The Effect of Farming Practices on Reducing Excess Nitrogen Fertilizer Use:
An Iowa Case Study

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Abstract - A nitrogen balance model is used to investigate the adoption of a
crop rotation and the limitation on the application of nitrogen fertilizer to
reduce excess nitrogen. For a farmer initially planting corn continuously,
the adoption of a soybeans-corn rotation will have a smaller compliance cost
but it will not eliminate the excess application of nitrogen fertilizer under
a relatively low nitrogen fertilizer to corn price ratio. An explicit
limitation on nitrogen fertilizer use would be needed to achieve this
objective. Limiting nitrogen fertilizer use on cropland susceptible to a high
potential for leaching will have a smaller compliance cost than on cropland
with a moderate potential for leaching.

Keywords: Compliance cost, excess nitrogen, nitrogen fertilizer use, water
quality

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members.
Introduction

Nitrogen is an essential plant nutrient required to produce food and fiber. While the increased use of nitrogen fertilizer has contributed to increased food and fiber production in the United States in recent years, it has also been identified as a major contributor to the elevated concentration levels of nitrates in ground water in some regions of the country (e.g., Office of Technology Assessment, Nielsen and Lee, and U.S. Environmental Protection Agency (EPA)). EPA's recent Pesticide Survey (1990) further indicate that many community water systems and rural wells where extensive application of nitrogen is found contain nitrates over the Maximum Contaminant Level.

High concentration levels of nitrates in drinking water supplied from ground water have become a public concern because of their real and suspected risks to human health (Freshwater Foundation). The presence of nitrates in drinking water can cause potentially fatal infant methemoglobinemia (blue baby syndrome). Nitrates are also linked to nitrosamine, a potent carcinogen affecting a wide range of organs in many animal species (Cantor).

Targeting vulnerable areas to reduce nitrate leaching associated with nitrogen fertilizer use into the ground water is a plausible national environmental policy. The targeting approach recognizes the differences in the vulnerability of various types of soils to leaching and, correspondingly, prescribes different policies to minimize (or at least mitigate) nitrate leaching. Additionally, the targeting approach is an effective tool if the objective is to minimize the social cost of the program (see, e.g., Tietenberg, Baumol and Oates).

In order to reduce the nitrogen fertilizer use that is a threat to the groundwater under the targeted cropland, a variety of methods are available. One approach is to adopt a fertilizer-reducing farming practice, such as a crop rotation in which a legume crop (e.g., soybeans) is rotated with a non-legume crop (e.g., corn). The legume crop is used to provide fixed-nitrogen as a substitute for fertilizer-nitrogen. Adoption of this sort of crop
rotation can reduce the residual (excessive) nitrogen (this will be discussed below) in the soil through a reduction in the frequency and amount of nitrogen fertilizer applications on a field and through the more efficient use of the nitrogen fertilizer applied because of more conducive soil conditions in which to grow a crop. The benefits and costs associated with this approach are the focus of this paper.

Adoption of a crop rotation and the limitation on nitrogen fertilizer use are two compliance options that can be used to reduce excess nitrogen use (A formal definition of excess nitrogen is provided below). While the adoption of a crop rotation is a effective way to reduce nitrogen fertilizer (and, hence, nitrogen) use, explicitly limiting nitrogen fertilizer use might be required to reduce excess nitrogen (Huang and Lantin). Much past research related to water quality protection from nitrate contamination has assumed arbitrary levels for reducing nitrogen fertilizer application rate (e.g., Taylor and Swanson). Very little research has used a nitrogen balance relationship to determine the approximate level to which nitrogen fertilizer application should be reduced. One exception is Walker and Swanson.

In what follows, the concept of excess nitrogen will be discussed. Alternative options designed to reduce the excess application rate of nitrogen fertilizer which leads to the presence of excess nitrogen available for potential leaching into the ground water will be delineated. A dynamic model for the evaluation of policy options is described. Finally, an Iowa case study is used to estimate the relative costs to a farmer to reduce the excessive nitrogen fertilizer application rate under each alternative on cropland with a moderate and a high potential for leaching.

\[ ^2 \] It is possible that planting soybeans can increase nitrogen loss because of increased loss of topsoil from the soybeans planting. However, research results indicate most of cropland highly vulnerable to chemical leaching are not vulnerable to soil erosion (Huang, et al.). For those highly vulnerable cropland acre, the loss of nitrogen from soil erosion can be insignificant as compared with the leaching loss. Furthermore, one of the most beneficial aspects of soybeans-corn rotation is its ability to reduce soil insect species such as corn rootworm, corn root aphids, wireworm species, and maize billbug (Fairchild; Smith and Pimentel). Reduction of insects population in the soil, resulting from soybeans-corn rotation, can improve plant health and increase nitrogen uptake efficiency.
The Definition of Excess Nitrogen

An accurate estimate of the excess nitrogen available for leaching is very difficult to obtain (Blackmer [1987]). For the purpose of this study, the amount of excessive nitrogen, \( n_0 \), available for potential leaching associated with farming activities is defined as the difference between the amount of nitrogen applied from all sources on one acre of cropland and the amount of nitrogen present in both crop (grain) harvested and plant residues removed, \( n_p \), at the end of the growing season. The amount of nitrogen applied includes that from nitrogen fertilizer, \( n_f \), nitrogen credited from previous legume crops, \( n_l \), and nitrogen from manure application, \( n_m \). The excess nitrogen available for potential leaching over a continuous time interval, \( t \), is thus computed as

\[
n_0(t) = n_f(t) + n_l(t) + n_m(t) - n_p(t)
\]

Note that this definition is concerned with the excess nitrogen caused only by human farming activities at time \( t \). It assumes that, for a given acre, the amount of nitrogen available for plant uptake from atmospheric nitrogen absorbed by the soil and nitrogen from the organic matter in the soil are negligible after subtracting nitrogen losses attributable to other factors. These other factors include nitrogen losses due to denitrification, volatilization, water run-off and soil erosion. Any of the assumptions above can be removed and a different estimate of the excess nitrogen can be calculated. For instance, for a particular cropland site encountering significant soil erosion, the nitrogen loss due to soil erosion can be estimated and subtracted from the right-hand-side of equation (1).

As defined, the concept of excess nitrogen has considerable practical appeal. Using the indicated definition, a farmer is able to estimate the amount of nitrogen added and the amount of nitrogen removed from a field to calculate the excess nitrogen residual in the soil. A farmer using this

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3For most productive cropland, the difference can be positive. The difference is due to inherent nitrogen in the cropland. The inherent nitrogen of a specific field can be computed from a long-term crop yields from the site without application of nitrogen fertilizer (Voss and Shrader).
relationship can apply the right amount of nitrogen fertilizer to minimize the excessive application of nitrogen, if he or she is concerned with nitrogen contamination in groundwater. A farmer can also use it to approximate the amount of nitrogen available for potential leaching in areas where soil conditions favor water infiltration. In these areas, reducing the excessive nitrogen that is available for potential leaching is tantamount to reducing excessive nitrogen leaching into the ground water. In what follows, the \( n_e \) can be used as a yardstick to quantify the excess nitrogen from crop production. For the purpose of exposition in this study, we set \( n_e \) to zero for cropland of high potential for leaching.

Options to Reduce Nitrogen Fertilizer Use

As noted above, rotating crops is one way a farmer can reduce his or her application of nitrogen fertilizer. This is what will be considered here. Several crop rotations will be evaluated to provide information on the relative costs of adopting alternative farming practices designed to reduce the nitrogen fertilizer application rate. The cost to a farmer of the rotations considered will vary from one option to another. The farm-level performance of various crop rotations under four different options is considered. The alternatives are enumerated below.

(a) No Restriction

Under this option, cropland targeted for reduction of nitrogen fertilizer application rate is in the farm program (as detailed in Glaser). No restriction on the nitrogen fertilizer application rate is imposed on crop rotations and no nitrogen credits are considered for growing legume crops prior to planting corn. This option is used as the basis for comparison of the different crop rotation patterns under a restriction on nitrogen fertilizer use.

(b) Continuous Planting of Corn with a Restriction on the Nitrogen Fertilizer Application Rate

A farmer continuously planting corn under this option will be allowed to participate in the farm program but he or she is required to reduce the nitrogen fertilizer application rate. A zero excess nitrogen available for
potential leaching (as defined by relationship (1)) constraint is imposed.4

(c) Soybeans-Corn Rotation with a Restriction on Nitrogen Fertilizer Use

A farmer growing soybeans and corn in rotation will be allowed to participate in the existing farm program under this option but he or she will be required to reduce the nitrogen fertilizer application rate so that the excessive nitrogen available for potential leaching (as defined by relationship (1)) is equal to zero. There will be a credit for nitrogen fixed by soybeans.

(d) Meadow-Corn Rotation with a Restriction on Nitrogen Fertilizer Use

Under this option, a farmer growing meadow and corn in rotation will be allowed to participate in the existing farm program but he or she will be required to reduce the nitrogen fertilizer application rate so that the excessive nitrogen available for potential leaching (as defined by relationship (1)) will equal zero. Note that there will be a credit for nitrogen fixed by meadow.

The Dynamic Optimization Model

Different options can have different impacts on a farmer's decision with regard to the application rate of nitrogen fertilizer. In order to formalize the farmer's decision process, consider the following. For an initial level of nitrogen in the soil, \( n_0 \), a farmer is confronted with selecting an optimal crop rotation subject to several constraints and physical relationships. Assume that the farmer is confronted with a set of viable crop rotations, \( \{ r_n, n=1, 2, \ldots, N \} \), and has as his or her objective the maximization of net per acre return, \( z \), which is accomplished by choosing the optimal crop rotation, \( r^* \). The decision process is therefore defined by

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4To compute the nitrogen application rate to achieve zero excess nitrogen for a specific crop requires the knowledge of the crop production function from which the relationship between the nitrogen application rate and the amount of nitrogen in grains and plant residues, \( n_p \), can be established. Using equation (1), a proper application rate can be computed. The purpose of enforcing zero excess is to compute its compliance cost which could be used for a comparison of the comparable rental cost under the Conservation Reserve Program (CRP). The CRP also implicitly suggests a zero leaching approach.
(2) \[ Z(n_0, r^n) = \text{Maximize} \{ z(n_0, r^n), n=1, 2, \ldots, N \} \]

where

\[ z(n_0, r^n) = \sum_{t} \left[ \left( p_m^{i(r^n)}(t) \cdot y_c^{i(r^n)}(t) - w \cdot n_r^{i(r^n)}(t) - c^{i(r^n)} \right) + \left( p_n^{i(r^n)} - \max(p_m^{i(r^n)}, p_{i_1}^{i(r^n)}) \cdot y_p^{i(r^n)} \right) \right] \left( 1-a_1 \right) \left( 1+s \right)^{-1} \] (3)

where \( p_m^{i}, p_n^{i}, \) and \( p_{i_1}^{i} \) are respective market price, target price and loan rate of crop \( i \) at time \( t \); \( y_c^{i} \) and \( y_p^{i} \) are, respectively, the per acre yield of crop \( i \) harvested, and the program yield (a constant) at time \( t \); \( w \) is the price of nitrogen fertilizer; \( n_r^{i} \) is the nitrogen fertilizer application rate for crop \( i \) at time \( t \); \( c^{i} \) is the per acre production cost excluding the cost of nitrogen fertilizer at time \( t \); \( a_1 \) is the percent of base acreage set-aside; and \( s \) is the rate of discount\(^5\). Note that the \( i(r^n) \) indicates that a specific crop is grown at each time period but that this crop might change depending on the rotation being considered over the summation. The decision process in this study ignores the change of net income due to risk in production and market prices.

This decision process will be subject to a series of constraints and physical relationships (exclusive of any constraints imposed in order to limit nitrogen fertilizer use):

(a) The amount of nitrogen available for plant uptake, \( n_r^{i} \), is limited by the per acre nitrogen fertilizer application rate, \( n_r^{i} \), and the residual nitrogen available from the previous periods for use at time \( t \), \( n_r^{i} \):

\[ n_r^{i}(t) = n_r^{i}(t) + n_r^{i}(t) \] (4a)

(b) The residual nitrogen at time \( t \), \( n_r^{i}(t) \), is a function of the excessive nitrogen available for potential leaching, \( n_e^{i}(t) \), and the residual nitrogen carried over from the previous period, \( n_r^{i}(t-1) \):

\[ n_r^{i}(t) = f(n_e^{i}(t), n_r^{i}(t-1)) \] (4b)

\(^5\) The discount rate is assumed to equal 0.04 throughout the analysis. See Dervis, et al. [1982] for a discussion of the reasonableness of this value.
where \( n_0(t) \) is defined in relationship (1).

(c) There is an initial amount of (residual) nitrogen in the soil:
\[
(4c) \quad n_0(0) = n_0.
\]

(d) Nitrogen uptake by crop i (for the plant and grain) at time \( t \), \( n^i_p(t) \), is a linear function of the crop yield:
\[
(4d) \quad n^i_p(t) = a^i y^{i\text{g}}(t)
\]
where \( a^i \) is a constant and the other terms are as previously defined. For the analysis in this paper, it is assumed that \( a=0.9 \) for corn grain. That is, there are 0.9 pounds of nitrogen contained in one bushel of corn (Fertilizer Institute [1976]).

(e) Crop yield at time \( t \), \( y^{i\text{g}}(t) \), is assumed to be a function of the nitrogen available for plant uptake at time \( t \), \( n_i(t) \):
\[
(4e) \quad y^{i\text{g}}(t) = g^{i\text{g}}(n_i(t)).
\]

Finally, it is assumed that no manure is applied by the farmer. That is, throughout the subsequent analysis, it is assumed that \( n_m = 0 \).

In order to empirically implement the model specified, it is necessary to have explicit representations for two sets of functions - the residual nitrogen transformation functions, \( n_i(t) = f(n_i(t), n_i(t-1)) \), and the crop yield functions, \( y^{i\text{g}}(t) = g^{i\text{g}}(n_i(t)) \). These will be discussed next.

Functional Representations

(a) Residual Nitrogen Transformation Functions - The Continuous Planting of Corn

The amount of available residual nitrogen in the soil, \( n_i(t) \), at time \( t \) under the continuous planting of corn at time \( t \) is given as
\[
(5) \quad n_i(t) = n_i(t-1) + n_i(t-1) - n_i(t-1) + n_i(t-1)
\]
where \( n_i(t-1) \) is the residual nitrogen available for crop use at time \( t-1 \); \( n_i(t-1) \) is the inherent nitrogen from precipitation and available for crop use at time \( t-1 \). If the excessive nitrogen available for potential leaching is greater than zero, it is assumed that \( k \) (for \( k \) between zero and 1) of it is leached. The amount of nitrogen, \( n_i(t) \), leached at time \( t \) is
\[
(6) \quad n_i(t) = k n_i(t)
\]
Given this relationship, relationship (5) can be rewritten as

\[ n_t(t) = (1-k) (n_s(t-1) - n_p(t-1) + n_i(t-1)). \]

An exact determination of a value for \( k \) is difficult to make. The value can be approximated, however, using the procedure suggested by Schaffer, et al. [1990].

Schaffer, et al. [1990] suggest the use of the following relationship in order to determine an appropriate value for \( k \):

\[ k(t) = \frac{1 - \exp(-1.2 \text{ wal}(t))}{\text{ por}} \]

where \( \text{ wal}(t) \) is the water available for leaching at time \( t \) and \( \text{ por} \) is the porosity of the soil in the root zone. The variable \( \text{ wal}(t) \) is computed as

\[ \text{ wal}(t) = \text{ pe}(t) - \text{ et}(t) - (\text{awhc} - \text{wr}(t)) \]

where \( \text{ pe}(t) \) is the effective precipitation at time \( t \), \( \text{ et}(t) \) is the potential evapotranspiration at time \( t \), \( \text{awhc} \) is the water holding capacity of the soil, and \( \text{wr}(t) \) is the water content of the soil at time \( t \).

In implementing equation (7), an average value for \( k(t) \) across time periods is assumed. In areas where the ground water is extremely vulnerable to nitrogen contamination due to leaching, the value of \( k \) will approach 1 while for areas where leaching is very unlikely, the value of \( k \) approaches 0. In this study, a value of \( k=1 \) will be used for areas considered to have a high potential for leaching while a value of \( k=0.5 \) will be used for areas where the leaching potential is only moderate.

(b) Residual Nitrogen Transformation Functions: The Legume - Corn Rotation

The amount of residual nitrogen in the soil which is available for corn use at time \( t \) when a legume crop (either soybeans or meadow) is grown at time \( t-1 \) is given as

\[ n_r(t) = n_r(t-1) + n_i(t-1) \]

where \( n_r(t) \) is the net legume-fixed nitrogen (\( n_p(t-1) = 0 \)) that can be used for growing corn. When a legume crop is grown in rotation with corn, it is further assumed that no fertilizer is applied to the legume crop (\( n_f(t-1)= 0 \)) and that the residual nitrogen from the previous corn crop is absorbed by the
legume crop at the beginning of the growing season (these assumptions are consistent with those made by Schaffer, et al. [1990]). No attempt will be made to estimate the amount of nitrogen fixed by legume and then leached out of the root zone during the legume growing period because of lack of experimental data.

(c) Yield Functions

Before discussing the yield functions, it is necessary to comment on the data used in the estimation since the data define the nature of these functions. The yield data (relating yield and nitrogen fertilizer use) were obtained from an Iowa State University research farm study at Kanawha, Iowa (Iowa State Experiment Station). This study examined the effects of nitrogen fertilizer application rates and crop rotation patterns on crop yields. In the study only the nitrogen fertilizer application rate and the sequence of crop rotations varied. All other factors were held constant. These data are used to estimate the yield functions for specific crop rotations. These estimated yield functions are used as the basis of the analysis. The crop rotations considered are soybeans-corn (BC) and meadow-corn (MC) in addition to the continuous planting of corn. These rotations are common in the Corn Belt region of the United States (Daberkow and Gill [1989]). The nitrogen application rate for corn production varies among rotations. In each rotation, only corn production receives nitrogen fertilizer. Soybeans and meadow yield levels are kept constant, regardless of the amount of nitrogen applied on preceding corn production in a rotation. The experimental data substantiate the integrity of this assumption (Voss and Shrader).

The estimated yield functions for the three different crop sequences are given in Table 1. The functions were estimated via ordinary least squares (Draper and Smith). The intercept term of the yield function for the continuous planting of corn is used as the measure of the inherent productivity of the soil. The intercept is the annual corn yield that would be realized from the soil without the application of any nitrogen fertilizer and is an indication of the initial nitrogen level, n₀, in the soil.
difference between the intercepts of the yield functions when corn is continuously planted and when one of the legume-corn rotation sequences is planted is the yield response attributable to the legume-fixed nitrogen used subsequently by the corn.

**Policy Option Constraints**

The options that are considered are those designed to limit the use of nitrogen fertilizer. The objective is to reduce the excess nitrogen available for potential leaching to zero on the targeted cropland with a high and a moderate potential for nitrogen leaching. This requires introducing two additional constraints into the problem formulation. The first additional constraint is for the continuous planting of corn. It requires that the residual nitrogen carried over from one period to the next, \( n_i(t) \), plus the nitrogen fertilizer applied, \( n_r \), must be less than or equal to the nitrogen removed from the field through plant uptake and removal of the harvested crop. That is,

\[
(11) \quad n_i(t) + n_r(t) \leq 0.9 y(t).
\]

The second additional constraint is for the legume-corn rotation. It requires that the nitrogen fixed by a legume crop, \( n_i(t) \), plus the inherent nitrogen, \( n_l(t) \), plus the nitrogen fertilizer applied, \( n_r(t) \), must be less than or equal to the nitrogen removed from the field. That is,

\[
(12) \quad n_i(t) + n_l(t) + n_r(t) \leq 0.9 y(t).
\]

Cost of production data are from Duffy and Chase [1988]. The cost data represent average production costs for farms in Iowa (Iowa State University [1989]). The commodity price data are from the Economic Research Service [1990]. The December 1989 nitrogen fertilizer price ($0.15 per pound) is assumed to prevail initially although a sensitivity analysis is conducted in order to examine the effect that variations in the price of nitrogen fertilizer have on the results.

**Simulation Results**

Each planting pattern under each of the policy options is examined for two types of cropland. For cropland with a high potential for leaching, it is
assumed that for each time period, \( t \), any unused nitrogen will be lost and hence cannot be used for future (i.e., \( t+1, t+2, \ldots \)) crop production. For cropland with a moderate leaching potential, it is assumed that 50 percent (i.e., \( k=0.5 \)) of the residual nitrogen is carried over from one period to the next. Cost of production data are from Duffy and Chase. The cost data represent average production costs for farms in Iowa (Iowa State University). The commodity price data are from the Economic Research Service. The December 1989 nitrogen fertilizer price ($0.15 per pound) is assumed to prevail initially although a sensitivity analysis is included in order to examine the effect that variations in the price of nitrogen fertilizer have on the results. The model defined by equations (2) to (10) is used for the analysis of no fertilizer restriction option. The initial level of nitrogen in the soil, \( n_0 \), is calculated by assuming the farmer is in the continuous planting of corn before a policy option is implemented. The Generalized Algebraic Modeling System (GAMS) is used to solve the model (Kendrick and Meeraus). GAMS is a mathematical programming package for solving linear, nonlinear, and mixed integer optimization problems.

(a) No Fertilizer Use Restriction

Regardless of the leaching potential of the cropland, switching from the continuous planting of corn to one of the legume-corn rotations while imposing no fertilizer use restriction will reduce the excess nitrogen available for potential leaching and it will increase net farm income. It will not, however, eliminate the excess nitrogen (as defined by equation (1)) on cropland with either a high or moderate leaching potential. A relatively large amount of nitrogen fertilizer is required for the production of corn. Nitrogen fixed by a legume crop alone will not be sufficient to produce corn so that the maximum net farm income will be realized. For example, the meadow-corn rotation needs an additional 116 pounds of nitrogen fertilizer per acre to grow corn (optimally) in addition to the nitrogen fixed by the meadow. This result is contingent on the relatively low ratio of the price of nitrogen fertilizer to the price of corn ($0.15/$2.10=0.071). If the nitrogen applied
in the form of fertilizer and that fixed by the legume crop are considered in concert, both the soybeans-corn and meadow-corn rotations exhibit excess nitrogen available for potential leaching on cropland susceptible to high as well as moderate leaching.

Furthermore, switching from the continuous planting of corn to a soybeans-corn rotation will have a larger impact on the reduction in nitrogen fertilizer (and, hence, excess nitrogen) use and the increase in net farm income on cropland with a high leaching potential relative to cropland with a moderate leaching potential. Thus, for example, the reduction in the nitrogen fertilizer use is 144 pounds on cropland with a high leaching potential compared to a reduction of 6 pounds on cropland with a moderate leaching. The difference in net farm income is $29 on cropland with a high leaching potential relative to $8 for cropland with a moderate leaching potential over a six year rotation cycle. These results clearly indicate that a policy aimed at reducing excessive nitrogen would be most effective if it is targeted at cropland with a high leaching potential.

(b) Limiting Fertilizer Use

Next, consider the impact on a farmer when nitrogen fertilizer use is constrained as defined by relationships (11) and (12). While the price of corn is assumed to be $2.10 per bushel (as before), it is now assumed that the price of nitrogen fertilizer ranges between $0.05 and $0.45 per pound in $0.10 increments. (This assumption allows for a study of how sensitive the results are to the price of nitrogen fertilizer.) As before, each rotation is examined based on cropland with either a high or moderate leaching potential. The effects on fertilizer application rates and net farm income of limiting fertilizer use are shown in Table 2a and Table 2b, respectively. The results show no difference in the nitrogen fertilizer application rate and net farm income between the two types of cropland. This result is not surprising because imposing a constraint on fertilizer use forces excess nitrogen to equal zero at each time period. The bottom line is that in order to have zero excess nitrogen available for potential leaching, a significant reduction in
the nitrogen fertilizer application rate is required for each of the planting options considered (i.e., the continuous planting of corn, a soybeans-corn rotation, and a meadow-corn rotation). Although both soybeans and meadow fix nitrogen that is available for the subsequent production of corn, the nitrogen fertilizer application rate for both the soybeans-corn and the meadow-corn rotations is constrained (i.e., constraint (12) is binding). This result is a consequence of the relatively low price of nitrogen fertilizer (at $0.15 per pound). A higher nitrogen fertilizer price at $0.35 will impact the fertilizer application rate on just the meadow-corn rotation. Utilizing the residual nitrogen in the soil, \( n_i(t) \), will reduce the excess nitrogen available for potential leaching at the same time resulting in an increase in net farm income. This reduction (in excess nitrogen) and gain (in net farm income), however, are mitigated as the price of nitrogen fertilizer increases. Further, under the limiting fertilizer use option, the soybeans-corn rotation will have the largest effect on net income. It becomes the most profitable practice if the nitrogen fertilizer price rises above $0.35 per pound.

(c) Compliance Cost

Finally, a farmer is inherently concerned with the effect on net farm income of adopting a different cropping practice. This effect can be computed simply as the difference in net farm income from the continuous planting of corn (assuming that this is the practice initially employed by the farmer) and the planting under a soybeans-corn or meadow-corn rotation. The effect is nominally referred to as the compliance cost. The compliance costs for the three different crop planting schemes were computed assuming that farmers were planting their crops, first, on land with a high potential for leaching and, second, on land with a moderate potential for leaching. The analysis focuses on crop rotations for corn production because corn uses large amounts of nitrogen fertilizer. Moreover, the continuous planting of corn (i.e., planting corn from one planting season to the next) is targeted for change because it is a common farming practice accounting currently for 26 percent of the total number of corn acres planted (Daberkow and Gill [1989]). The
continuous planting of corn uses nitrogen fertilizer inefficiently\(^6\) and is potentially the source of a large amount of nitrate leaching into the ground water. The results are presented in Table 3a. They show that when the nitrogen fertilizer price is relatively low, a fertilizer use restriction on cropland that is highly vulnerable to potential leaching will have a slightly smaller compliance cost relative to cropland with a moderate leaching potential. The compliance cost on both types of cropland decreases as the price of nitrogen fertilizer increases. The soybeans-corn rotation with a restriction on fertilizer use has the lowest compliance cost. In fact, this compliance cost becomes negative (i.e., the net farm income under the soybeans-corn rotation actually exceeds the net farm income from the continuous planting of corn) for a price of nitrogen fertilizer exceeding $0.25 per pound.

Associated with each of the cropping patterns discussed will be a change in nitrogen fertilizer use. These changes will impact net farm income. The effect on net farm income of a change in nitrogen fertilizer use for each option is given in Table 3b. The reduction in net farm income associated with the change in nitrogen fertilizer use when the cropland is highly vulnerable to potential leaching relative to cropland with a moderate leaching potential is quite significant. For example, at a nitrogen fertilizer price of $0.15 per pound, the fall in net farm income when excess nitrogen is reduced by one pound under the soybeans-corn rotation in areas with a moderate potential for leaching is nearly twice that as in areas with a high potential for leaching. Given that analogous results hold over most of the range in the price of nitrogen fertilizer considered, it can be concluded that reducing excess nitrogen in soils with a moderate leaching potential results in a greater decline in net farm income than would be realized if the soil possesses a high potential for leaching when the nitrogen fertilizer price is between $0.15 and

\(^6\)The continuous planting of corn use nitrogen fertilizer inefficiently is based on large quantity of excess nitrogen, \(n\), the difference between the amount of nitrogen fertilizer applied and the amount of nitrogen removed from the field, using the Iowa State field experimental data (Voss and Shrader).
$0.35 per pound.

This result can be explained as follows. Under the no fertilizer use restriction scenario, corn grown on the cropland with a moderate leaching potential commands a higher net return than corn grown on the highly leachable cropland because the moderately leachable cropland requires less nitrogen fertilizer for plant uptake. As a zero excess standard is enforced, net incomes from crops grown on both types of cropland, however, will be reduced to the same level because the nitrogen fertilizer application rate will be the same. The reason for same application rate for both types of cropland is because, in a long run, there will be no residual nitrogen for carry-over on the moderately leachable cropland, even though it is capable of carrying part of the residual nitrogen over to next time period. Thus, if a zero excess standard is enforced, the income loss (compliance cost) will be higher for the moderately leachable cropland.

Conclusions

This article is concerned with the excessive application of nitrogen fertilizer that is a threat to contaminate groundwater. Under the circumstance of this concern, we have investigated the effects of several options designed to reduce nitrogen fertilizer use. For a farmer currently growing corn from one year to the next, adopting a soybeans-corn rotation can reduce the excess nitrogen in the soil and increase net farm income in the process. Adopting a meadow-corn rotation in deference to continuously planting corn, on the other hand, can reduce by a significant amount the excess nitrogen in the soil and available for potential leaching into the ground water but this would involve a relatively sizeable reduction in net farm income. Additionally, in order to achieve a goal of zero excess nitrogen in the soil over time, both rotation schemes must involve a limitation on the nitrogen fertilizer application rate.

Practicing the continuous planting of corn while coincidentally limiting the use of nitrogen fertilizer can effectively reduce the excess nitrogen in the soil to zero for a relatively low price for nitrogen fertilizer. Adoption
of a soybeans-corn rotation, however, while limiting the nitrogen fertilizer application rate will have the lowest compliance cost for a farmer irrespective of the price of nitrogen fertilizer and also irrespective of the vulnerability of cropland to potential leaching.

Finally, a fertilizer use restriction on cropland that is highly vulnerable to potential leaching will have a smaller compliance cost (i.e., a lower cost to the farmer) per pound reduction in the nitrogen fertilizer application rate relative to cropland with a moderate leaching potential.
References


Iowa State Experiment Station at Kanawha. Experiment Station Report ORC87-14.22, Iowa State University, 1986.

Iowa State University. Estimated Costs of Crop Production -1989, Extension


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<tr>
<th>Rotations</th>
<th>A(i,j)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Corn after Corn</td>
<td>65.64 (4.31)</td>
<td>0.730 (0.088)</td>
<td>-0.0017 (0.0004)</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Sample size = 16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn after Soybeans</td>
<td>107.0 (5.1)</td>
<td>0.521 (0.105)</td>
<td>-0.0012 (0.0004)</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Sample Size = 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn after Meadow</td>
<td>149.9 (3.17)</td>
<td>0.165 (0.066)</td>
<td>-0.0004 (0.0003)</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Sample Size = 8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 The yield function is specified as \( y(i,j) = A(i,j) + B(i,j)(n_{(i,j)}) + C(i,j)((n_{(i,j)})^2 \) where \( y(i,n) \) denotes the yield for crop i preceded by crop j, \( n_{(i,j)} \) is the nitrogen fertilizer application rate for crop i when preceded by crop j, and A(i,j), B(i,j) and C(i,j) are coefficients to be estimated. In the field experiments, only corn received nitrogen fertilizer applications.

Note that the values in parentheses are standard errors of the estimates.
Table 2a. Nitrogen Fertilizer Application Rate When Nitrogen Fertilizer Use is Constrained in Iowa

<table>
<thead>
<tr>
<th>Crop Rotation</th>
<th>Nitrogen Fertilizer Price</th>
<th>$0.05</th>
<th>$0.15</th>
<th>$0.25</th>
<th>$0.35</th>
<th>$0.45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Planting of Corn with No Fertilizer Use Restriction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- On Cropland with a High Potential for Leaching</td>
<td></td>
<td>207</td>
<td>193</td>
<td>180</td>
<td>165</td>
<td>151</td>
</tr>
<tr>
<td>- On Cropland with a Moderate Potential for Leaching</td>
<td></td>
<td>170</td>
<td>166</td>
<td>162</td>
<td>157</td>
<td>146</td>
</tr>
<tr>
<td>Continuous Planting of Corn with a Restriction on Fertilizer Use</td>
<td></td>
<td>114</td>
<td>114</td>
<td>114</td>
<td>114</td>
<td>114</td>
</tr>
<tr>
<td>Soybeans-Corn Rotation with a Restriction on Fertilizer Use</td>
<td></td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>Meadow-Corn Rotation with a Restriction on Fertilizer Use</td>
<td></td>
<td>67</td>
<td>67</td>
<td>57</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 2b. Net Farm Income When Nitrogen Fertilizer Use is Constrained in Iowa

<table>
<thead>
<tr>
<th>Crop Rotation</th>
<th>Nitrogen Fertilizer Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0.05</td>
</tr>
<tr>
<td>Continuous Planting of Corn with No Fertilizer Use Restriction</td>
<td></td>
</tr>
<tr>
<td>- On Cropland with a High Potential for Leaching</td>
<td></td>
</tr>
<tr>
<td>Net Income</td>
<td>$855</td>
</tr>
<tr>
<td>- On Cropland with a Moderate Potential for Leaching</td>
<td></td>
</tr>
<tr>
<td>Net Income</td>
<td>$864</td>
</tr>
<tr>
<td>Continuous Planting of Corn with a Restriction on Fertilizer Use</td>
<td></td>
</tr>
<tr>
<td>Soybeans-Corn Rotation with a Restriction on Fertilizer Use</td>
<td></td>
</tr>
<tr>
<td>Net Income</td>
<td>$707</td>
</tr>
<tr>
<td>Meadow-Corn Rotation with a Restriction on Fertilizer Use</td>
<td></td>
</tr>
<tr>
<td>Net Income</td>
<td>$665</td>
</tr>
</tbody>
</table>
Table 3a. Reduction in Net Farm Income When Switching from Continuous Planting of Corn Without Nitrogen Fertilizer Restriction to Crop Rotations With Nitrogen Fertilizer Restriction in Iowa

<table>
<thead>
<tr>
<th>Nitrogen Fertilizer Price</th>
<th>$0.05</th>
<th>$0.15</th>
<th>$0.25</th>
<th>$0.35</th>
<th>$0.45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop Rotation</td>
<td>Net Income</td>
<td>Dollars per acre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous Planting of Corn</td>
<td>25</td>
<td>18</td>
<td>12</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Soybeans-Corn Rotation</td>
<td>16</td>
<td>4</td>
<td>-7</td>
<td>-17</td>
<td>-26</td>
</tr>
<tr>
<td>Meadow-Corn Rotation</td>
<td>32</td>
<td>18</td>
<td>6</td>
<td>-6</td>
<td>-18</td>
</tr>
<tr>
<td>Continuous Planting of Corn</td>
<td>26</td>
<td>22</td>
<td>15</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Soybeans-Corn Rotation</td>
<td>18</td>
<td>8</td>
<td>-5</td>
<td>-13</td>
<td>-21</td>
</tr>
<tr>
<td>Meadow-Corn Rotation</td>
<td>33</td>
<td>22</td>
<td>9</td>
<td>-2</td>
<td>-13</td>
</tr>
</tbody>
</table>

Note it is assumed that the price of corn is $2.10 per bushel.
Table 3b. Reduction in Average Net Farm Income Per Pound Reduction in Excess Nitrogen Fertilizer Use When Switching from Continuous Planting of Corn Without Nitrogen Fertilizer Restriction to Crop Rotations With Nitrogen Fertilizer Restriction in Iowa

<table>
<thead>
<tr>
<th>Nitrogen Fertilizer Price</th>
<th>Continuous Planting of Corn</th>
<th>Soybeans-Corn Rotation</th>
<th>Meadow-Corn Rotation</th>
<th>Soybeans-Corn Rotation</th>
<th>Meadow-Corn Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.05</td>
<td>0.32</td>
<td>0.21</td>
<td>0.41</td>
<td>0.65</td>
<td>0.44</td>
</tr>
<tr>
<td>$0.15</td>
<td>0.28</td>
<td>0.06</td>
<td>0.29</td>
<td>0.60</td>
<td>0.21</td>
</tr>
<tr>
<td>$0.25</td>
<td>0.23</td>
<td>-0.14</td>
<td>0.12</td>
<td>0.45</td>
<td>-0.14</td>
</tr>
<tr>
<td>$0.35</td>
<td>0.19</td>
<td>-0.44</td>
<td>-0.16</td>
<td>0.43</td>
<td>-0.46</td>
</tr>
<tr>
<td>$0.45</td>
<td>0.14</td>
<td>-0.98</td>
<td>-0.67</td>
<td>0.35</td>
<td>-0.81</td>
</tr>
</tbody>
</table>

Note that it is assumed that the price of corn is $2.10 per bushel.