprise mix, 9,211 lbs of nitrate leaching was projected to occur.

Policy Alternatives to Encourage Resource-conserving Crops

Various permutations of five alternative policies were reviewed with the objective of maintaining income levels while reducing nitrate leaching through the adoption of crop rotations and RCC's. These policies included 1) a tax credit for nitrogen predicted to be fixed biologically by rotational crops, 2) a nitrogen fertilizer tax, 3) a "quasi-deficiency" payment to the producer for each corn base payment acre planted in a rotation including RCC's, 4) permitting wheat to be harvested under the IFMPO program, and 5) elimination of the current deficiency payment program. A Pigouvian tax on nitrate leaching, which has been reviewed elsewhere (Johnson, Adams and Perry), was not included due to the impracticality of its application.

The original enterprise mix under FACTA remained optimal under a tax credit on biologically fixed nitrogen up to 163% (31¢/lb), a nitrogen input tax up to 121% (23¢/lb), and a rotational crop quasi-deficiency payment up to $24.00 per acre (roughly two-sevenths the value of the full $86.40

Table 3. Crop Enterprise Acreage and Gross Margins for a Representative Southwest Michigan Cash Grain Farm Under Alternative Policy Scenarios

	FACTA: Base Case	FACTA w/121% N Tax or 163% Biol. N Credit or $24 Rotation Payment	No Commodity Program	Rotation Payment of $28.00 w/ no Other Program
Gross margin ($)	69,112	62,983 or 69,155 or 69,237	62,208	62,230
Nitrate leached (lbs)	10,906	10,550	4,000	7,273
	Acres			
Corn base acres				
High yield corn in CS rotation	187.5	0.0	N.A.	N.A.
High yield corn in CCSW/Cl rotation	0.0	187.5	N.A.	N.A.
Normal flex soybeans	37.5	37.5	N.A.	N.A.
Set-aside (ARP)	25.0	25.0	N.A.	N.A.
Non-base acres				
Soybean in CS rotation	187.5	0.0	0.0	0.0
Soybean (continuous)	62.5	62.5	500.0	318.2
Corn in CCSW/Cl rotation	0.0	0.0	0.0	90.9
Soybean in CCSW/Cl rotation	0.0	93.75	0.0	45.45
Wheat in CCSW/Cl rotation	0.0	93.75	0.0	45.45

corn deficiency payment on the registered ASCS yield of 120 bushels). Above these thresholds, all three policies would result in switches from the high-yield corn on corn base payment acres (in rotation with soybean on non-base acres) to the high-yield corn part of the corn-corn-soybean-wheat/clover rotation on payment acres, as shown in Table 3. Nitrate leaching would fall to 10,550 lbs, a 3% decrease from the FACTA base case. Farm gross margins, however, would differ according to whether the policy was a tax or a subsidy. The tax would reduce the gross margin to $62,983, while the biological nitrogen tax credit or the rotation payment would increase farm gross margin to $69,155 or $69,237, respectively.

If the IFMPO allowed wheat harvest, that program would still not enter the optimal enterprise mix in this farm model. However, if forced into the solution, the wheat/clover crop mix would enter (in lieu of the oat/clover mix under the current program). The marginal cost per acre would drop to $20.94/acre, and leaching would be 10,011 lbs/acre. This would be less financially damaging than adoption of the current IFMPO program, but it would also lead to more leaching.

If the commodity programs with their associated restrictions on beneficiary crops and deficiency payments were eliminated, the optimal enterprise mix would be pure soybeans[1], for a farm gross margin of $62,208, as shown in column 3 of Table 3. Because soybean tends to use up existing soil nitrogen and then fixes most of its supplementary nitrogen needs, nitrate leaching would be low, only 4,000 lbs total. If, in the absence of other commodity programs, a $28 per acre rotation credit were offered, then the farm gross margin would be maximized by raising a corn-corn-soybean-wheat/clover rotation on 182.2 acres, as shown in the last column of Table 3. This would generate an annual gross margin of $62,230, but would raise nitrate leaching to 7,273 lbs. A slightly higher rotation credit of $29/acre would induce all land to move to the CCSW/Cl rotation with 13,000 lbs/acre of nitrate leaching. Clearly, a rotation credit can have the undesired effect of increasing leachate by replacing soybeans with crops that are more prone to inefficient nitrogen uptake and higher fertilizer nitrogen requirements.

The least costly means to reduce nitrate leaching while retaining the feed grains program can be found by parametrically restricting the amount of leaching allowed. These results are presented in Table 4. As leachate is restricted from 10,906 to 4,000 lbs, high yield corn and the associated crops on corn base land are systematically substituted by soybeans outside the government program. At the

[1] This result is admittedly unrealistic, since few producers would care to rely entirely on a single crop. It results from the desire to model policy effects as simply as possible. The only resources constrained are land and seasonal labor availability. This enterprise mix is stable up to a corn price of $2.28/bushel, above which level the optimal solutions would switch to a mix of soybeans and high-yield corn, switching entirely to corn above a corn price of $2.32/bushel. However, such a corn price would be on the high side of the historic corn-soybean price ratio for a soybean price of $5.60.

Table 4. Parametric Programming Results of Increasing the Restriction on Maximum Nitrate Leaching Under FACTA

	Maximum Permissible Nitrate Leachate (lbs)			
Activities	10,906	4,000	2,300	300
Gross margin ($)	69,112	62,208	51,838	19,534
	Acres			
Corn base acres				
High yield corn in CS rotation	187.5	0.0	0.0	0.0
0/92 Fallow	0.0	0.0	187.5	187.5
Flex soybean	37.5	0.0	37.5	37.5
Set-aside	0.0	0.0	25.0	25.0
Non-base acres				
Soybean in CS rotation	187.5	0.0	0.0	0.0
Soybean (continuous)	62.5	500.0	250.0	0.0

4,000 lb leachate level, the marginal value of an acre of corn base land is zero, as compared with $26.60 with no restriction. From that level down to 2,300 lbs of leachate, 0/92 fallow, normal flex soybeans and set-aside replace non-program soybeans on corn base acres, which begin to have value again. From 2,300 to 300 lbs of leachate, soybeans grown outside the corn base are systematically replaced with fallow, and the marginal value of land is zero. Finally, below 300 lbs of leachate, the corn base land is fallowed. In the absence of the commodity program, reducing the permissible level of nitrate leaching below 4,000 lbs simply leads to the fallowing of soybean land.

Sensitivity analysis of the nitrogen tax, biological nitrogen tax credit, and rotation payment policies revealed their solutions to be very stable around the enterprise mix in column 2 of Table 3. Between the 121% and 780% levels, the nitrogen input tax enterprise mix remains unchanged (although, of course, gross margin declines as the tax rises). That mix is also stable for a biological nitrogen tax credit between 163% and 400%, as well as a rotation payment at any level above $24/acre.

Table 5. Estimated Marginal Private and Social Costs Per Pound of Reduced Nitrate Leaching Under FACTA (Based on Results of Parametric Leachate Programming)

	Change in Nitrate Leaching (lbs)			
Policy Alternative	10,906 to 4,000	4,000 to 2,300	2,300 to 300	300 to 0
	Dollars			
Marginal private cost	1.00	6.10	16.15	65.11
Marginal private plus government cost	−1.35	14.87	16.15	15.43

Efficiency of Alternative Policies to Reduce Nitrate Leaching

The welfare effects of the policies proposed above vary sharply from one to another. Under the nitrogen tax, the producer bears all the costs of leachate reduction, while the government obtains tax revenues (which might be used to cover costs of that leaching which still occurs). Under the rotation payment scheme, the producer is fully compensated for changing his or her system, and the costs of leachate reduction are borne by taxpayers. However, the net effect on taxpayers is ameliorated somewhat by the fact that the rotation payment supplants the deficiency payment on corn base acres. While the distributional effects of policy alternatives are central to political debate, the federal budget deficit makes program costs especially important.

Distributional impacts aside, these policies should also be evaluated according to their efficiency at reaching desired goals in nitrate leaching reduction. The results presented above provide the basis for a static approximation of the marginal private cost (MPC) per pound of leachate reduction as the change in gross margin divided by the change in leachate levels. More relevant for policy purposes, however, is to a measure marginal private plus government cost (*MPGC*) per pound of nitrate leaching reduction by factoring in government costs and revenues as well. *MPGC* is as follows:

$$MPGC = \frac{\Delta GM + \Delta Tax - \Delta Payments}{\Delta Leachate}$$

where *GM* is gross margin, *Tax* is government tax revenues, *Payments* is government payments, *Leachate* is nitrate leached, and Δ denotes change from one level to another. This measure of MPGC is limited in that 1) it omits health and environmental costs, and 2) the linearity of the denominator implies that the marginal value of leachate reduction to society does not change from the first unit to the last. In spite of these limitations, this MPGC measure represents an improvement on marginal private cost alone.

The most striking difference between estimated private and social marginal costs is that of reducing leachate to 4,000 lbs/acre. Table 4 shows that while under FACTA such a reduction would incur private costs of $1.00 per pound of nitrate leaching reduction (as land switched out of the government corn program to continuous soybean), the switch would actually generate a net social *gain* of $1.35/lb. Further leachate reduction below 4,000 lbs nitrate/acre causes both MPC's and MPGC's to rise at much higher rates. As expected, the marginal private cost of leachate reduction rises at an increasing rate.

By comparison with eliminating the commodity program, none of the other policies examined is comparably cost-effective. First, the nitrogen input tax, the biological nitrogen tax credit, and the rotation payment all resulted in a whole-farm leachate reduction of only 356 lbs. Second, and partly due to this small magnitude, the MPGC per pound of leachate reduction was $12.30 in all three instances. The private marginal cost ranged from $17.20 for the tax to marginal gains of 0.12 and 0.35 per pound under the biological nitrogen credit and rotation payment, respectively. Obligatory IFMPO would appear to be a more efficient approach. Under this policy alternative the MPC and MPGC are equal at $1.87/lb leachate over the range 10,906 to 9,211 lbs. If IFMPO were obligatory but wheat harvest were permitted, the marginal costs of leachate reduction would fall further to $1.17/lb over the range from 10,906 to 10,011 lbs.

Conclusion and Suggestions for Future Research

This paper has explored alternative policies to attain a goal of reduced nitrate leaching under conditions typical of a southern Michigan cash grain farm. The results are indicative only, and are limited by the specification of technical parameters and price/cost relationships. They are also limited to what might be termed "first-round" effects (Helmers et al.), since they would have major general equilibrium effects which would alter future relative prices. However, they illustrate that a public program not designed for that purpose does not provide financial incentives for farmers to reducing nitrate leaching from row crops.

Under the current federal commodity programs of the 1990 FACTA, resource-conserving crops do not enter the most profitable enterprise mix. While taxing leachate is demonstratably the most efficient solution in the absence of administrative transactions costs (e.g., Johnson, Adams and Perry), these are widely recognized to be high enough that making such an effluent tax is impracticable. The marginal private plus government cost estimates suggest that eliminating the current commodity program is the most efficient second-best means to reduce nitrate leaching. Surprisingly, this is true from both a private and a government perspective (financial only) in the case examined.

The marginal private plus government cost estimates beg a marginal social benefit measure for comparison. While numerous studies exist on the costs of agricultural pollution reduction measures (Clark; Helmers et al.; Helmers and Wehrman; Johnson, Adams and Perry; Williams and Diebel), comparable benefit valuation studies are not available. Indeed, only Poe and Bishop have addressed the subject. Where marginal private benefits of nitrate leaching reduction are perceived, there is potential for voluntary reductions in nitrogen use. However, major research advances are needed on the valuation of benefits from reduced health risk due to groundwater contaminants.

A simpler approach to voluntary reduction of nitrate leaching is by soil and tissue sample testing to improve the timing of nitrogen applications. Babcock and Blackmer have demonstrated that soil nitrate test information can significantly increase profits and reduce nitrogen quantities applied to Iowa corn (and hence subsequent nitrate leaching). If they become commercially available, more rapid tissue sample nitrogen tests might allow nitrogen sidedress fertilization to be even more carefully calibrated to plant needs.

An important extension of the research presented here is to incorporate financial risk management into a model of the interaction between the commodity programs and nitrate leaching. Financial risk management has been demonstrated to rationalize farm program participation by risk averse producers using quadratic programming (Scott and Baker) and MOTAD models (Olson and Eidman). Risk aversion may also justify heavy nitrogen fertilization (Babcock). It could reasonably be expected that for a risk averse producer, the difference between the private expected utility of net income with and without deficiency payments would be smaller than that calculated here for a risk averse producer. Another useful extension would be to incorporate nitrate leaching dynamics, either in a multiperiod LP (see Gillespie, Hatch and Duffy; Mims, Duffy and Young), or else by linking a LP model to a simulation model (e.g., Faeth; Johnson, Adams and Perry; Taylor, Adams and Miller).

An important research gap exists on the biophysical side in predicting optimal timing of nitrogen amendments and in understanding nitrogen movement in the soil under alternative vegetative covers. The work of Harwood and his associates suggests that crop diversity (including cover crops) has the potential to reduce erosion and leaching by improving nitrogen uptake during the crop season and immobilizing soil nitrogen during the off-season. The research on soil nitrogen dynamics needed to test this hypothesis could provide the data base for a more sophisticated and realistic model of farmer nitrogen management. Moreover, if the Harwood hypothesis can be substantiated in the form of crop and soil fertility management recommendations, important reductions in nitrate leaching and runoff may be obtained by educational efforts. Such crop management innovations could reduce the cost of commodity program incentives based on such environmental criteria as reductions in erosion or leaching of agricultural chemicals.

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