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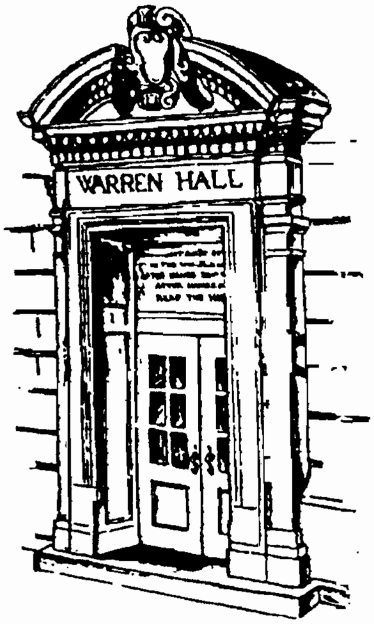

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ECONOMETRIC RELATIONSHIPS FOR ESTIMATING AND RANKING DISTRIBUTIONS OF NITRATE LEACHING FROM CORN PRODUCTION

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by

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ABSTRACT

Recognizing the difficulty in incorporating models that simulate the leaching and runoff of nitrogen for individual soils into economic models, this paper demonstrates that the output from a model like GLEAMS can be used to estimate econometric relationships that relate nitrogen leaching to weather, soil characteristics, and farm production practices.

This information is useful in examining the change at the margin in nitrogen leaching and runoff from changes in these variables. When applied to soils with characteristics similar to those used in estimation, the equations are an effective way to estimate the distribution of nitrogen leaching and runoff over 30 years for corn production on farms in New York for which detailed soils information is available. These are the types of consistent leaching distributions for many individual soils that are needed as input into chance constrained and other mathematical programming models of agricultural chemical runoff and leaching.

For purposes here, the leaching and runoff distributions for the 160 farms are ranked by second-degree stochastic dominance to identify any policy implications that could be drawn from the variation in nitrogen leaching and runoff potential across farms or regions in New York. On the basis of these rankings alone, we argue that it would be difficult to be able to target policies designed to reduce nitrogen leaching and runoff to specific farms or regions based on differences in their soils.

If we rank soils on the basis of productivity, the less productive soils also appear to be the less leachable as well. Clearly, it appears that policies should be focused on the more productive soils, but more research is needed to identify the tradeoffs between nitrogen leaching, corn yields, and farm income across a wide range of soils.

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Introduction

Partially in response to the increasingly wide-spread concern over the quality of our Nation's groundwater, research to quantify the relationships among agricultural production, soils, and agricultural chemicals that affect leaching and runoff potential has expanded rapidly over the past several years. Soil scientists, agronomists and others have focused their attention on articulating the physical relationships, and their efforts have resulted in the development of a number of simulation models designed for that purpose. These models are generally designed to simulate some combination of leaching and runoff potential of particular chemicals or nutrients for a specific soil, given specific field conditions, cropping practices, and weather conditions. For example, the Ground Water Loading Effects of Agricultural Management Systems, (GLEAMS) is one such model designed to simulate the effects of agricultural management systems on the movement of agricultural chemicals within and through the plant root zone (Knisel, *et al.*, n.d.; and Leonard, *et al.*, 1987).

At one extreme, these types of models are valuable for a detailed assessment of conditions on a specific agricultural field for a given weather event, while at the other, the output from the models has been used to develop procedures to assist in screening soil-pesticide or soil-nutrient interactions at the national and regional levels (e.g. Kellogg, Maizel, and Goss, 1992; Nielsen and Lee, 1987). Used in this way, these models can point to areas where the potential contamination is high and for which there is need for further in-depth analysis. Scientists are quick to point out that such screening procedures are "intended to be a first tier evaluation ...[and] are not intended for regulation" (Goss and Wauchope, 1991, p. 472) .

Accompanying these efforts, economists have attempted to use the information generated by these physical models to evaluate the effects on agricultural production, farm profitability, and environmental quality of various policies designed to restrict agricultural nutrient and chemical runoff and leaching. However, such efforts can often be frustrating. On the one hand, it is not possible to incorporate detailed simulations of the leaching and runoff potential of individual soils for specific weather events into economic models at the farm or regional levels. On the other hand, the first-tier screening procedures tend to rank soils qualitatively and provide no specific estimates of runoff or leaching potential. This usually means that the economic models are developed using one, or a small number of "representative" soils (e.g. Schmit, 1994; Zhu *et al.*, 1994; Segarra *et al.*, 1985; and

Young and Crowder, 1986). While this type of analysis is valuable, it abstracts from any farm-to-farm variation in soils and runoff and leaching potential of agricultural chemicals or nutrients. These considerations have important implications for implementation of environmental policy designed to reduce pollution from agricultural chemicals.

For this reason, some "middle-ground" strategy is needed: a procedure based on the simulation output from the physical models can be used to provide quantitative estimates of the distribution of runoff and leaching for a range of soils without the need for repeated runs of the simulation model for each economic application. Admittedly, in such a procedure, some loss in accuracy of the estimates of runoff and leaching is sacrificed to facilitate consistent policy analysis across a wide range of agricultural production situations. This should be of little concern because it is impossible to implement policy on the basis of the detailed simulation results for individual fields or weather events.

The primary purpose of the research underlying this paper is to develop such a procedure for estimating nitrate leaching and runoff in corn production and illustrate its use. In particular, we use GLEAMS to simulate both nitrogen leachate and runoff for a wide range of soils using different length corn rotations and fertilization rates. Simulations are for thirty years using weather data from the mid-1950s through the mid-1980s.[1] The results of these simulations are combined into a single data set so that equations relating soil characteristics, weather, rotations, and fertilization levels to nitrogen runoff and leaching can be estimated econometrically. Soil characteristics and weather data used in the analysis are readily available from the Soils 5 data base and the weather service. To illustrate the use of the equations, the distributions of nitrate leachate (based on 30 years of weather data) are estimated for 160 farms in New York for which detailed soils information is available. These distributions are characterized, and are ranked according to stochastic dominance criteria. This ranking has important implications for the design of policies to limit nitrate contamination and for identifying the differential policy effects on farms throughout a region.

The Runoff and Leaching Functions

To model nitrate runoff and leaching from the simulated results from the GLEAMS model, it is necessary to find a functional form capable of relating these nitrate runoff and leaching data to soil characteristics, weather, and cropping practices. For this purpose, generalized quadratic, as well as translog functions were estimated. The generalized quadratic functions have been used extensively to model yield response functions (e.g. Bailey and Boisvert, 1991; and Hexem and Heady, 1978; and Lanzer and

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[1] GLEAMS is used in this analysis primarily because, in addition to providing estimates of nitrogen leaching, it also generates consistent estimates of nitrogen runoff. Although not used in this paper, GLEAMS also provides estimates of both pesticide leaching and runoff which are an integral part of other aspects of the research to which this paper contributes.

Paris, 1981), but they did not perform well for modeling nitrogen runoff and leaching. As is seen below, the translog function, on the other hand, performed quite well.

Although the translog form has most often been used for modeling production processes at the firm or aggregate levels (Boisvert, 1982), it does have some distinct characteristics advantageous for modeling runoff and leaching. For example, this function can account for the interaction between soil characteristics, weather and cropping practices. It prevents estimates of leaching and runoff from being negative; and the contribution to leaching or runoff at the margin to changes in soil characteristics, weather and cropping practices can be either positive or negative over certain ranges in these variables (Boisvert, 1982).

The function is given by:

$$(1)\ z = a_0 \prod_{k=1}^{k} e^{d_k D_k} \prod_{i=1}^{N} X_i^{a_i} \prod_{i=1}^{N} X_i^{1/2\left(\sum_{i=1}^{N} b_{ij} \ln X_j\right)}$$

where z is either nitrogen runoff or leaching; D_k are dummy variables which take on the value of 1 if a soil is in hydrologic group k and zero otherwise: and X_i is the ith soil characteristic, weather variable, or cropping practice. To see its various properties, it is convenient to write the translog function in logarithmic form:

$$(2)\ \ln z = \ln a_0 + \sum_{k=1}^{K} d_k D_k + \sum_{i=1}^{N} a_i \ln X_i + 1/2 \sum_{i=1}^{N} \sum_{j=1}^{N} b_{ij} \ln X_i \ln X_j .$$

The effect on z of marginal changes in these variables is given by the partial derivative of the translog function (1) with respect to each of the arguments X_i. Since the function in (2) is written in logarithmic form, we can find these partial derivatives in the following fashion:

$$(3)\ \frac{\partial z}{\partial X_i} = \left[\frac{\partial \ln z}{\partial \ln X_i}\right] \bullet \left[\frac{z}{X_i}\right] = (a_i + \sum b_{ij} \ln X_j)\left[\frac{z}{X_i}\right].$$

This expression depends on the levels of the explanatory variables X_j, and it can be positive or negative over separate ranges, depending on the relative sizes of the a_i's and b_{ij}'s and whether $\ln X_j < 0$ $(0 < X_j < 1)$ or $\ln X_j > 0$ $(X_j > 1)$. These marginal effects, measured in percentage terms, are given by the elasticities:

$$(4)\ \frac{\partial \ln z}{\partial \ln X_i} = (a_i + \sum b_{ij} \ln X_j)$$

which are identical to the logarithmic partial derivatives. Since z and X_i are both positive, these elasticities have the same sign as the marginal effects in equation (3) over certain ranges in the data.

Simulating Nitrate Leaching and Runoff Data Using GLEAMS

To generate the data used to estimate the translog runoff and leaching equations, the GLEAMS model was run using data from 105 New York soils. Of these, about 20 percent are from hydrologic group A, about 35 percent are from hydrologic group B, while the remaining 45 percent are from hydrologic group C. These soils reflect a wide range of other characteristics such as slope, organic matter content, etc., and vary in productivity. Nitrogen runoff and leaching were then simulated over the 30 years for which there were weather data, assuming that corn was grown in rotation with hay and small grains. Rotations are those recommended under best management practices. Commercial fertilizer applications were varied, as were application rates for manure.

Once the GLEAMS output was generated, the leaching and runoff data for each year in which corn was grown were combined with data on weather and soil characteristics into a SAS data set. This strategy generated 1,361 observations for use in the subsequent econometric estimation. Summary statistics for simulated nitrogen leaching and runoff across these observations are given in Table 1.[2]

It is difficult to know how reasonable these simulated runoff and leaching estimates are, and the estimates would certainly vary depending on which of several available simulation models were used. The average leaching of 12.1 kg./ha. is between 50 and 60 percent of the levels generated using NLEAP (Follett *et al.*, 1991) by Thomas (1994) for seven New York soils. Much of the explanation for these differences lies in the fact that Thomas' soils were on average inherently more leachable than many in this study, and Thomas' average fertilization levels were about 20 percent higher. In addition, Thomas' estimates were based only on yearly rainfall. By not accounting for the actual timing of significant storms, estimates based on annual rainfall are likely to be higher than would otherwise be the case.

Viewed in relative terms, the data in Table 1 suggest that 7.8 percent of the nitrogen applied is leached below the root zone, which is about midway between Thomas' estimate and the 2.1 percent figure (based on the EPIC model from Williams *et al.*, 1984) found in a regional analysis of the central high plains by Bernardo *et al.* (1993).[3]

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[2] Throughout this paper, nitrogen leaching and runoff are taken to mean nitrate leaching and runoff. Leaching is defined as movement of nitrates below the crop root zone.

[3] Estimates of nitrogen runoff are significantly lower in this study than those reported by Bernardo *et al.* (1993), in large measure due to the fact that much of the agriculture in the central high plains is irrigated. In addition, to predict runoff accurately, GLEAMS needs information regarding the proximity of the field to a stream. In this analysis, it was necessary to make general assumptions about these parameters, which would necessarily lead to conservative estimates of runoff.

Table 1. Descriptive Statistics for Use in Regression Equations

		All Soils		A&B Soils		C Soils	
Variable		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
	Descriptive Statistics in level terms, not logs:						
RUNNO3	Nitrogen runoff (kg/ha)	2.85	1.04	2.30	0.70	3.49	1.00
LCHNO3	Nitrogen leaching (kg/ha)	12.07	12.49	12.47	11.77	11.59	13.27
Soil Characteristics:							
HYDA	Dummy for hydrologic soil group A	0.20	0.40	0.37	0.48	0.00	0.00
HYDB	Dummy for hydrologic soil group B	0.34	0.47	0.63	0.48	0.00	0.00
HYDC	Dummy for hydrologic soil group C	0.46	0.50	0.00	0.00	0.46	0.50
H1	Soil horizon depth (cm)	16.11	11.21	14.19	10.49	18.33	11.60
SLP	Average field slope (%)	4.65	4.55	4.61	4.51	4.70	4.60
MINN	Nitrogen mineralized by soil (kg/ha)	79.37	6.14	80.03	4.78	78.60	7.35
KAY	K erodibility factor	0.29	0.09	0.29	0.08	0.30	0.10
ORG	Organic Matter (%)	4.28	0.83	4.27	0.79	4.31	0.89
Weather Characteristics:							
PRECIP	Total annual rainfall (cm)	98.67	16.55	97.30	15.90	100.27	17.15
PRSTRM	Rainfall in storms w/in 14 days of planting (cm)*	2.13	2.34	2.19	2.27	2.06	2.43
FRSTRM	Rainfall in storms w/in 14 days of fertilizer (cm)*	3.68	3.91	3.64	3.77	3.73	4.07
HRSTRM	Rainfall in storms w/in 14 days of harvest (cm)*	4.05	4.26	3.96	4.15	4.14	4.38
Management Characteristics:							
KGMAN	Total fertilizer applications (kg/ha)**	155.14	12.16	156.03	11.87	154.10	12.41
ROT	Years of corn in 10 year rotation	4.91	1.68	5.32	1.63	4.44	1.61
LAGCOR	Dummy, corn previous year	0.52	0.50	0.55	0.50	0.48	0.50
MANURE	Dummy, manure application	0.56	0.50	0.54	0.50	0.59	0.49

* These variables reflect rainfall in storms of at least 0.5 inches (1.3 cm.).

** Includes nitrogen from manure.

Empirical Results for the Response Relations

The results for the econometric estimation (based on data summarized in Table 1) are shown in Table 2. The variables used in estimation can be placed in three groups related to soil characteristics, precipitation, and management. The variables related to soil characteristics include hydrologic group, the depth of the soil horizon, slope, organic matter, K from the universal soil loss equation as a measure of erodibility, and a measure of the mineralizable nitrogen in the soil. The weather data measure annual precipitation and the amounts of precipitation in storms within two weeks of planting, and within two weeks of fertilizer application. These latter two variables reflect the rain in storms of 0.5 inches of rain or more within two weeks following planting or fertilizer application in an attempt to capture the effects of serious weather events in and around critical field operations. The management characteristics include the application rates of nitrogen fertilizer (both commercial and that applied through manure[4]), as well as the years corn is in rotation and whether or not corn was on the land in the previous year. These variables are transformed into logarithmic form for use in estimating the translog functions.

The Regression Equations

To estimate nitrogen runoff and leaching, three equations are estimated. The equation for nitrogen runoff included all soils, with dummy variables to reflect the differences due to hydrologic group. For leaching, the results are substantially improved by estimating a separate equation for soils in hydrologic groups A and B and one for soils in group C. These runoff and leaching equations are estimated in a two-stage fashion. As is shown in Table 2, nitrogen runoff appears as an explanatory variable in both leaching equations.[5] The argument for this specification is that as there is more nitrogen runoff, there is less nitrogen left in the soil to leach.

The estimated equations are in Table 2, and they are encouraging, although the R^2 values are not as high as one would like. More is said about this below. However, the variables, and their various transformations all have standard errors that are small relative to coefficients, even after the standard errors are corrected for heteroskedasticity.[6] Based

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[4] In this analysis, commercial fertilizer application is combined with the nitrogen equivalent included in the various rates of manure application. There was some experimentation with separate variables for commercial nitrogen and manure, but these models did not perform as well as the ones where the sources of nitrogen were combined.

[5] To estimate the leaching equation, runoff appears as a quadratic in the list of regressors. Also, to purge the runoff variables from any unexplained random component, the predicted values from the runoff equation are used in the leaching equation. This is equivalent to an instrumental variable procedure (Judge *et al.*, 1988).

[6] According to the SPEC option in SAS, Chi-square test statistics for heteroskedasticity were calculated to be 229 for the runoff equation and 246 and 240 for the two leaching equations, indicating the presence of heteroskedastic errors in both. Since the coefficient estimates remain unbiased, the equations were not reestimated, but the standard errors were recalculated as the square root of the diagonal elements of the estimated asymptotic covariance matrix. Thus, these corrected standard errors are consistent (White, 1980).

Table 2. Regression Equations for Nitrogen Runoff and Leaching

	Runoff, All Soils			Leaching, A & B Soils			Leaching, C Soils		
Variable	Coef.	Std. Error	t-ratio	Coef.	Std. Error	t-ratio	Coef.	Std. Error	t-ratio
		R^2=0.49			R^2=0.51			R^2=0.35	
Constant	-4.930	0.64	-7.65	-89.416	9.49	-9.42	-54.723	14.56	-3.76
NITRUN				-7.456	1.69	-4.41	-12.740	6.80	-1.87
NITRUNSQ				1.755	1.15	1.52	3.432	2.82	1.22
LH1				5.657	0.77	7.32	4.378	1.81	2.42
LSLP				-1.577	0.42	-3.78	-0.701	0.27	-2.60
LSLPH1				0.455	0.17	2.66	0.203	0.09	2.17
LKAY	0.059	0.03	1.98	-7.776	1.01	-7.71	-5.571	1.42	-3.93
LKAYH1				2.318	0.34	6.81	2.017	0.54	3.71
LORG	3.231	0.34	9.61	7.274	1.34	5.41	1.897	2.28	0.83
LORGSQ	-1.035	0.12	-8.87						
LORGH1				-2.126	0.43	-4.99	-1.110	0.87	-1.27
LMINN	-0.586	0.09	-6.51	5.449	0.94	5.80	-1.067	1.90	-0.56
LRAIN	0.646	0.04	14.49	5.994	0.67	8.96	8.211	1.68	4.89
LPRSTM	0.047	0.01	5.53						
LPRSTMSQ	0.023	0.00	6.40	0.078	0.02	3.34	0.100	0.06	1.60
NITPRSTM				0.254	0.07	3.87	0.212	0.11	1.93
LFRSTM				0.122	0.03	3.62	-0.018	0.08	-0.24
LFRSTMSQ	0.008	0.00	6.09	0.113	0.05	2.20	0.103	0.03	3.27
LKGMAN	0.630	0.09	7.01	5.168	1.07	4.84	4.581	2.55	1.80
LROT				-0.620	0.14	-4.51	-0.411	0.18	-2.29
LAGCORN				-0.668	0.10	-6.45	-1.156	0.18	-6.47
LHRSTM				0.033	0.03	0.99	0.111	0.07	1.60
HYDA	-0.453	0.02	-27.65	0.266	0.10	2.56			
HYDB	-0.359	0.02	-20.62						
MANURE				0.242	0.14	1.67	0.104	0.29	0.36

Note: OLS coefficients; standard errors and t-ratios are corrected for heteroskedastic errors. Except for the dummy variables, the variables are logarithmic transformations of the variables in Table 1. In some cases, the variable represents a square of the logarithm (sq) or the product of two logarithms. NITRUN is the logarithm of estimated runoff from the runoff equations.

on these corrected standard errors, the t-ratios for the variables are all quite high. The signs of the coefficients on the variables are also as expected.

Because the reference soil in the regression for nitrogen runoff is for hydrologic group C, it is expected that the coefficients on the dummy variables for group A and group B soils would be negative. In the leaching equation for A and B soils, the dummy variable for A soils is positive, as one would expect. The signs on the coefficients for the lagged corn variable are negative in both leaching equations. That is, *ceteris paribus* (e.g. all other inputs such as commercial nitrogen and manure etc. held constant), if corn was grown on the land in the previous year, then leaching is reduced in the current year. This interpretation is logical because if this were not the case, nitrogen fixed from a previous year of a legume would also be available for leaching. To put it differently, it appears that nitrogen carryover available for leaching from the legume crop is greater than that from corn, *ceteris paribus*.

Since the marginal effects (and therefore the elasticities) of the other variables on runoff and leaching are not measured by the individual coefficients, it is much easier to discuss them in elasticity terms. The elasticities of leaching and runoff are calculated according to equation (4), and are reported in Table 3 for the minimum, maximum, and average values of each explanatory variable. Some of the elasticities are constant over the range in the data; in cases where the variable is included as a squared or interaction term, the elasticities vary.

Beginning with the runoff equation (Table 3), it is clear that most of the elasticities are of the appropriate sign. As one would expect, nitrogen runoff increases with increases in the rate of nitrogen application and annual precipitation. On soils under the same management practices, one might also expect nitrogen runoff to increase with the erosive nature of the soil, as measured by the K factor of the universal soil loss equation. The rate of nitrogen runoff is negatively related to the capacity of the soil to "mineralize" nitrogen. This also seems reasonable. Since none of these variables involve a squared or interaction term with other variables in the equation, the elasticities are constant throughout the range in each variable.

This is not the case for the other variables in the model, organic matter content and the two episodic rain variables. For organic matter, one might well expect that nitrogen runoff would decline as organic matter rises. This is indeed what happens once organic matter reaches somewhere between 4.7 and 5.4 %, but the relationship is positive for soils where the organic matter is lower than this level. Even though the relationship is a positive one for soils with low organic content, the elasticity declines monotonically throughout the range. The situation is exactly the reverse for the two episodic rain variables. Here, the elasticity is negative for very small levels of these variables, and this is an unexpected result. However, this particular result presents little difficulty when one recalls how these variables are defined. Since they represent cumulative rainfall in storms of 1.3 cm. (0.5 inches) or more in two-week periods following some field operation, the minimum value they can assume is 1.3. This is below the mean but above the range where

Table 3. Elasticities and Marginal Effects on Nitrogen Runoff and Leaching

	Runoff, all Soils			Leaching, A&B Soils			Leaching, C Soils		
Variable	Min.	Mean#	Max.	Min.	Mean#	Max.	Min.	Mean#	Max.
NITRUN				1.21	2.21	3.18	1.91	3.35	4.98
Elasticity				-7.01	-4.90	-3.63	-8.49	-4.64	-1.90
MP				-1334.99	-14.53	-1.58	-695.57	-5.88	-0.41
H1				6.00	11.65	40.00	5.00	14.86	40.00
Elasticity				0.19	0.19	0.19	0.47	0.47	0.47
MP				0.18	0.11	0.04	0.20	0.11	0.07
SLP				1.00	3.21	20.00	0.01	2.72	20.00
Elasticity				-0.46	-0.46	-0.46	-0.15	-0.15	-0.15
MP				-5.94	-1.08	-0.08	-155.08	-0.24	-0.02
KAY	0.17	0.28	0.49	0.24	0.28	0.49	0.17	0.29	0.49
Elasticity	0.06	0.06	0.06	-2.08	-2.08	-2.08	-0.13	-0.13	-0.13
MP	0.77	0.48	0.28	-58.84	-35.08	-5.35	-32.16	-14.25	-6.24
ORG	2.06	4.20	7.06	2.06	4.20	7.06	3.20	4.21	6.06
Elasticity	1.74	0.26	-0.82	2.05	2.05	2.05	-1.10	-1.10	-1.10
MP	0.99	0.14	-0.24	63.65	2.11	7.33	-34.96	-6.54	-4.18
MINN	56.04	79.12	89.66	56.04	79.87	84.06	56.04	78.22	89.66
Elasticity	-0.59	-0.59	-0.59	5.45	5.45	5.45	-1.07	-1.07	-1.07
MP	-0.03	-0.02	-0.01	0.03	0.37	0.53	-0.26	-0.46	-0.62
KGMAN	140.05	154.62	167.17	140.05	155.57	167.16	140.05	153.60	167.16
Elasticity	0.63	0.63	0.63	5.17	5.17	5.17	4.58	4.58	4.58
MP	0.01	0.01	0.01	0.15	0.17	0.19	1.08	0.98	0.91
ROT				1.00	4.90	7.00	1.00	4.05	7.00
Elasticity				-0.62	-0.62	-0.62	-0.41	-0.41	-0.41
MP				-11.61	-0.88	-0.50	-2.97	-0.41	-0.19
RAIN	49.90	97.22	134.29	49.88	96.00	134.28	49.88	98.74	134.28
Elasticity	0.65	0.65	0.65	5.99	5.99	5.99	8.21	8.21	8.21
MP	0.02	0.02	0.01	0.13	0.34	0.70	0.89	2.27	6.96
FRSTM	0.02	1.05	17.08	0.02	1.09	16.47	0.02	1.01	17.08
Elasticity	-0.06	0.00	0.05	-0.71	0.14	0.75	-0.77	-0.02	0.56
MP	-6.22	0.00	0.01	-177.98	0.48	0.41	-1649.68	-0.47	1.22
PRSTM	0.02	0.41	7.62	0.02	0.41	7.62	0.02	0.41	7.62
Elasticity	-0.12	0.01	0.14	-0.36	0.04	0.55	-0.56	0.08	0.60
MP	-11.65	0.04	0.05	-63.36	0.63	0.44	-737.69	3.80	2.09
HRSTM				0.02	1.76	23.83	0.02	1.45	23.83
Elasticity				0.03	0.03	0.03	0.11	0.11	0.11
MP				8.06	0.13	0.01	11.49	0.31	0.03

Note: Minimum, maximum and mean values for the variables may be slightly different from those in Table 1, because here they are calculated as the antilog of the logarithms of the minimum, maximum and mean values rounded to two places. MP is marginal effect.

either of these two elasticities is negative. That is, throughout the entire positive range of values that these two variables can assume, an increase in rainfall in storms of more than a half inch (1.27 cm.) of rain lead to greater nitrogen runoff. And, on a percentage basis, the effect increases with the level of accumulated rainfall.

In turning to the interpretation of the nitrate leaching equations, it is important to recall that nitrate leachate is determined in a two-stage fashion with nitrogen runoff. This two-stage hypothesis is supported by the negative elasticities of nitrogen leaching with respect to runoff (Table 3). Furthermore, these elasticities decline as the level of nitrogen runoff rises. These results are consistent with the negative elasticities of leaching with respect to slope and the K factor, both of which would be expected to be positively related to runoff. And, while slope did not perform well and was eliminated from the runoff equation, K is retained in both the leaching and runoff equations. Thus, the effect of the erosive nature of the soil, as measured by K, influences leaching indirectly through runoff and directly through the leaching equation itself. This direct and indirect linkage is also evident for most of the remaining variables in the leaching equation, with the exception of depth of the first soil horizon and the rotation variable.

For these remaining variables, the elasticities of leaching with respect to annual rainfall, and the episodic rainfall variables are positive,[7] as they are for the level of nitrogen application. Increases in the depth of the first soil horizon, in organic matter, and in the mineralizable nitrogen in the soil all contribute to higher levels of nitrogen leaching for soils in hydrologic groups A and B. The elasticities for organic matter and mineralizable nitrogen for soils in group C are unexpectedly negative, just one of several indications of the difficulty in estimating leaching on these heavy soils. Finally, holding all else constant, the more years out of 10 a soil can sustain corn production, the smaller is the amount of annual leaching of nitrogen applied likely to occur.

Predicting Nitrogen Runoff and Leaching Using the Regression Equations

The fact that most of the individual coefficients in the regression equations have the expected signs, as do the elasticities and marginal products, is particularly encouraging if one is only interested in the effects on runoff and leaching from marginal changes in these variables. These results do not guarantee that the equations will predict well for other soils. To develop a better idea of their predictive power, we calculated the relative error between the actual observations and their predicted values for important ranges in runoff and leaching. The runoff equation performed very well, with an average error of just over three percent for the whole sample of 1,361 data points.

The situation is quite different for the two leaching equations. For both leaching equations, the relative error across all 1,361 observations is extremely high (in the hundreds of percentage points). This result would be most disturbing and completely

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[7] The one exception is for the negative elasticity of low levels of FSTRM in the leaching equation for C soils. However, as in the case of runoff, the elasticity is positive for most valid values of this episodic rain variable.

unacceptable if it were not for the systematic nature of the large percentage errors. If one restricts attention to the 1,060 sample points where leachate is above two kg./ha., the relative error averages plus seven and minus 10 percent for the A&B soils and the C soils, respectively. Thus, the vast majority of the extremely large percentage errors occur at the lowest extremes of the distributions (where leaching is near zero). For the observations at the lower end of the distribution, it not unusual that the regression equations over predict leaching, and while the equations perform much better at the upper end, it is true that there is a slight systematic underestimation of leachate in the upper tail.

Regardless of these errors in prediction, these equations can be quite useful from a policy perspective. Large errors at leachate levels near zero are of little consequence because for policy purposes, one is primarily concerned with the size and shape of the upper tail of the distribution, and it is here where the nitrate leachate equation performs very well, although in this range the estimates are systematically biased downward slightly for all soils. Since this small bias is consistently in a downward direction, we are able to use the equations to predict leachate on soils for a sample of 160 farms in New York and rank them consistently relative to one another by second-degree stochastic dominance. It is to this task that we now turn.

The Risk Analysis

Some Theory

Normally in conducting a risk analysis for individual farms or for agricultural regions, it is assumed that the farmer's utility function (or some social utility function) depends on current or discounted income or some measure of wealth. In reality, however, we know that there are other arguments in the utility function, and it is reasonable to assume that one of these arguments is environmental quality. Since environmental quality is inversely related to the amount of nitrogen leaching and runoff (z), then it is reasonable to assume that $Y = -z$ is also an argument in the utility function. For a given income (I), utility, U, is given by: $U = u(Y|I)$, where $u'(Y|I) > 0$. This implies that as the quality of the environment (as measured by the negative of the amount of leaching) improves, utility improves as well. Under these assumptions, one can rank the 30-year distributions of leachate for the 160 farms mentioned above by the stochastic dominance criteria developed by Hadar and Russell (1969) and Hanoch and Levy (1969).

For first degree stochastic dominance (FSD), preferences are restricted to the set of utility functions where $u'(Y|I) > 0$. The ordering rule for FSD is: The alternative F dominates G if and only if $F(Y) \leq G(Y)$ with the strict equality holding for at least one value of Y, where F and G are the cumulative probability functions on Y for alternative farms or regions f and g. By ranking distributions in this fashion, FSD is consistent with decisionmakers who prefer higher environmental quality *ceteris paribus* to lower environmental quality.

While the concept of FSD is easily understood, it is unable to rank distributions whose cumulative distributions cross, but some of the alternatives can be eliminated by SSD, second degree stochastic dominance. To apply this criterion, decisionmakers must be risk averse in addition to preferring more to less. That is , $u'(Y|I) > 0$ and $u''(Y|I) < 0$. These two conditions imply that utility increases with an improvement in environmental quality, but at a decreasing rate. Under the application of SSD , alternative F is preferred to G if the area under the cumulative distribution function of F never exceeds that of G, and is somewhere less than the area under the cumulative distribution function of G (Bailey and Boisvert, 1991)[8].

Ranking Soils on New York Farms

In order to use the theory outlined above to rank soils on New York farms, we used a sample of farms across the state for which the cropland on the farms has been identified on a number of county soil maps. These farms are part of a much larger random sample of farms surveyed in 1987 to study energy use on farms in New York (Kelleher and Bills, 1989). Nearly 300 farms were mapped in this way, and in the final analysis, there were 160 farms with data usable for purposes here. In the year of the survey, 8,754 hectares of cropland on these farms were planted to corn. For this analysis, nitrogen leaching and runoff on the land in corn were simulated over the 30-year period for which there is weather data using the equations in Table 2. Soils 5 data were used to determine the soil characteristics, weather data were from typical weather stations in the general region of the farms, and nitrogen fertilization rates were determined from conversations with Stuart Klausner and information in Cornell Recommends (1992).[9] Thus, for an individual soil, any variation in nitrogen leaching over the 30 years is strictly due to differences in weather because soil characteristics and fertilizer levels are fixed. However, average leaching and runoff per hectare (weighted by the area of the various soils) in any given year varies across farms because of differences in soils and local weather conditions.

It is the 30-year distribution of average nitrogen leaching and runoff per hectare (weighted by the area of the various soils) for each of the 160 farms that is used to rank the leaching potential of the soils according to FSD and SSD.[10] The analysis involves

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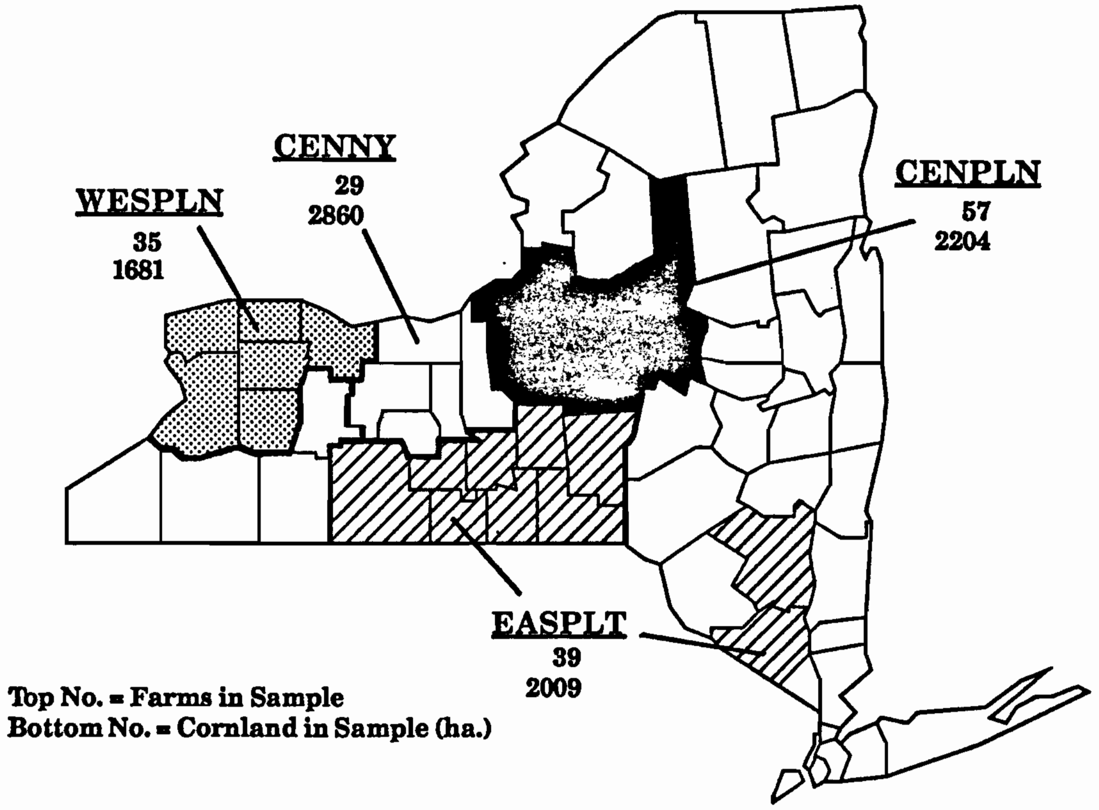
[8] Formally, the ordering rule for SSD is: *F* dominates *G* if and only if $F_2(Y) \leq G_2(Y)$ with the strict inequality for at least one value of Y, where $F_2(Y) = \int_0^Y F(t)dt$.

[9] Nitrogen application is given by NA = ((1.22 YP - SN - NP) / NE) - NM, where NA is nitrogen rates in lb./acre, YP is corn yield potential, SN is soil nitrogen, NE is nitrogen efficiency, NP is nitrogen from cover crops, and NM is nitrogen from organic manure. NA is converted to kg./ha. to be equivalent to KGMAN, the fertilizer variable needed to predict runoff and leaching from the equations in Table 2. Manure available was determined on the basis of the number of cows on the farm; application rates are assumed to be uniform across all soils on the farm. This is a necessary simplification of reality, but given the specification of the equations in Table 2, it is only the total nitrogen applied that is critical to the analysis.

[10] The ranking of the distributions of nitrate leachate is conducted using a FORTRAN program given in Anderson *et al.* (1977). Before the data for each of the 30-year distributions on nitrate leachate are

Figure 1. Four Farming Regions in New York State



ranking the combined leaching plus runoff distributions for each of the 160 farms, as well as ranking the weighted average per hectare leaching and runoff potential for all the soils aggregated into four regions (Figure 1). These regions generally follow the boundaries of some farm management regions used in Cornell Dairy Farm Business Summary (Smith *et al.*, 1994), although farms in several counties were shifted between regions so that for this analysis the four regions contained roughly the same amount of land. Within these regions, soils were also placed into four groups according to their corn yield potential to identify any systematic relationship between yield and leaching and runoff potential.[11] Table 4 contains summary information used to simulate leaching and runoff on the farms

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entered into the program, the observations are ranked from high to low, and are then multiplied by -1, translating $-z$ into Y.

[11] The four yield groups are: high is for yields greater than 135 bu./acre, m-high for yields between 125 and 135 bu./acre, m-low is for yields between 115 and 125 bu./acre, and low is for yields less than 115 bu./acre.

Table 4. Average Values of Variables Used in Nitrogen Leaching Simulations by Region

		Regions			
Variable		CENNY	CENPLN	EASPLT	WESPLN
Soil Characteristics:					
HYDA	Dummy for hydrologic soil group A*	0.02	0.07	0.21	0.07
		[0.01]	[0.08]	[0.11]	[0.08]
HYDB	Dummy for hydrologic soil group B*	0.70	0.71	0.37	0.31
		[0.66]	[0.48]	[0.14]	[0.43]
HYDC	Dummy for hydrologic soil group C*	0.28	0.22	0.42	0.62
		[0.32]	[0.44]	[0.75]	[0.48]
H1	Soil horizon depth (cm)	12.92	10.66	17.57	15.67
SLP	Average field slope (%)	5.27	7.34	6.51	4.83
MINN	Nitrogen mineralized by soil (kg/ha)	79.61	80.09	80.27	78.48
KAY	K erodibility factor	0.31	0.30	0.29	0.30
ORG	Organic Matter (%)	4.51	4.59	4.41	4.74
Weather Characteristics:					
PRECIP	Total annual rainfall (cm)	93.26	99.25	92.07	94.17
PRSTRM	Rainfall in storms w/in 14 days of planting (cm)	1.89	1.94	1.84	2.12
FRSTRM	Rainfall in storms w/in 14 days of fertilizer (cm)	3.23	2.97	2.81	3.59
Management Characteristics:					
KGMAN	Total fertilizer applications (kg/ha)	139.62	136.88	128.75	126.53
ROT	Years of corn in 10 year rotation	4.36	4.02	4.48	4.40
LAGCORN	Dummy, corn previous year	0.00	0.00	0.00	0.00

* The proportions of soils in the sample [the 1982 NRI] in each of the hydrologic groups.

in the four regions. Since average rainfall, recommended fertilizer application rates, and the proportions of group A land were all somewhat lower than for the soils used in the regression analysis, average leaching and runoff were somewhat lower as well. This is reflected in the leaching distributions contained in the figures below.

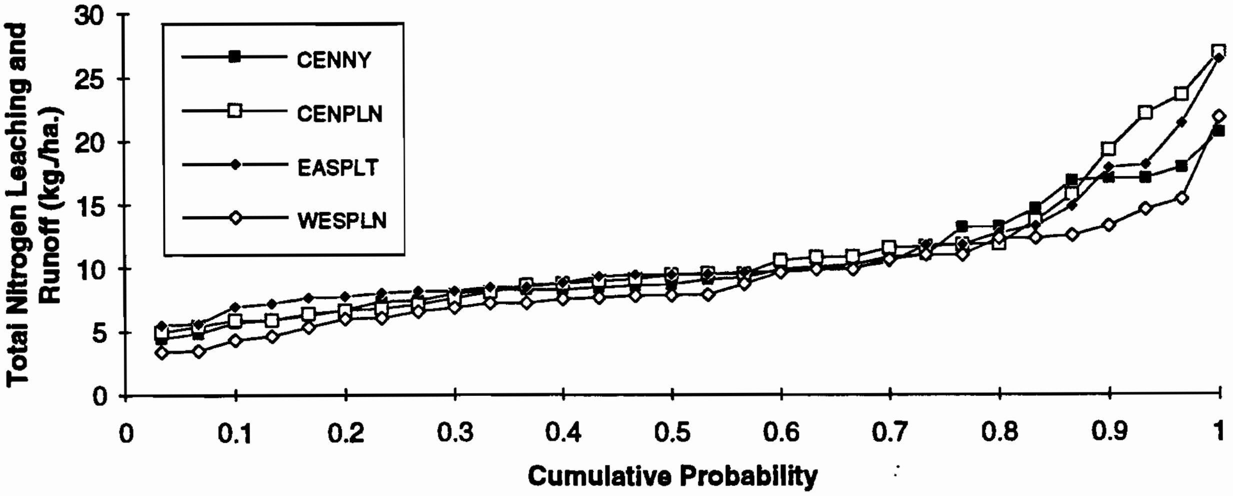
It is difficult to know if these distributions of soils from the sample of farms is representative of that found on all farms within the region. However, by looking only at the proportions of soils in the three hydrologic groups (Table 4), one might suspect that the proportion of cropland in hydrologic group A in the EASPLT Region is too large. Data from the 1982 National Resources Inventory (NRI) which estimates there to be only 11 percent of the cropland in hydrologic group A (compared with 21 percent for the sample) seems to reinforce this observation. By a similar comparison, the sample of the CENPLN soils seems to be weighted too heavily by Group B soils. The distributions of cropland by hydrologic group in the sample are much more consistent with the NRI data for the other two regions. If these relatively old NRI data are still more representative of soil distributions throughout the regions, there is a good chance that nitrogen leaching is overestimated for the EASPLT and CENPLN Regions. By the same token, the runoff is probably underestimated, but not one for one. It is difficult to know how the SSD ranking below would be affected if this sample of cropland were indeed more representative.

The results of the stochastic dominance analysis are quite interesting. Of the 160 farms, the average leaching potential for only three of them are SSD efficient. The situation is similar when farms within the regions are ranked among themselves. These results suggest that for the vast majority of farms across the state, cropland is so heterogeneous that ranking farms on any consistent basis in terms of the nitrogen leaching potential of the soils is nearly impossible. Thus, from a policy perspective, it is unlikely that prescriptions to reduce nitrogen leaching could be tailored specifically by general farm characteristics.

When the leaching and runoff potential of the soils on these farms is grouped into the four regions in Figure 1, the situation is somewhat different. That is, at the aggregate level, the leaching potential of the soils in the CENNY and WESPLN Regions dominate the leaching potential in the other two regions by both FSD and SSD. The advantage offered by soils in these regions due to their somewhat lower average leaching and runoff is seen in Figure 2, where the distributions generally lie below those for the CENPLN and EASPLT Regions.

Although the SSD ranking indicates differences in leaching and runoff potential by region, we would be more confident in the existence of this advantage if the dominant

Figure 2. Distribution of Nitrogen Leaching and Runoff In Four New York Regions



distributions nowhere crossed the other two distributions and were well below them. Consequently, the conclusion that the two regions are dominant is likely to be quite sensitive to our particular sample of soils, and the likelihood that the EASPLT region contains too large a proportion of group A soils. Therefore, it is difficult to argue on the basis of this evidence alone that the nitrogen leaching and runoff potential is sufficiently different to call for different policy strategies to reduce nitrogen leaching across regions in New York.

A much clearer ranking of soils by nitrogen leaching and runoff potential is found when the soils in each region are grouped into the four corn yield categories described above. By grouping soils in this way, it is clear that soils in the two lowest yield categories dominate the two highest yield categories by SSD. In CENNY, the low yield group dominates, while in CENPLN, it is the m-low yield group. For the other two regions, soils in both the m-low and low yield groups dominate. This is seen clearly in Figures 3 through 6, where the distributions of nitrogen leachate and runoff in these dominant groups lie strictly below the distributions for the dominated yield groups.

While this may not be a terribly surprising result because nitrogen application rates are higher for higher yielding soils, and these soils are predominately in hydrologic groups A and B, this analysis does provide a systematic way to highlight the tradeoff between crop yields and nitrogen leaching and runoff. Since the elasticity of runoff with respect to fertilizer application is constant across soils, an effective way to examine this tradeoff is to focus on nitrogen leaching.[12] That is, if one were to design policies to reduce nitrogen leaching from corn production, the primary focus would be on the highest yielding soils. This conclusion is reinforced by the information in Table 3. Comparing the elasticities of nitrogen leaching with respect to fertilizer application (KGMAN), it is clear that a one percent reduction in fertilizer on groups A and B soils leads to a larger reduction in leaching (5.2 percent) than it does on group C soils (4.6 percent).

A preliminary indication of the implications of this strategy for the tradeoff between nitrogen leaching and farm income can be derived from independent estimates of the corn yield response to fertilizer found in Thomas (1994). As one might expect, his data suggest that corn production on soils in groups A and B soils is more responsive to nitrogen fertilizer (from 0.58 to 0.53 in elasticity terms, respectively) than it is on group C soils (an elasticity of 0.43). Thus, even though a reduction in nitrogen on the more productive soils leads to a larger reduction in leaching, the effect on yield is higher as well. With no specific information on net returns from corn production across specific soils, it is impossible to know what this tradeoff implies for reductions in farm income.

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[12] Since the stochastic dominance results are essentially the same if one ranks the leaching distributions, rather than the combined leaching and runoff (see appendix tables), the conclusions regarding tradeoff between nitrogen leaching and yield probably hold for the combined distributions as well.

Figure 3. Distribution of Nitrogen Leaching and Runoff in Region CENNY by Corn Yield Category

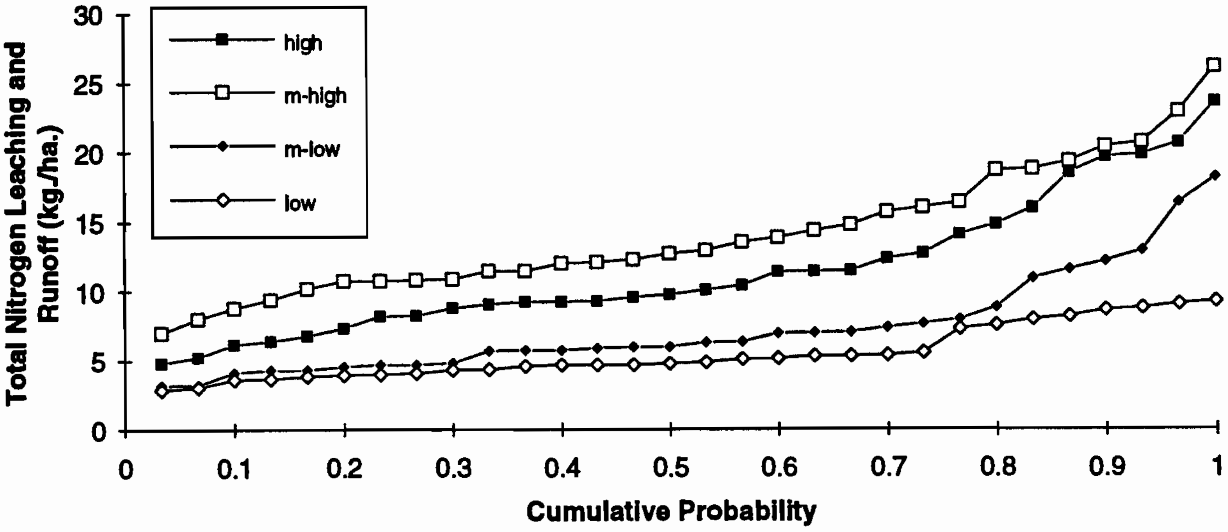


Figure 4. Distribution of Nitrogen Leaching and Runoff in Region CENPLN by Corn Yield Category

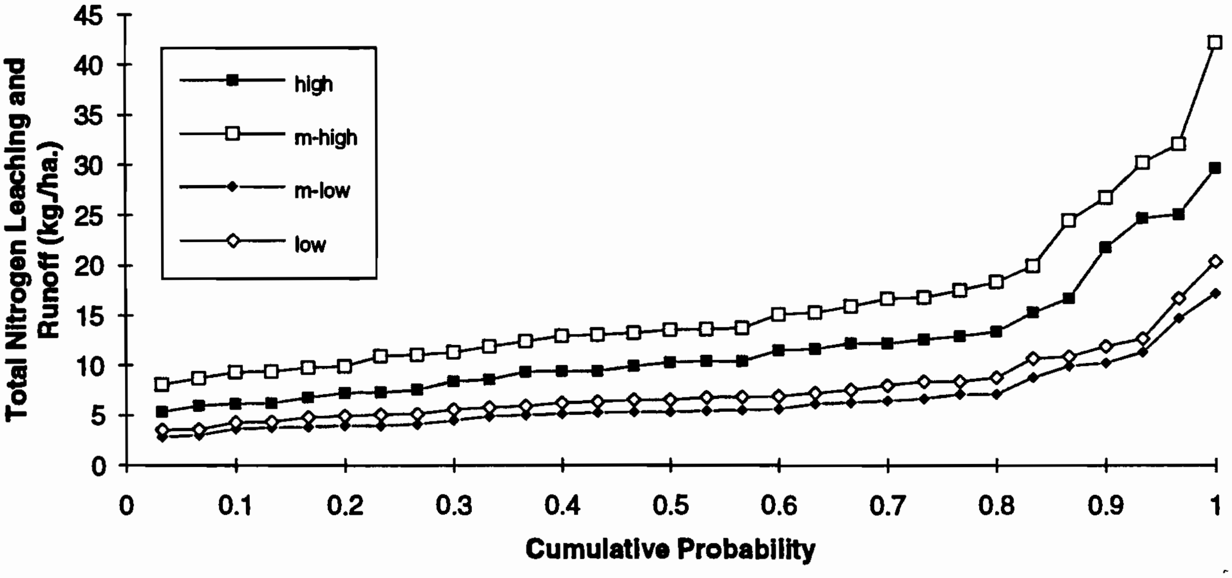


Figure 5. Distribution of Nitrogen Leaching and Runoff in Region EASPLT by Corn Yield Category

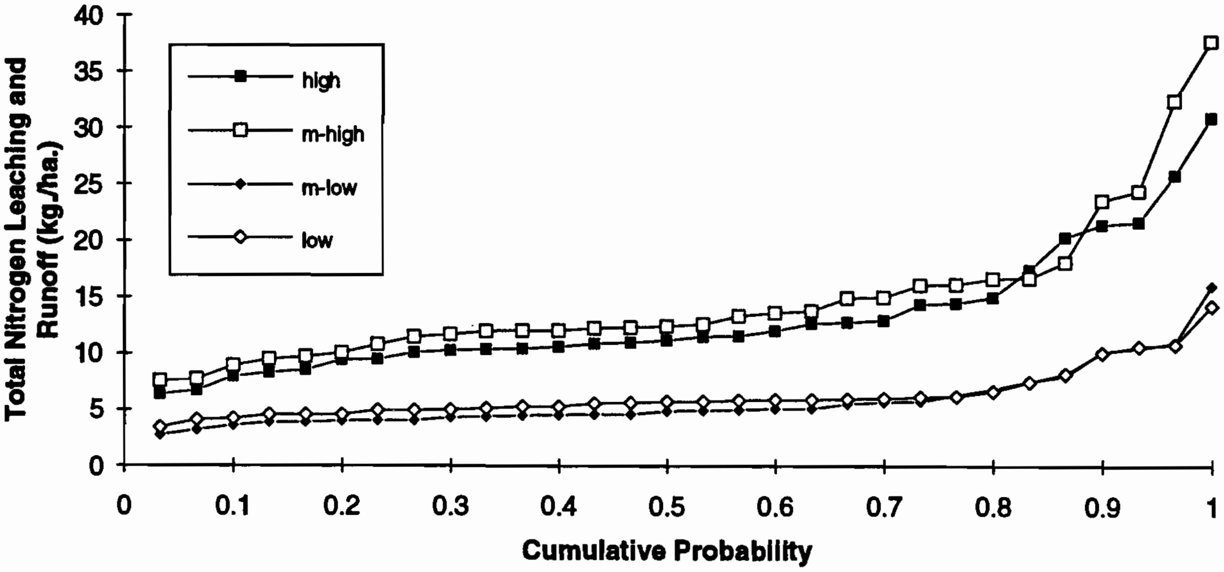
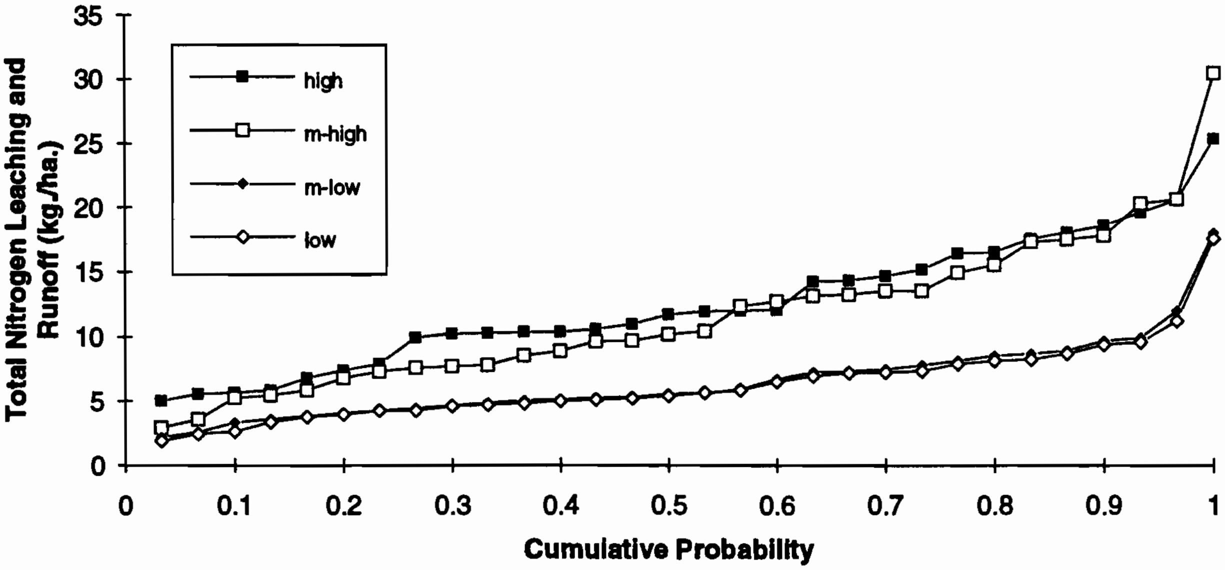


Figure 6. Distribution of Nitrogen Leaching and Runoff in Region WESPLN by Corn Yield Category



Summary and Implications for Further Research

Recognizing the difficulty in incorporating models that simulate the leaching and runoff of nitrogen for individual soils into economic models, this paper demonstrates that the output from a model like GLEAMS can be used to estimate econometric relationships that relate nitrogen leaching to weather, soil characteristics, and farm production practices. These econometric relationships performed quite well, and elasticities of leaching with respect to various weather variables, soil characteristics, and fertilization levels, for the most part are of the expected sign and of reasonable magnitudes.

This information alone is useful in examining the change at the margin in nitrogen leaching from changes in these variables. More importantly, when applied to soils with characteristics similar to those used in estimation, the equations are an effective way to estimate the distribution of nitrogen leaching over 30 years for corn production on 160 farms in New York for which detailed soils information is available. These are the types of consistent leaching and runoff distributions for many individual soils that are needed as input into chance constrained and other mathematical programming models of agricultural chemical runoff and leaching such as those used by Schmit (1994), Zhu *et al.* (1994), Segarra *et al.* (1985); and Young and Crowder (1986). Models of this kind are currently being developed for these New York farms as part of ongoing research.

For purposes here, however, the leaching and runoff distributions for the 160 farms are ranked by second-degree stochastic dominance to identify any policy implications that could be drawn from the variation in nitrogen leaching and runoff potential across farms or regions in New York. On the basis of these rankings alone, we argue that it would be difficult to be able to target policies designed to reduce nitrogen leaching to specific farms based on differences in their soils. The case for targeting certain regions is a bit stronger, but, in general, soils on New York farms are too heterogeneous for targeting policies.

This is not true, however, if we rank soils on the basis of productivity. Here, the less productive soils also appear to be the less leachable as well. Clearly, it appears that policies should be focused on the more productive soils, but more research is needed to identify the tradeoffs between nitrogen leaching and runoff, corn yields, and farm income across a wide range of soils. The work in this paper provides a foundation for this more extensive analysis, but estimates of the distributions over time in corn yields due to weather and other conditions are also needed to complete examination of this issue.

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APPENDIX

DISTRIBUTION OF NITROGEN LEACHING BY REGION

Figure A1. Distribution of Nitrogen Leaching in Four New York Regions

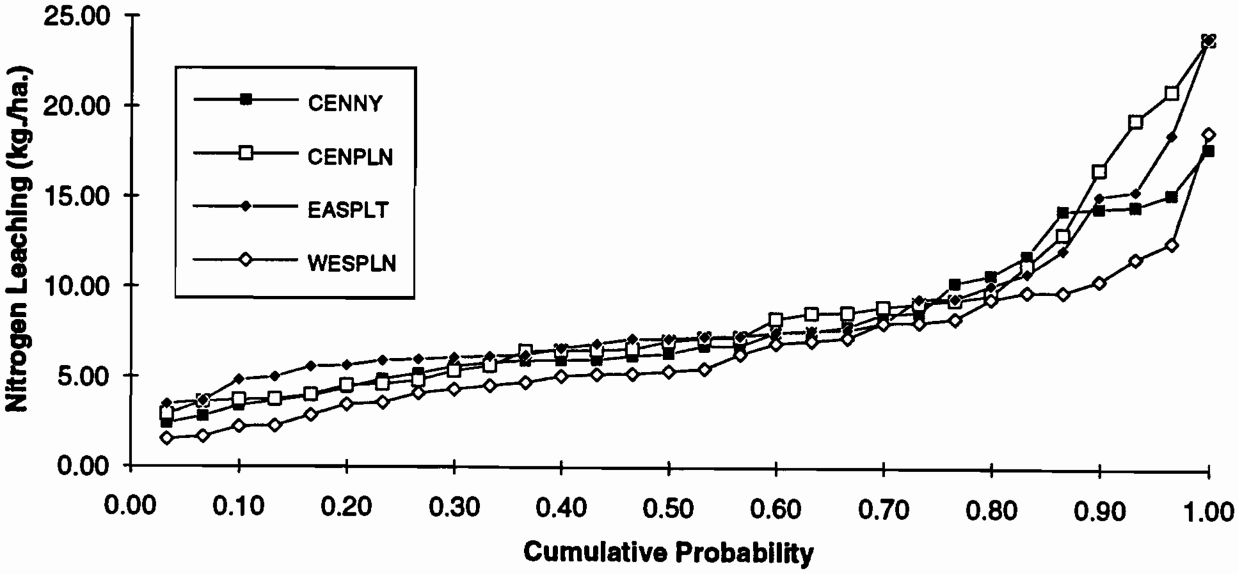


Figure A2. Distribution of Nitrogen Leaching in Region CENNY by Corn Yield Category

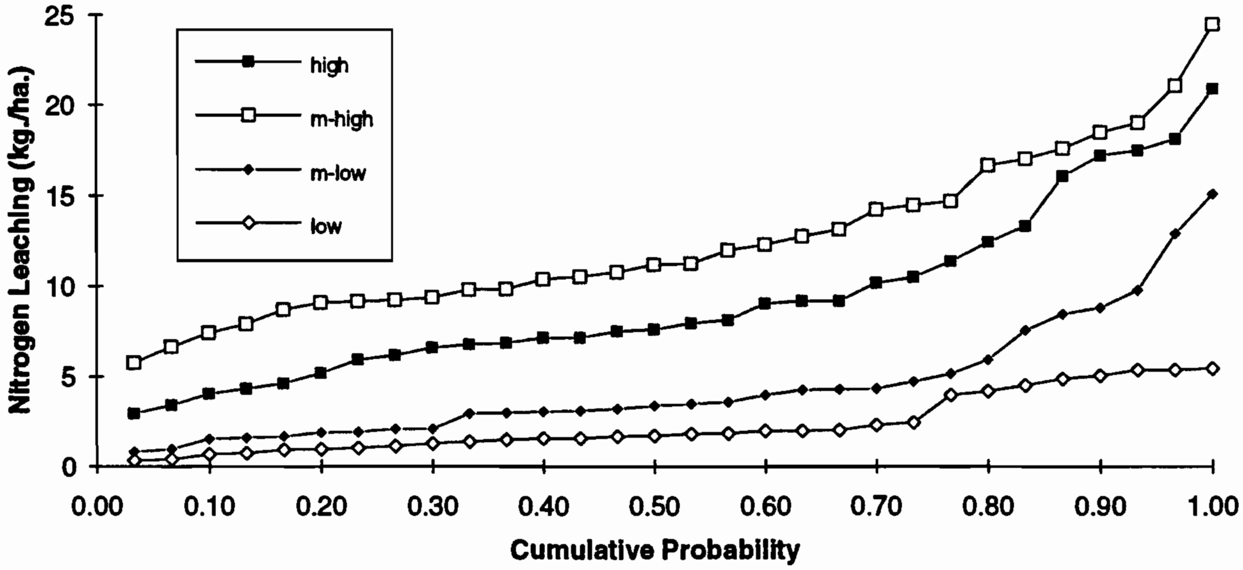


Figure A3. Distribution of Nitrogen Leaching in Region CENPLN by Corn Yield Category

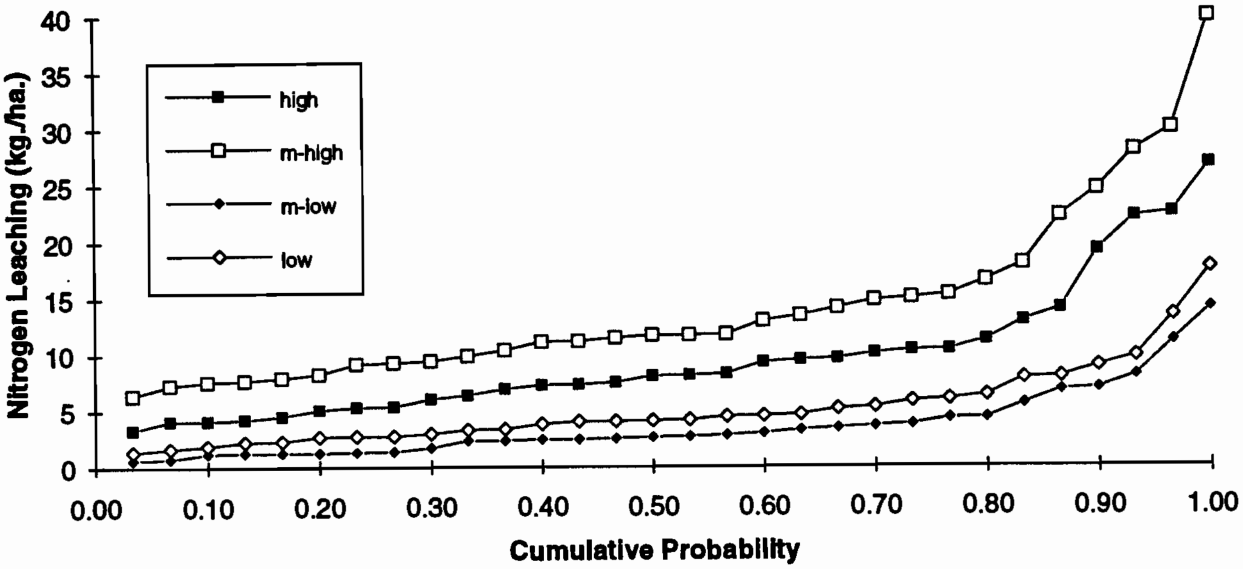


Figure A4. Distribution of Nitrogen Leaching in Region EASPLT by Corn Yield Category

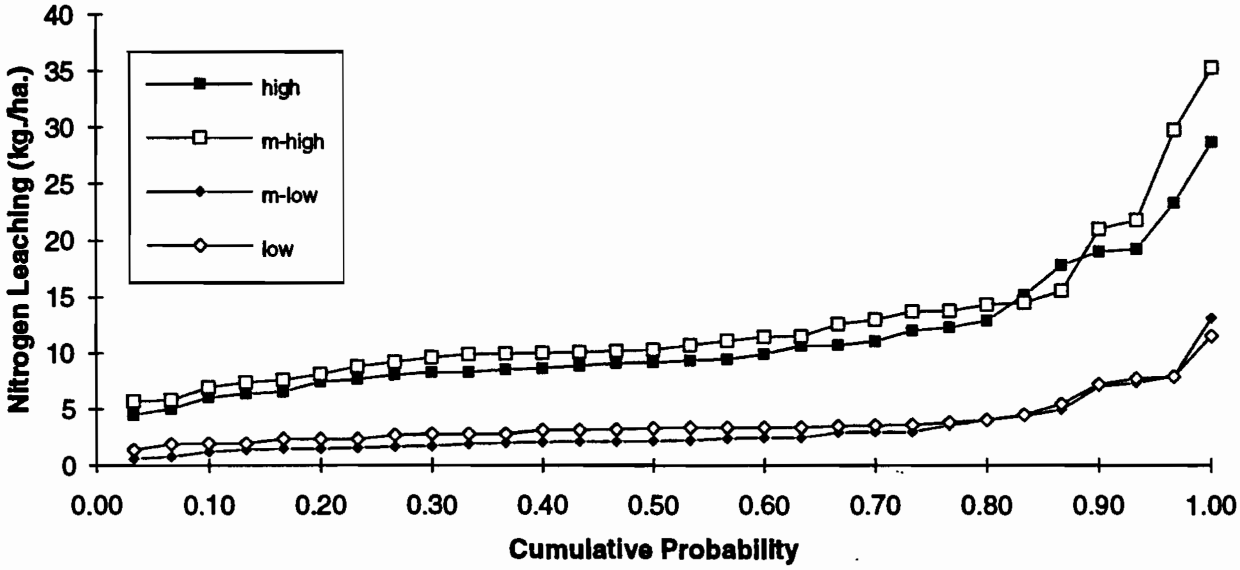
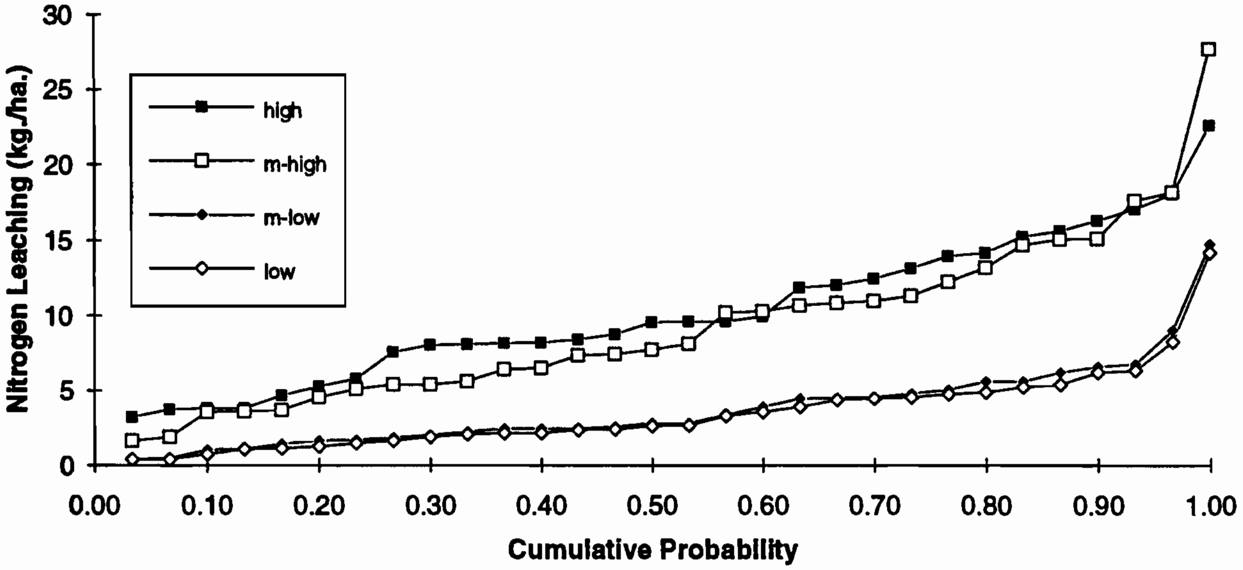


Figure A5. Distribution of Nitrogen Leaching In Region WESPLN by Corn Yield Category



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