Simulation of a Group Incentive Program for Farmer Adoption of Best Management Practices

Viju C. Ipe, Eric A. DeVuyst, John B. Braden, and David C. White

A group incentive program to encourage farmer adoption of best management practices is simulated for a typical watershed in central Illinois. The incentive payments, program costs and environmental impacts of the program are simulated. The results show that the best management practices may not actually reduce farm profits but may increase farm profits and reduce environmental pollution. The sponsor in most cases may not have to pay anything under the incentive contract. This may bring about a win-win situation for the sponsor, the farmer participating in the program, and society as a whole. The program could be implemented as an educational effort to demonstrate the benefits of sound management practices.

Improvement in quality of our waters for safe use is a policy priority in both the national and regional environmental programs. Having achieved significant progress in the control of pollution from point sources, future improvements in water quality linger largely on the pollution reduction from nonpoint sources (U.S. EPA 1995). Among the nonpoint sources, the major pollutants are the runoff of fertilizers and pesticides from agricultural fields. When individual farmer actions are not observable (moral hazard), it may not be possible to enforce strict control measures like a tax or fine on pollution. A tax on the polluting input however may not be feasible since a very high tax rate may be required to achieve desired objectives. In a study of Indiana farmers, Randhir and Lee (1997) observed that a tax rate up to about 400% on nitrogen fertilizer may be required to reduce nitrogen pollution by 1%. Best Management Practices (BMP) have often been proposed as method of Nonpoint Source Pollution (NPS) pollution control. Some BMPs, in addition to their environmental advantages may increase farm profits (Cooper and Keim 1996). However, farmer adoption may be low because they will not capture the full benefits of BMP adoption (Duttweiler and Nicholson 1983). Further, farmers may be skeptical about the profitability of BMPs. Hence, incentives may be needed to promote adoption of BMPs. DeVuyst and Ipe (1999) proposed a group incentive contract which will encourage adoption of pollution abatement practices and demonstrated the elimination of moral hazard under the proposed program. This paper builds on their work by demonstrating the potential for economic as well as environmental benefits of the program for a watershed. Using mathematical simulation, the program payments, costs of implementing the program, and the resulting environmental improvement are illustrated for a watershed in Illinois.

The objectives of this paper are to simulate and demonstrate a group incentive program for adoption of best management practices in a typical watershed in Central Illinois facing water quality problems due to nitrates and analyze the costs and environmental benefits of the program. The management practices considered are changing the timing of fertilizer application and reducing the application rate. The hypothesis here is that the pro-

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The authors are grateful to three anonymous reviewers for many useful comments. Any remaining errors are sole responsibility of the authors.

posed incentive program is a win-win situation where both the farmer and the program sponsor benefit.

Definition of the Incentive Program

The program guarantees the farmers who adopt the BMP at least the same level of profit on average as those who do not adopt the practice. Thus, the program compensates the farmers for the loss in profits, if any, due to program participation. Under the program there are two groups of farmers. Those farmers who adopt the practice are designated the participating farmers and those who do not adopt the practice are designated the non-participating farmers. Both groups of farmers are assumed to be in a watershed or neighboring watersheds with similar soil and climatic conditions. The program first calculates the long-run average and current average profit for the two groups of farmers. Then the percentage deviation of the current group averages from the respective long-run averages are computed for the two groups. The participating farmers receive the incentive payment when the percentage deviation (from the long-run average) for the participating farmers is below the percentage deviation for the non-participating farmers. A mathematical definition of the payment scheme is presented below. The incentive scheme is similar to the group crop insurance plan or Group Risk Plan, where the insured farmers are compensated when the county average yield falls below a trigger yield (Banquet and Skees 1994).

Let $\hat{A}$ be the desired management practice in order to achieve the environmental objective. Then, the current year, t, profit of a farmer i who adopts the desired level of abatement is denoted as $\pi^p_{it}(\hat{A})$, where p refers to participation. Let there be G farmers participating in the incentive program. For a group of G participating farmers adopting the desired level of abatement, the current group average profit is represented as $\bar{\pi}^p_t(\hat{A}) = \sum_{i=1}^{G} \pi^p_{it}(\hat{A})/G$. The nonparticipating farmers choose management practices which maximize their expected profits based on their subjective beliefs. Let A^*_j represent the management practice chosen by the non-participants. Then the current year, t, profit of an individual farmer not participating in the program is denoted as $\pi^n_{jt}(A^*_j)$, where n refers to a non-participating farmer. The management practice followed by non-participants is assumed to be unaffected by the abatement practice followed by the participants. Let there be H farmers in the non-participating group. Then, the current group average profit for the non-participating farmers is $\bar{\pi}^n_t(A^*) = \sum_{j=1}^{H} \pi^n_{jt}(A_j^*/H)$.

The program is based also on the long-run average profits of the two groups of farmers, which need to be defined. Let the long-run average profits of a farmer, i, participating in the program be represented as $\bar{\pi}^{p_i}_{LR} = \sum_{t=1}^{T} \pi_{it}(\hat{A}_i)/T$, where T is the long-run time period considered. Then the long-run group average profit for the participating farmers may be represented as $\bar{\pi}^p_{LR} = \sum_{i=1}^{G} \pi^{p_i}_{LR}/G$. Let the long-run average profit of the j'th nonparticipating farmer be $\bar{\pi}^{n_j}_{LR} = \sum_{t=1}^{T} \pi^n_{jt}(A_j^*)/T$ and the corresponding group average profit is $\bar{\pi}^n_{LR} = \sum_{j=1}^{H} \pi^{n_j}_{LR}/H$. The incentive payment is defined as in DeVuyst and Ipe (1999):

$$I = Max\left[0, \left(\frac{\bar{\pi}^p_{LR} - \bar{\pi}^p_t(\hat{A})}{\bar{\pi}^p_{LR}} - \frac{\bar{\pi}^n_{LR} - \bar{\pi}^n_t(A^*)}{\bar{\pi}^n_{LR}}\right) * \bar{\pi}^p_{LR}\right], \tag{1}$$

where, $\bar{\pi}^p_{LR}$ is the long-run group average profit of the participating farmers, $\bar{\pi}^p_t$ is the current group average profit of the participating farmers, $\bar{\pi}^n_{LR}$ is the long-run group average profit of the non-participating farmers, and $\bar{\pi}^n_t$ is the current group average profit of the non-participating farmers.

It is assumed that the yields and nitrogen management practices followed by the participating farmers are observable and that both groups of farmers are risk averse. The assumption that nitrogen application levels can be observed is the core element of the program. This may be justified because the custom application of fertilizers and use of computerized application equipment is increasing in the Midwest. The program participants could be farmers who choose to employ custom application of fertilizers and computerized application equipment. The participants would also be required to reveal the records of the applicators and yields to the program sponsor. The other management practices like pesticide applications are, however, unobservable and moral hazard arises if the participating farmers fail to adopt the specified management practices and enjoy compensation. DeVuyst and Ipe (1999) show that since the incentive scheme is based on group average profits, there is no moral hazard arising from such unobservable actions. They show that the optimal strategies in the absence of the incentive program are still optimal with the incentive program.

Our incentive program exploits correlated risks. It is assumed that the yields of the farmers within each group are correlated among themselves and thus with the averages. As the correlations increase, the program becomes more effective. Since the incentive payment is based on relative deviations in profits, the correlated risks can be exploited to eliminate the possibility of participating farmers getting compensated due to random factors like adverse weather or pests.

Our program is not budget balancing. It is proposed as an incentive payment scheme which insures the participating farmers at least the same level of profits as the non-participating group of farmers. In other words, the incentive scheme compensates the farmers for the loss in profits, it any, due to adoption of best management practices. This could be used as an educational effort to educate farmers about the benefits, private and social, from adopting best management practices. We expect that once the farmers start to realize the benefits of better nitrogen fertilizer management they will adopt such practices voluntarily.

Data

The program is simulated for the Lake Decatur watershed in Central Illinois. The city of Decatur depends on the water from Lake Decatur for its drinking water. The water in the lake is affected by nitrate pollution from agricultural activities in this watershed. Hence the Lake Decatur watershed and the lake offer a perfect site for simulating the program and assessing the economic and environmental impacts. Two different management practices are considered in this study. Nitrogen fertilizers applied in spring tend to be less polluting than when applied in fall (Illinois Agronomy Handbook). Hence changing the time of fertilizer application from fall to spring is one of the management practices considered in this study. The second BMP considered is reducing the quantity of nitrogen fertilizer applied. In order to model the crop growth and nitrate emissions in the watershed, the Erosion Productivity Impact Calculator-Water Quality, (EPIC) is used. Following White et al. (1998), a sample of five soil types is selected to represent the whole watershed. A transect sampling procedure is first used to make an inventory of soils in the watershed. The watershed is first subdivided into several sub-watersheds and a list of the soil types is prepared for each sub-basin. Two to four transects are then drawn across each sub-basin. The results of each of the sub-watershed are then added to provide an inventory of the soils for the entire watershed. A total of 53 soil types are identified by this approach. They were then grouped according to their similarities of texture, natural internal drainage, and productivity when drained. Then, a sample of five soil types was selected so as to reflect both the predominant, as well as some of the less common soils, in the watershed. The predominance of the soil type, geographic separation, and availability of detailed profile information needed by EPIC are other considerations that are important to the final selection of the sample of five soil types. The selected soil types are Drummer, Sable, Ashkum, Catlin, and Elliot. Yields and nitrate emissions from corn grown under corn-soybean rotation and mulch till systems are simulated using EPIC. The fertilizer application times considered are fall application, spring application, and side dress application. The simulations use the weather patterns in Farmer City, the weather station closest to the center of the watershed. This is the only weather station within the watershed with the required data to run EPIC simulations. Typically, a farmer will have a mixture of soil types. In order to compute the program payments and annual emissions, the EPIC simulations for the five soil types are first pooled together assuming that Drummer account for 33% of the total area, Elliot 22%, Catlin 20%, Sable 14% and Ashkum 11%. The proportional representation of the soil types is based on the predominance of the soils in the watershed (White et al. 1998).

In order to simulate the program, the practices of the non-participating farmers referred to in the rest of paper as baseline application rates were defined first. This was done in such a way that the practices closely resemble the current practices followed by most farmers in this watershed. There is ample evidence that farmers apply nitrogen at rates higher than the recommended rates. A survey of the fertilizer management practices in the watershed shows that most farmers apply nitrogen fertilizers at rates higher than the recommended rate (United States Department of Agriculture, Soil Conservation Water District, Champaign County. Unpublished survey of the Big Ditch watershed. 1995). The above survey shows that 80% of the farmers apply at least 20% more nitrogen than is recommended. Further, studies by Bullock and Bullock (1994) show that agronomic recommendations are as much as 97% above the expected profit-maximizing level for one Illinois location and roughly equal to it at another location. In the case of Drummer soil type, the *Illinois Agronomy Handbook* recommends a nitrogen application rate of 193 pounds/acre for a corn:nitrogen price ratio of 15:1. The corresponding rate for Sable is 198 pounds/acre, Catlin (193 pounds/acre), and Elliot and Ashkum (153–163 pounds/acre). When corn is grown after soybeans, the *Handbook* recommends a downward adjustment of nitrogen application rates by about 40 pounds/acre. Based on the above results; *Illinois Agronomy Handbook* recommendations; discussion with the field staffs of the Illinois Farm Business and Farm Management Association (FBFM); and information from the Illinois Cooperative Extension Service, the following baseline application rates (lbs/acre) were defined: Ashkum 150, Catlin 175, Drummer 175, Elliot 150, and Sable 200. Seventy-five percent of the total nitrogen is applied in fall and the rest in spring. The abatement practices suggested are reducing the quantity of fertilizer applied and changing the time of fertilizer application. In order to define the management practices four alternative scenarios are defined as follows:

Scenario 1: Nitrogen application is done in the fall and spring: 75% in fall and 25% in spring.
Scenario 2: One-half of the total nitrogen is applied in fall and one-half in spring.
Scenario 3: 75% of the total nitrogen fertilizer is applied in the spring and 25% in the fall.
Scenario 4: 25% of the total nitrogen is fall applied, 50% spring applied, and the remaining 25% is side dressed.

Under each of the four scenarios reductions in nitrogen application at the increments of 5 lbs/acre from the baseline are considered. Thus, the management practice of a non-participant can be characterized as nitrogen applied at the baseline rates under scenario 1. A movement from scenario 1 to scenarios 2, 3, and 4 without any reduction in nitrogen application rates represents reduction in the share of nitrogen applied in fall. The program payments and the annual emissions of nitrates under participation and non-participation are then computed for all combinations of the four different scenarios and reductions in nitrogen application rates.

The yield response models in EPIC were first calibrated for the specific soils selected and for the Decatur watershed area based on yield response observed at the experimental stations and the county level data. The calibrated EPIC program is then used to simulate crop growth and emissions for a total period of eighty years for all combinations of soil types, fertilizer application times, and application rates. The data for the first forty years are used to establish the long-run average profits. Both groups are assumed to have the same historical long-run average profits. The data for the second set of forty years are used to simulate the expected incentive payments, the program costs, and the water quality impacts. The simulation captures the major sources of variability in farm profits. The hypothesis here is that variability in weather conditions, and output prices are the major sources of variability in farm profits. A recent survey of agricultural producers across twelve states shows that the most important source of variability in farm profits is the weather followed by output prices (Fleisher 1990). The simulations for a period of forty years account for the variability due to weather conditions. In order to account for the variability due to output prices, a ten-year series of corn prices collected from the *USDA Feed Situation and Outlook Yearbook* (1999) is used to calculate the returns and profits. The ten year price series is then replicated for each of the forty years. The distributions of revenues are obtained by assuming that yields and prices are independently distributed for a particular watershed. The costs of fertilizer application alone are considered as all other costs are assumed to be the same for both the groups of farmers. Phosphorous and potassium fertilizer application rates are those recommended by the *University of Illinois Agronomy Handbook*; 65 and 45 pounds per acre respectively. Nitrogen is priced at $0.20 per pound and phosphorus and potassium at $0.24 and $0.13 respectively (University of Illinois FaRMLab). Since the effect of fertilizer prices on variability of the farm profits are negligible (Fleisher 1999), a series for fertilizer prices is not used in this study. The simulated model is dynamic as the simulations run through forty years and the variability in prices is incorporated by replicating simulations for each of the forty years using the ten year price series. The results reported here are summary measures of those 400 data points.

In order to analyze the impacts of the program on the water quality in the lake, the EPIC simulation results are translated into nitrate concentration in the lake water using a hydrology model developed by White et al. (1998). The daily records of the amount of water and nitrate that are being vectored out of the soil column as surface water, shallow groundwater and tile flow for a period of 40 years obtained from the EPIC simulations are used to approximate the hydrology of the watershed as a nitrate delivery model. The EPIC outputs of five simulated soil columns are translated into nitrate concentrations in the lake through a series of numerical model calibrations. The first step in the calibration is computing weighted averages for EPIC outputs relevant to the quantity and nitrate content of surface, subsurface, and tile water flows. The weights were assigned to reflect the extent of each of the soil types, and soil specific fertilizer application rates needed to comprise the base case management scenario for the watershed as a whole.

In the second step, spatial dynamics is incorporated by specifying lags between rainfall and water released from drain tiles to become surface flow as a distributed lag. The distributed lag is modeled after a hydrograph obtained from monitoring a field tile draining approximately 100 acres (David et al. 1994). The lag structure spreads each daily output of water and nitrate over fourteen days in such a way that it increases the flow for five days and then decreases for nine days. The weighted averages obtained from the distributed lag model are then calibrated to emulate the actual observations measured by the Illinois State Water Survey (1996). The intended yearly variability is then incorporated by normalizing the monthly surface flow to the long-term average but allowing to vary from year-to-year in proportion to the deviation of the monthly total precipitation in that year from the normal. The normalized monthly surface flow is calculated as the ratio of monthly total precipitation to the long-run monthly average precipitation normalized by the long-run average monthly surface flow. The White et al. (1998) model then simulates the weekly nitrate concentration of the "river flow" as a function of the weekly simulated tile flow, the volume of the average monthly subsurface flows recorded by the Illinois State Water Survey, and the adjusted monthly surface flow. In the next step the mixing of the incoming river water with the water already in the lake is modeled. This dynamic process is approximated as

$$LC_w = \frac{RC_w * (Q_w + SSF_w) + LC_{w-1} * LV}{Q_w + SSF_w + LV}$$

where LC_w is the lake concentration in week w, RC_w is the river concentration in week w, Q_w is the runoff in week w, SSF_w is the subsurface flow in week w, and LV is the lake volume. The model now yielded reasonably realistic 40-year averages of weekly nitrate concentrations in the lake. In order for the lake concentration to better mimic the actual observations a final calibration was performed. This was done by differentially adjusting the lake concentration based on how much they differ from the median. The adjustment is made in such a way that the pattern generated by plotting each simulated maximum annual concentration against the likelihood of it being exceeded compares reasonably with similar patterns based on actual recorded data on lake concentration.

The study area is a 956.9 square mile watershed, which is the drainage area of Lake Decatur. Eighty-seven percent of the total area is under row crops, half of which is corn and the rest soybeans, 3% small grains and hay and the rest in non-agricultural uses. Since drainage under natural conditions is poor, extensive areas of the watershed are artificially drained. A forty-year database of simulated weekly lake nitrate concentrations is first produced at the baseline nitrogen application rates and timing. Similar data of weekly lake nitrate concentrations for reductions in nitrogen application rates by 25 pounds and 50 pounds from the baseline for the four different scenarios are then produced. It is assumed that 98% of the total corn acreage is under corn-soybean rotation and the rest under continuous-corn. The simulated forty year weekly average concentrations are then used to compute the probability of nitrate concentrations exceeding the 10 mg/l level for the different reductions in nitrogen application rates considered.

Program Simulation

Simulated programs under the four different scenarios are presented in this section. In the first scenario, the only management practice considered is a reduction in nitrogen application rates. In scenarios 2–4, the fertilizer application time is changed along with reductions in application rates. The expected payment, E (I), the minimum payment, Min (I), the maximum payment, Max (I), variance of the payment, Var (I), expected profits, E (π), expected total profits with the incentive payment, E (π + I), variance of profit, Var (π), and the variance of the total profits, Var (π + I) under Scenario 1 are reported in table 1. The expected profits and the variance of the profits under non-participation are presented in the first row of the table. The expected payment ranges from $0.02 per acre for five pound-reduction per acre in nitrogen application rate to $1.43 per acre when the application rate is reduced by 50 pounds. The expected payment increases at an increasing rate as nitrogen application rates are reduced from the baseline. The minimum payment is zero in all the cases except for the 50-pound reduction. The expected payment, maximum payment and the variance of the payment increase with higher reductions in nitrogen application rates. The simulations demonstrate that the expected total profit under non-participation is less than that under participation for all the reductions in nitrogen application rates considered. Similarly the variance of the total profits, V(π + I) under participation is less than that under non-participation. Among the nitrogen application rates considered, the expected profit is the highest when nitrogen application is reduced by 40 pounds from the baseline.

The simulation results also indicate that a farmer

Table 1. Program Simulation under Scenario 1

N Reduction	E(I) ($/acre)	Min(I) ($/acre)	Max (I) ($/acre)	Var (I)	E(π) ($/acre)	E(π+I) ($/acre)	Var (π)	Var (π+I)
NP*	0.00	0.00	0.00	0.00	278.54	278.54	4004.40	4004.40
5	0.02	0.00	0.32	0.01	279.49	279.51	3997.49	3996.73
10	0.03	0.00	0.63	0.01	280.41	280.44	3990.35	3989.49
15	0.17	0.00	3.54	0.35	281.28	281.45	3978.42	3958.56
20	0.24	0.00	4.20	0.56	281.93	282.17	3973.41	3949.64
25	0.34	0.00	4.69	0.81	282.60	282.93	3957.45	3931.06
30	0.43	0.00	5.27	1.10	283.21	283.64	3939.86	3909.71
35	0.54	0.00	5.81	1.48	283.79	284.34	3920.63	3884.67
40	0.70	0.00	6.64	2.17	284.31	285.00	3899.17	3857.81
45	1.04	0.00	8.65	4.14	284.23	285.26	3844.15	3787.99
50	1.43	1.60	11.60	7.24	284.12	285.55	3805.04	3725.64

*Non-participation.

participating in the program realizes a higher level of expected profits even without an incentive payment as the nitrogen application rate is reduced. This is because the baseline application rates could be higher than the profit-maximizing level and so a reduction in nitrogen application from the baseline rates actually increases profits. Participation also reduces the variance of the total profits. This is because nitrogen is treated as a risk increasing factor in the production function used in the EPIC simulator. A second reason for the decrease in variability of total profits with reductions in nitrogen application rates is the incentive program itself as the program reduces the variability of total profits by truncating the tails of the profit distribution. Under the mean-variance criterion, a risk-averse farmer is better-off by participating in the program. The results further indicate that the variance of profits without the incentive payment, V(π), is greater than that with the incentive payment, V(π + I). The results are similar under the other three scenarios considered and are presented in appendix 1. The second row in appendix 1 represents the case when the timing of fertilizer application alone is changed (less nitrogen applied in fall) with no reduction in the total quantity of nitrogen applied. Note that the expected payments are zero in all these cases. The above results show that participation mean-variance dominates the non-participation in all the cases considered. Hence a risk-averse farmer is better off by participating in the simulated program under the mean-variance criterion. Although spring application is less polluting than in fall, farmers tend to apply nitrogen in fall due to timeliness in spring. The spring season is more time constrained and scheduling an application with the spring rains may sometimes be difficult.

The results presented so far are based on a mixture of the five soil types. The sponsor of the program may want to target the program to soil types. The participation response of farmers to such targeted programs may also differ. In order to demonstrate, the incentive program is simulated separately for each of the five soil types (table 2). It is assumed that the non-participating farmers apply nitrogen at the baseline application rates and timings. In the case of Drummer and Catlin soils, the expected payments based on the program developed for individual soil is in general higher than the payments for the composite soil type. Hence, a farmer with these soil types may prefer the incentive program developed based on individual soil types rather than based on the composite soil type. The reverse is true in the case of Elliot, Sable and Ashkum soils. As in the case of the composite soil, participation mean-variance dominates non-participation for all simulations with individual soil types. However, it may be noted that the differences in variance in some cases are very small.

The program requires that amount and time of fertilizers applied by the participants have to be observed. These could be observed in the case of farmers who custom apply fertilizers and use computerized application equipment. Hence, such farmers could qualify to be participants. Another factor that affects participation is the budget constraint of the program sponsor. The sponsor may only have a limited budget and the budget constraint could define the number of farmers to be enrolled in the program. The sponsor's water quality objectives could be another factor that defines participation. The water quality objectives could be met, say, with a subset of farms enrolling in the program.

An agency willing to sponsor such a program may be interested in the mean and range in expected total costs it would have to incur, and the

Table 2. Program Simulations Targeted At Individual Soil Types under Scenario 1

	Drummer			Elliot			Catlin			Sable			Ashkum		
NR	E(I)	E(π)	E(π+I)	E(I)	E(π)	E(π+I)	E(I)	E(π)	E(π+I)	E(I)	E(π)	E(π+I)	E(I)	E(π)	E(π+I)
N	0.00	278.5	278.5	0.00	227.55	227.55	0.00	294.57	294.57	0.00	311.34	311.34	0.00	249.77	249.77
P		(4004)	(4004)		(9649)	(9649)		(3059)	(3059)		(2265)	(2265)		(6902)	(6902)
5	0.0	299.5	299.5	0.00	228.50	228.50	0.00	295.43	295.43	0.00	312.33	312.33	0.00	250.75	250.75
		(3773)	(3773)		(9639)	(9639)		(3050)	(3050)		(2265)	(2265)		(6896)	(6896)
10	0.1	300.4	300.4	0.00	229.45	229.45	0.00	296.37	296.37	0.00	313.33	313.33	0.00	251.71	251.71
		(3372)	(3369)		(9627)	(9627)		(3039)	(3039)		(2265)	(2265)		(6888)	(6888)
15	0.2	300.9	301.2	0.02	230.31	230.31	0.02	296.90	297.32	0.00	314.33	314.33	0.01	252.67	252.68
		(3367)	(3394)		(9610)	(9610)		(3029)	(2953)		(2264)	(2264)		(6882)	(6880)
20	0.4	301.6	302.0	0.04	231.05	231.09	0.04	297.65	298.16	0.00	315.22	315.22	0.02	253.61	253.63
		(3363)	(3361)		(9581)	(9576)		(3014)	(2927)		(2259	(2259)		(6873)	(6869)
25	0.6	302.2	302.8	0.09	231.79	231.88	0.09	298.34	298.92	0.01	315.86	315.86	0.05	254.51	254.56
		(3354)	(3353)		(9555)	(9545)		(2992)	(2898)		(2249)	(2248)		(6862)	(6854)
30	0.8	302.8	303.5	0.16	232.44	232.60	0.16	298.97	299.62	0.09	316.21	316.29	0.06	255.39	255.45
		(3350)	(3348)		(9525)	(9509)		(2984)	(2868)		(2222)	(2219)		(6847)	(6837)
35	0.9	303.2	304.1	0.22	232.93	233.15	0.22	299.39	300.16	0.25	316.59	316.83	0.07	255.80	255.87
		(3343)	(3343)		(9493)	(9480)		(2968)	(2829)		(2201)	(2188)		(6836)	(6817)
40	1.0	303.2	304.2	0.36	232.97	233.33	0.36	299.30	300.27	0.54	316.94	317.48	0.08	256.27	256.34
		(3339)	(3336)		(9426)	(9416)		(2943)	(2783)		(2191)	(2176)		(6827)	(6823)
45	1.5	303.5	305.0	0.80	233.17	233.97	0.80	300.30	301.49	0.88	317.32	318.18	0.11	257.14	257.25
		(3287)	(3285)		(9378)	(9229)		(2888)	(2740)		(2181)	(2152)		(6738)	(6721)
50	1.9	303.1	305.0	1.36	232.97	234.33	1.36	300.48	301.98	1.34	316.98	318.32	0.14	257.32	257.47
		(3243)	(3233)		(9319)	(9120)		(2855)	(2681)		(2145)	(2108)		(6706)	(6690)

Figures in parentheses are variances of the respective variables; NR: Nitrogen reduction.

Table 3. Total Costs of Sponsoring the Program in the Lake Decatur Watershed (Dollars)

N Reduction (lbs)	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
0	NA*	NA	NA	0	0	0	0	0	0	0	0	0
5	5328	0	253080	0	0	0	0	0	0	0	0	0
10	7992	0	508824	0	0	0	0	0	0	0	0	0
15	45288	0	967032	10656	0	372960	7992	0	348984	7992	0	218448
20	63936	0	1292040	10656	0	434232	13320	0	514152	15984	0	325008
25	90576	0	2136528	13320	0	436896	15984	0	642024	21312	0	594072
30	114552	0	2461536	23976	0	556776	23976	0	857808	29304	0	844488
35	143856	0	2783880	34632	0	687312	34632	0	1001664	31968	0	1158840
40	186480	0	3108888	50616	0	1062936	58608	0	1305360	63936	0	1470528
45	277056	0	4478184	130536	0	2069928	133200	0	2213784	141192	0	1710288
50	380952	34632	4832496	215784	0	2781216	223776	0	3159504	226440	0	2605392

NA: Not Applicable.

amount of reserves the agency needs to set aside as reserve funds. In order to assess the costs of sponsoring the program, the total area of the watershed is approximated at 956.9 square miles (612.42 thousand acres). Out of the total watershed area about 87% is under row crops (Demisie and Keefer 1996). Corn, which accounts for almost 50% of the total area under row crops, is assumed to be 50% of the crop acres. The expected total cost and range in total costs of sponsoring the program in the whole watershed under each of the four different scenarios is presented in table 3. The program payments alone are considered to evaluate the total costs. The costs tend to rise at an increasing rate as the nitrogen application rate is reduced from the baseline rate. The costs are the highest under scenario 1. The total costs are zero for reduction in nitrogen application rates up to 10 pounds per acre under scenarios 2, 3, and 4. Further reductions in nitrogen application rates increase the costs but are less than those under scenario 1. These results indicate that the proposed program may be more efficient when reduction in nitrogen application rate is combined with changing the time of fertilizer application.

Environmental Benefits

In order to evaluate the environmental impacts, the reductions in annual emissions of nitrates per acre under corn-soybean rotation and the effect of the program on the nitrate concentration in the lake water are analyzed.

Annual Emissions

The impact of the program on nitrate loading per acre into surface water under the four alternative scenarios is reported in table 4 (nitrate emissions from corn acres alone are reported). The loadings are annual averages based on forty years of simulation. As nitrogen application rate is reduced from the baseline, the average emissions first decreases rapidly, but then later slows. A five-pound reduction in application rate from the baseline application rate produces a reduction in loadings of 10.45% under scenario 1. Further reductions in nitrogen application rates reduced emissions at a decreasing rate. Reduction in nitrogen application by 50 pounds per acre reduced emissions under scenario 1 by 41%. Similar results are observed under Scenarios 2, 3, and 4. Movement from scenario 1 (75% fall application and 25% spring application) to scenario 2 (50% fall application and 50% spring application) without any reduction in nitrogen application rate reduces emissions by 10.87%. When the proportion of nitrogen applied in fall is further reduced to 25% (75% in spring) the average annual emissions falls by 21% without any reduction in nitrogen application rate. Similarly, under scenario 4 (25% fall, 50% spring and 25% split application) the emissions are 23% less than the baseline without any reduction in nitrogen application rate. These results indicate that changing the time of fertilizer application alone without any reduction in nitrogen application rate will significantly reduce emissions.

It may be useful to compare the expected payment and the annual reduction in emissions under the four different scenarios (table 5). Under scenario 1 emission reduction up to 34% could be achieved by a 25-pound reduction in nitrogen application with an expected program payment of $0.34 per acre. Under scenarios 2, 3, and 4 expected payments are zero as application rate is reduced up to 10 pounds per acre. Under scenario 1, when nitrogen application is reduced by 50 pounds

Table 4. Annual Average Emissions of Nitrates (per/acre) into Surface Water

N Reduction (lbs/acre)	Scenario 1 (lbs/acre)	Scenario 2 (lbs/acre)	Scenario 3 (lbs/acre)	Scenario 4 (lbs/acre)
0	4.5797 (Baseline)	4.0818 (10.87)	3.5840 (21.74)	3.5024 (23.52)
5	4.1011 (10.45)*	3.6912 (19.40)	3.2613 (28.79)	2.7436 (40.09)
10	3.7911 (17.22)	3.4123 (25.49)	3.0056 (34.37)	2.3852 (47.92)
15	3.4805 (24.00)	3.1370 (31.50)	2.7352 (40.28)	2.3253 (49.23)
20	3.2878 (28.21)	2.9616 (35.33)	2.5635 (44.02)	2.2709 (50.41)
25	3.0893 (32.54)	2.7932 (39.01)	2.4050 (47.49)	2.2136 (51.66)
30	3.0047 (34.39)	2.7119 (40.78)	2.2913 (49.97)	2.1643 (52.74)
35	2.9219 (36.20)	2.5743 (43.79)	2.1667 (52.69)	2.1170 (53.77)
40	2.8389 (38.01)	2.4948 (45.52)	2.1107 (53.91)	2.0674 (54.86)
45	2.7581 (39.77)	2.4084 (47.41)	2.0586 (55.05)	2.0214 (55.86)
50	2.6997 (41.05)	2.3575 (48.52)	2.0153 (55.99)	1.9811 (56.74)

*Figures in parentheses are percentage reduction in emissions compared to the baseline.

the expected payment is about $1.40 per acre and the expected reduction in emissions is 41%. Our results indicate that the scenarios 2, 3, and 4 give high abatement per dollar of expected cost.

The emissions from the drainage area of the lake eventually reach the lake water. Hence, the success of the program needs to be judged, in part, in terms of its effect on the water quality in the lake. Since nitrate pollution is seasonal with concentration exceeding the permissible levels mostly in spring, the average weekly concentrations without and with the program are simulated to analyze the effects of the program. The daily emissions under all combinations of soil types, rotations, and fertilizer application rates are first simulated using EPIC. The daily emissions are then used as an input in the nitrate delivery model (White et al. 1997) to calculate the weekly average nitrate concentration in the lake in each of the forty years simulated. The probability that the weekly nitrate concentration exceeds the 10 mg/liter is then computed as

$$P(CC_w > 10) = \frac{X}{40}, \quad (2)$$

where P is the probability, CC_w is the weekly nitrate concentration (mg/l) in the lake water, and X is the number of years in which the concentration exceeds the 10 mg/l level.

The results show that in general the nitrate concentration in the lake water reaches a peak level during the spring. The probability that the weekly nitrate concentration exceeds the 10 mg/l level when nitrogen application rates are at the baseline and when the rates are reduced by 25 and 50 pounds under the four scenarios are presented in table 6. The nonzero probabilities alone are reported. Under scenario 1 the probability ranges from 0 to 0.40 when nitrogen is applied at the baseline rates. When the nitrogen application rate is reduced by 25 pounds per acre, the corresponding probability ranges from 0 to 0.28. When nitrogen application rates are reduced by 50 pounds per acre from the baseline application rate, the probabilities range from 0 to 0.20. Thus the results show that the probabilities dropped by about 50% as the nitrogen application rate is reduced by 50 pounds from the baseline. The average weekly nitrate concentrations also show similar patterns. At the baseline application rate, it is highest (9.05 mg/

Table 5. Expected Payment and Expected Reduction in Annual Nitrate Emissions

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
N Reduction	Payment ($/acre)	% Emission Reduction	Payment	% Emission Reduction	Payment	% Emission Reduction	Payment	% Emission Reduction
0	NA	NA	0.00	10.87	0.00	21.74	0.00	23.52
5	0.02	10.45	0.00	19.40	0.00	28.79	0.00	46.79
10	0.03	17.22	0.00	25.49	0.00	34.37	0.00	47.92
15	0.17	24.00	0.04	31.50	0.03	40.28	0.03	49.23
20	0.24	28.21	0.04	35.33	0.05	44.02	0.06	50.41
25	0.34	32.54	0.05	39.01	0.06	47.49	0.08	51.66
30	0.43	34.39	0.09	40.78	0.11	49.97	0.11	52.74
35	0.54	36.20	0.13	43.79	0.14	52.69	0.12	53.77
40	0.70	38.01	0.19	45.52	0.22	53.91	0.24	54.86
45	1.04	39.77	0.49	47.41	0.50	55.05	0.53	55.86
50	1.43	41.05	0.81	48.52	0.84	55.99	0.85	56.74

Table 6. Probability that the Nitrate Concentration in the Lake Water Exceeds 10 ppm; Scenario 1

	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	N Reduction			N Reduction			N Reduction			N Reduction		
Week	0	25	50	0	25	50	0	25	50	0	25	50
6*	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.05	0.03	0.00	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.08	0.05	0.00	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.10	0.03	0.00	0.10	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.18	0.10	0.05	0.18	0.10	0.08	0.00	0.00	0.00	0.03	0.03	0.03
13	0.23	0.18	0.10	0.23	0.18	0.10	0.10	0.03	0.03	0.10	0.03	0.03
14	0.28	0.18	0.13	0.28	0.20	0.15	0.15	0.08	0.03	0.15	0.05	0.03
15	0.30	0.23	0.18	0.30	0.23	0.23	0.20	0.13	0.13	0.18	0.13	0.10
16	0.30	0.25	0.18	0.30	0.25	0.23	0.35	0.20	0.18	0.35	0.20	0.18
17	0.38	0.28	0.23	0.38	0.28	0.25	1.52	0.23	0.20	0.35	0.23	0.20
18	0.40	0.28	0.20	0.40	0.28	0.20	0.35	0.18	0.13	0.23	0.18	0.13
19	0.33	0.23	0.18	0.33	0.28	0.20	0.23	0.15	0.13	0.20	0.15	0.10
20	0.30	0.25	0.13	0.30	0.28	0.13	0.23	0.13	0.08	0.23	0.10	0.08
21	0.23	0.18	0.13	0.23	0.18	0.13	0.18	0.10	0.08	0.15	0.10	0.05
22	0.15	0.13	0.08	0.15	0.15	0.10	0.10	0.10	0.08	0.10	0.10	0.08
23	0.13	0.08	0.08	0.13	0.08	0.08	0.08	0.08	0.05	0.08	0.08	0.05
24	0.08	0.08	0.03	0.08	0.08	0.03	0.08	0.03	0.00	0.08	0.03	0.00
25	0.08	0.05	0.03	0.08	0.08	0.05	0.05	0.05	0.00	0.05	0.03	0.00
26	0.03	0.03	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.03	0.03	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*Probabilities are zero for all weeks other than those listed.

l) in the 20th week. As nitrogen application rate is reduced by 50 pounds, the peak weekly average nitrate concentration drops to 7.07 mg/l. The simulations demonstrate similar results under the other scenarios too. The results further indicate that the program is more effective under scenarios 3 and 4. This is because runoff of nitrogen fertilizers applied in fall is higher than that applied in spring or side-dressed (*Illinois Agronomy Handbook* 1996).

Conclusions

The simulated program shows that a risk averse farmer may be better off by participating in the incentive program. The farmers may currently be applying nitrogen fertilizers at rates above the profit-maximizing levels. Hence reduction in nitrogen application rates actually increased farmer profits and the sponsor of the program may not pay for the initial reductions in nitrogen application rates. Farmers may be too optimistic about the response of profits to nitrogen application, which in turn result in application of nitrogen at rates higher than the profit maximizing levels. Similar results were obtained by Yadav (1997) and Bullock and Bullock (1994). Our results show that reducing the nitrogen application rate by up to about 35 pounds does not reduce profits. Instead it may increase profits as farmers currently may be applying nitrogen at rates above the profit maximizing levels. The proposed program increases farmer profits, reduces variance of profits, and reduces pollution, while the sponsor does not pay for up to about a 35-pound reduction in nitrogen application. Thus, the program will result in a win-win situation for both the farmer and the sponsor. This incentive program could be implemented as an educational effort by promoting farmer experimentation. It is unique in that the educational effort is backed by an appropriate insurance mechanism to produce the desired effect. The program could be implemented as a short term demonstration program in farmers' fields. As farmers learn from their own experimentation, it may result in a larger adoption of sound management practices. Even if the payments are positive, the total program payments may be much less than the costs of cleaning up the polluted water. Thus, the farmer will benefit from higher profits and reduced risk. The water supply authority is better off because it is cheaper to implement the incentive program than to clean up the polluted water, and society benefits from the overall improvement in water quality.

Our results, however, have the following limitations. The program exploits correlated risks across farmers in the watershed. The program would become less effective as yields and risks become less correlated. We have assumed that the yields and prices are independent at the watershed level, but there may be some relationship between yields and national prices. Similarly, output price variability could affect the farmer response. This analysis is based on the assumption that all farmers in the watershed would adopt the nitrogen fertilizer management program. In the real world full participation would not occur. When there is less than full participation, one may not observe a linear relationship between the extent of participation and its impact on the water quality in the lake, although partial participation will result in significant improvement of water quality in the lake.

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Appendix 1. Program Simulations Under Scenarios 2, 3, and 4

N Reduction (lbs/acre)	Scenario 2			Scenario 3			Scenario 4		
	E(I)	E(π)	E(π+I)	E(I)	E(π)	E(π+I)	E(I)	E(π)	E(π+I)
NP*	0.00	278.54	278.54	0.00	278.54	278.54	0.00	278.54	278.54
		(4004.40)	(4004.40)		(4004.40)	(4004.40)		(4004.40)	(4004.40)
0	0.00	278.55	278.55	0.00	278.55	278.55	0.00	278.56	278.56
		(4004.40)	(4004.40)		(4004.40)	(4004.40)		(4003.33)	(4003.33)
5	0.00	279.49	279.49	0.00	279.51	279.51	0.00	279.53	279.53
		(3996.73)	(3996.73)		(4001.02)	(4001.02)		(4001.34)	(4001.34)
10	0.00	280.41	280.41	0.00	280.43	280.43	0.00	280.46	280.46
		(3989.49)	(3989.49)		(3992.87)	(3992.87)		(3996.29)	(3996.29)
15	0.04	281.16	281.20	0.03	281.21	281.24	0.03	281.25	281.28
		(3972.56)	(3964.47)		(3975.54)	(3967.98)		(3978.58)	(3971.55)
20	0.04	281.93	281.97	0.05	281.96	282.01	0.06	282.00	282.06
		(3958.95)	(3949.64)		(3960.99)	(3949.98)		(3963.16)	(3950.43)
25	0.05	282.60	282.65	0.06	282.61	282.67	0.08	282.63	282.71
		(3940.24)	(3931.06)		(3943.12)	(3929.50)		(3946.12)	(3928.23)
30	0.09	283.21	283.31	0.11	283.23	283.32	0.11	283.26	283.37
		(3920.57)	(3909.71)		(3924.25)	(3906.42)		(3927.86)	(3903.59)
35	0.13	283.79	283.92	0.14	283.83	283.96	0.12	283.87	283.99
		(3897.49)	(3884.67)		(3901.70)	(3881.52)		(3906.43)	(3879.00)
40	0.19	284.31	284.50	0.22	284.34	284.56	0.24	284.37	284.61
		(3874.26)	(3857.81)		(3879.08)	(3850.76)		(3884.50)	(3844.63)
45	0.49	284.23	284.72	0.50	284.24	284.74	0.53	284.26	284.79
		(3829.62)	(3788.00)		(3834.01)	(3781.75)		(3841.31)	(3776.74)
50	0.81	284.12	284.93	0.84	284.11	284.95	0.85	284.14	284.99
		(3795.25)	(3725.64)		(2802.23)	(3720.65)		(3810.86)	(3719.51)

Figures in parentheses are variances.