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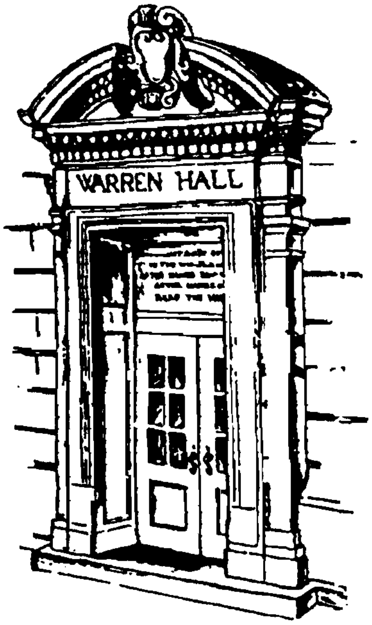

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Policy Implications of Ranking Distributions of Nitrate Runoff and Leaching by Farm, Region, and Soil Productivity

by

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ABSTRACT

The purpose of this study is to understand the implications of farm-to-farm and regional variations in nitrogen runoff and leaching for targeting specific policies to reduce nutrient contamination. To do this, we estimate 30-year distributions of nitrate runoff and leaching for individual soils on nearly 150 farms in three farm production regions of New York and rank the distributions according to second degree stochastic dominance criteria. Based on these rankings, it is evident that cropland across farms and regions of New York is so heterogeneous that it is impossible to target policies to reduce nitrate contamination based on farm or regional characteristics. A much clearer ranking is found if soils are grouped by productivity group as measured by corn yield. Based on the estimated elasticities of nitrate runoff and leaching with respect to nitrogen application, one can target those areas where contamination problems are most severe by focusing on soils with potential yields greater than 125 bu./ac. For it to make sense to target lower productivity soils, the productivity of additional nitrogen application at the margin on the highest yielding soils would have to be about double that of the lower yielding group. Evidence indicates that the ratios of productivities are less than unity in all three production regions.

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Introduction

In response to the increasing concern over the quality of our Nation's groundwater, soil scientists, agronomists, and others have designed numerous models such as the Ground Water Loading Effects of Agricultural Management Systems (GLEAMS) to simulate combinations of runoff and leaching potential of particular chemicals or nutrients for a specific soil, given specific field conditions, cropping practices, and weather conditions (Knisel, *et al.*, 1992; and Leonard, *et al.*, 1987). These types of models are valuable for a detailed assessment of conditions on a specific agricultural field for a given weather event. Economists often incorporate information from these models for representative soils into mathematical programming models to evaluate the effects of policies to restrict agricultural nutrient and chemical runoff and leaching (e.g. Schmit, 1994; Zhu *et al.*, 1994; Segarra *et al.*, 1985; and Young and Crowder, 1986).

Models such as GLEAMS have also provided the basis for screening procedures to evaluate the relative loss of pesticides and nutrients from soils in order to identify potential problem areas both nationally and at regional levels (e.g. Kellogg, *et al.*, 1992). One such screening procedure groups soil loss or pesticide loss into categories from high to low. After simulating losses for thousands of combinations of soil and pesticide parameters using

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GLEAMS, the screening procedures were formulated from stepwise regression procedures "...to select the soil or pesticide input parameters weighted most heavily for estimating each category of pesticide loss from the GLEAMS runs" (Goss and Wauchope, 1991, p 474). While useful in identifying potential problem areas, these screening procedures provide no quantitative estimates of contamination levels or the effects of contamination due to marginal changes in input levels or management practices. This additional information is essential for a systematic evaluation of specific policy alternatives, particularly in understanding the implications for policy designed to account for farm-to-farm and regional variation in soils and contamination potential.

The primary purpose of this paper is to understand the implications of farm-to-farm and regional variations in nitrogen runoff and leaching potential from growing corn in New York for targeting specific policies to reduce nutrient contamination from agricultural production. This study is possible in large measure because of the availability of a unique data set containing detailed soils data for a sample of nearly 150 farms in three regions of the State.

To accomplish this objective, we first obtain estimates of nitrogen runoff and leachate generated using GLEAMS, for a wide range of soils using different length corn rotations and fertilization rates. These data are used to estimate several equations that relate nitrate runoff and leaching from corn production to soil characteristics, weather, rotations, and fertilization. In turn, these equations are used in conjunction with weather data and the detailed soils information on the sample of farms to generate 30-year distributions of nitrate runoff and leachate by farm, by region, and by soil productivity group. The rankings of these distributions according to stochastic dominance criteria have important implications for targeting policies to limit nitrate contamination. In the final section, these policy implications are underscored by using the elasticities (percentage changes) in combined runoff and leaching with respect to a change in nitrogen application derived from the estimated equations to assess the differential effectiveness of reducing nitrogen application by region and soil productivity group.

Simulating Nitrate Runoff and Leaching Data Using GLEAMS

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) is a mathematical model developed for field-size areas to evaluate the effects of management systems on the movement of agricultural nutrients and chemicals through the plant root zone. It is capable of generating stormloads and average concentrations of sediment-associated and dissolved chemicals in the runoff, sediment, and percolate fractions. Its components (hydrology, erosion/sedimentation, and chemistry/pesticide) are described in detail by Knisel *et al.* (1981) and Leonard *et al.* (1987), along with a comparison with other models.

To generate the data used to estimate the runoff and leaching equations, GLEAMS was run using data from 105 New York soils reflecting a wide range of characteristics such as slope, organic matter content, etc., and productivity. Nitrogen runoff and leaching were then simulated over the 30 years for which there were weather data, assuming that corn was grown in recommended rotations with hay and small grains. Commercial fertilizer application rates were varied, as were application rates for manure. From these simulations the runoff and leaching estimates for each year of the simulations in which corn was grown were combined with data on weather and soil characteristics for the statistical estimation. There were 1,361 observations in the data set. Table 1 provides means, standard deviations, and ranges in soil characteristics, rainfall, and fertilizer on which the GLEAMS simulations are based.

Table 1. Descriptive Statistics for Soils Used in To Simulate Nitrate Runoff and Leaching

Variable		Mean	Standard Deviation	Minimum	Maximum
	Descriptive Statistics in level terms, not logs:				
RUNNO3N	Nitrogen runoff (lb/ac)	2.55	0.93	0.74	6.87
LCHNO3N	Nitrogen leaching (lb/ac)	10.77	11.15	0.00	73.01
Soil Characteristics:					
HYDA	Dummy for hydrologic soil group A[†]	0.20	0.40	0.00	1.00
HYDB	Dummy for hydrologic soil group B[†]	0.34	0.47	0.00	1.00
HYDC	Dummy for hydrologic soil group C[†]	0.46	0.50	0.00	1.00
H1	Soil horizon depth (in)	6.34	4.41	1.97	15.75
SLP	Average field slope (%)	4.65	4.55	0.01	20.00
MINN	Nitrogen mineralized by soil (lb/ac)	70.87	5.49	50.04	80.07
KAY	K erodibility factor	0.29	0.09	0.17	0.49
ORG	Organic Matter (%)	4.28	0.83	2.06	7.06
Weather Characteristics:					
PRECIP	Total annual rainfall (in)	39.47	6.62	19.95	53.71
PRSTRM	Rainfall in storms w/in 14 days of planting (in)[‡]	0.85	0.94	0.00	3.05
FRSTRM	Rainfall in storms w/in 14 days of fertilizer (in)[‡]	1.47	1.56	0.00	6.83
HRSTRM	Rainfall in storms w/in 14 days of harvest (in)[‡]	1.61	1.70	0.00	9.35
Management Characteristics:					
LBMAN	Total fertilizer application (lb/ac)[§]	138.53	10.86	125.05	149.27
ROT	Years of corn in 10 year rotation	4.91	1.68	1.00	7.00
LAGCORN	Dummy, corn previous year	0.52	0.50	0.00	1.00
MANURE	Dummy, manure application	0.56	0.50	0.00	1.00

[†] Means of these dummy variables essentially give the proportions of soils in these groups.

[‡] These variables reflect rainfall in storms of at least 0.5 inches.

[§] Includes nitrogen from manure. If manure was applied, it was at a 10 or 20 t/ac. Commercial nitrogen applications ranged from 55 to nearly 150 lb/ac.

It is difficult to know how reasonable these simulated runoff and leaching estimates are, and the estimates would certainly differ depending on which of several available simulation models were used. The average leaching of 10.8 lb/ac is about 60% of the levels generated using NLEAP (Follett *et al.*, 1991) by Thomas (1994) for seven New York soils. However, Thomas' soils were on average inherently more leachable and his average fertilization levels were about 20% higher. His estimates, based on yearly rainfall and not accounting for actual timing of significant storms, are likely to be higher than would otherwise be the case. Viewed in relative terms, the data in Table 1 suggest that 7.8% of the nitrogen applied is leached below the root zone, which is about midway between Thomas' estimate and the 2.1 % 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).[1]

The Runoff and Leaching Functions

To model nitrate runoff and leaching from the simulated GLEAMS results, it is necessary to find a functional form capable of capturing the relationships between the nitrate runoff and leaching estimates and the data on soil characteristics, weather, and cropping practices. Although the translog form has most often been used for modeling agricultural production functions at the firm or aggregate levels (Boisvert, 1982), it also has some distinct characteristics advantageous for modeling runoff and leaching. It can account for the interaction among soil characteristics, weather, and cropping practices; and it prevents estimates of runoff and leaching from being negative.

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[1] 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.

The function is given by:

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

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 i^{th} soil characteristic, weather variable, or cropping practice. 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:

$$(2)\ \frac{\partial z}{\partial X_i} = \left[\frac{\partial \ln z}{\partial \ln X_i}\right] \bullet \left[\frac{z}{X_i}\right] = (a_i + \sum b_{ij} \ln X_j)\left[\frac{z}{X_i}\right].$$

These marginal effects, measured as the percentage change in z for a one percent change in X_i, are given by the elasticities:

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

Both expressions depend on the levels of the explanatory variables X_j, and they 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 $\ln X_j > 0$ $(X_j > 1)$.

Empirical Results for the Response Relations

To estimate these translog functions for nitrogen runoff and leaching, three equations are specified. The equation for nitrogen runoff is based on data for all soils, with dummy variables to capture differences by hydrologic group. For leaching, there is one equation based on soils in hydrologic groups A and B and one for soils in group C. The estimated equations are in Table 2; the variables have standard errors that are small relative to the coefficients. This means that we

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=0.509			R^2=0.494			R^2=0.348	
Constant	-4.402	0.627	-7.017	-75.568	8.079	-9.353	-42.276	12.879	-3.282
NITRUN[‡]				-6.739	1.538	-4.380	-11.576	6.135	-1.887
NITRUNSQ				2.119	1.204	1.760	3.880	2.841	1.366
LH1				5.638	0.769	7.332	4.663	1.793	2.600
LSLP				-1.154	0.264	-4.373	-0.525	0.182	-2.881
LSLPH1				0.453	0.171	2.657	0.209	0.093	2.251
LKAY	0.058	0.028	2.088	-5.594	0.707	-7.911	-3.838	0.918	-4.180
LKAYH1				2.287	0.336	6.802	2.062	0.543	3.797
LORG	3.241	0.351	9.241	5.235	0.950	5.512	0.876	1.533	0.571
LORGSQ	-1.039	0.123	-8.474						
LORGH1				-2.127	0.425	-5.009	-1.259	0.861	-1.461
LMINN	-0.581	0.088	-6.601	5.442	0.937	5.810	-0.357	1.683	-0.212
LRAIN	0.652	0.043	15.269	5.768	0.619	9.325	7.593	1.462	5.192
LPRSTM	0.089	0.015	5.937						
LPRSTMSQ	0.023	0.004	6.474	0.056	0.017	3.338	0.068	0.047	1.435
NITPRSTM				0.363	0.097	3.746	0.280	0.168	1.668
LFRSTM				0.256	0.051	5.050	0.098	0.108	0.910
LFRSTMSQ	0.005	0.001	5.825	0.094	0.014	6.587	0.080	0.026	3.122
LLBMAN	0.628	0.089	7.048	4.824	1.009	4.780	3.916	2.364	1.656
LROT				-0.627	0.138	-4.554	-0.417	0.180	-2.318
LAGCORN				-0.668	0.103	-6.493	-1.167	0.178	-6.545
LHRSTM				0.039	0.033	1.177	0.116	0.070	1.649
HYDA	-0.453	0.020	-23.058	0.290	0.101	2.868			
HYDB	-0.359	0.016	-22.109						
MANURE[¶]				0.235	0.145	1.623	0.102	0.289	0.352

[†] Except for the dummy variables, the variables are logarithmic transformations of those in Table 1; some of the variables represent a square of the logarithm (sq) or the product of two logarithms. NITRUN is the logarithm of estimated runoff from the runoff equations.

[‡] Chi-square test statistics for heteroskedasticity were 229 for the runoff equation and 246 and 240 for the two leaching equations. Standard errors were recalculated as the square root of the diagonal elements of the estimated asymptotic covariance matrix. These standard errors are consistent (White, 1980).

[§] To purge the runoff variables from any unexplained random component, the predicted values from the runoff equation are used in the leaching equation (Judge *et al.*, 1988).

[¶] Commercial fertilizer application is combined with the nitrogen equivalent included in the various rates of manure application; any differential effect is captured through a dummy variable.

can have confidence in the magnitude of the individual coefficients, even though the R^2's are not as high as one would hope. More is said about this below.

To begin discussing the results, it is important to note that nitrogen runoff (NITRUN) appears as an explanatory variable in both leaching equations. The argument for this two-stage, or recursive, specification is that as there is more nitrogen runoff, there is less nitrogen left in the soil to leach. Because the reference soil in the regression for nitrogen runoff is for hydrologic group C, containing heavier soils with generally greater slope, the coefficients on the dummy variables for group A (HYDA) and group B (HYDB) soils are negative, indicating that runoff is lower for these soils. In the leaching equation for A and B soils, the dummy variable for the lighter, and generally flatter A soils is positive, indicating a greater amount of leaching. The signs on the coefficients for the lagged corn (LAGCORN) variable are negative in both leaching equations. Holding all other inputs such as commercial nitrogen, manure, etc. constant, if corn was grown on the land in the previous year, then leaching is reduced in the current year; one possible explanation is that nitrogen carryover available for leaching from the legume crop is greater than that from corn.

The Elasticities

To understand how the changes in other variables affect runoff and leaching, it is easiest to look at the elasticities in Table 3. Nitrogen runoff increases with both the rate of nitrogen application (LBMAN) and annual precipitation (RAIN). Nitrogen runoff also increases with the erosive nature of the soil, as measured by the K factor (KAY), but runoff is negatively related to the capacity of the soil to mineralize nitrogen (MINN).

Table 3. Elasticities of 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				1.10	1.97	2.84	1.70	2.99	4.46
Elasticity				-7.00	-4.52	-2.97	-7.94	-3.59	-0.48
H1				2.36	4.59	15.75	1.97	5.85	15.75
Elasticity				0.21	0.21	0.21	0.49	0.49	0.49
SLP				1.00	3.21	20.00	0.01	2.72	20.00
Elasticity				-0.46	-0.46	-0.46	-0.16	-0.16	-0.16
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	-2.11	-2.11	-2.11	-0.20	-0.20	-0.20
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	2.00	2.00	2.00	-1.35	-1.35	-1.35
MINN	50.04	70.64	80.07	50.04	71.32	75.07	50.04	69.85	80.07
Elasticity	-0.58	-0.58	-0.58	5.44	5.44	5.44	-0.36	-0.36	-0.36
LBMAN	125.05	138.10	149.27	125.05	138.92	149.27	125.05	137.16	149.27
Elasticity	0.63	0.63	0.63	4.82	4.82	4.82	3.92	3.92	3.92
ROT				1.00	4.90	7.00	1.00	4.05	7.00
Elasticity				-0.63	-0.63	-0.63	-0.42	-0.42	-0.42
RAIN	19.95	38.90	53.71	19.95	38.40	53.71	19.95	39.49	53.71
Elasticity	0.65	0.65	0.65	5.77	5.77	5.77	7.59	7.59	7.59
FRSTM[‡]	0.50	1.98	6.83	0.50	1.93	6.59	0.50	2.03	6.83
Elasticity	0.00	0.01	0.02	0.13	0.38	0.61	0.00	0.21	0.41
PRSTM[‡]	0.50	1.47	3.05	0.50	1.43	3.05	0.50	1.51	3.05
Elasticity	0.06	0.11	0.14	0.23	0.38	0.50	0.15	0.32	0.44
HRSTM[‡]				0.50	1.84	9.53	0.50	2.06	9.53
Elasticity				0.04	0.04	0.04	0.12	0.12	0.12

[†] The elasticity of runoff and leaching are calculated using equation (3) for the minimum, maximum and mean values of the variables. All other variables are at mean levels. 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.

[‡] Minimum episodic rain variables reflect minimum storm level requirement of 0.5 inches.

Nitrogen runoff declines as organic matter (ORG) rises 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 episodic rain variables represent cumulative rainfall in storms of 0.5 inches or more in two-week periods following some field operation. Both variables (FRSTM and PRSTM) indicate an increase in rainfall in storms of more than a half inch of rain leads to greater nitrogen runoff. On a percentage basis, the effect increases with the level of accumulated rainfall.

In turning to the nitrate leaching equations, the two-stage hypothesis is supported by the negative elasticities of nitrogen leaching with respect to runoff (Table 3). These elasticities decline as the level of nitrogen runoff rises. These results are consistent with the negative elasticities of leaching with respect to slope (SLP) and the K factor. While slope did not perform well and was eliminated from the runoff equation, K, and other important variables are retained in both runoff and leaching equations, thus affecting leaching both directly and indirectly.

The elasticities of leaching with respect to annual rainfall, and the episodic rainfall variables (FRSTM, PRSTM, and HRSTM) are positive, as they are for the level of nitrogen application. Increases in the depth of the first soil horizon (H1), 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 the heavier soils in group C, however, are negative.

Predicting Nitrogen Runoff and Leaching Using the Regression Equations

To use these equations in estimating the distributions of runoff and leaching on the soils in the sample of farms in New York, it is necessary to investigate the predictive ability of these equations. To do so, we calculated the relative error between the simulated runoff and leaching observations from GLEAMS used in estimating the equations in Table 2 and predicted values of runoff and leaching calculated by substituting the values of the explanatory variables for each observation into the estimated equations.

The runoff equation performs very well, with an average error of just over three percent for the entire sample. For both leaching equations, the relative error across all 1,361 observations is high. If, however, one restricts attention to the 1,060 sample points where leachate is above 1.8 lb/ac, the relative error averages plus seven and minus 10% for the A&B soils and the C soils, respectively. Thus, the vast majority of the extremely large percentage errors occur at the lower tails of the distributions. Larger errors in this range are of little consequence for policy purposes, because it is only at the upper tails of the distributions where leaching is highest that there is potentially an environmental problem. It is here where the nitrate leachate equations perform very well, although in this range the estimates are systematically biased downward slightly for all soils. Because of the systematic nature of this small bias, the ranking the distributions of nitrogen runoff and leaching on soils for our sample of farms in New York should be unaffected. Despite these good results, it would be inadvisable to apply these equations to soils whose characteristics are beyond the range of the data or where climatic conditions or geographic locations are distinctly different from those in the Northeast.

The Risk Analysis

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 income or some measure of wealth. In reality, however, we know there are other arguments in the utility function such as environmental quality. Since environmental quality is inversely related to the combined amount of nitrogen runoff and leaching (z), then if $Y = -z$ and I = income, then utility, U, is given by: $U = u(Y|I)$, where $u_y(Y|I) > 0$. This implies that as the quality of the environment improves (i.e. Y increases (z decreases) for a given level of income), utility improves as well. Under these conditions and by assuming given levels of income, one can rank the 30-year distributions of runoff and leachate for the 142 farms mentioned above by the stochastic dominance criteria developed by Hadar and Russell (1969).

For first degree stochastic dominance (FSD), preferences are restricted to the set of utility functions where $u_y(Y|I) > 0$. 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. FSD is consistent with decisionmakers (or a society) 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 also be risk averse. That is, the first and second derivatives of utility with respect to y are positive and negative, respectively(i.e., $u_y(Y|I) > 0$ and $u_{yy}(Y|I) < 0$). These two conditions imply that a farmer's utility increases with an improvement in environmental quality, but at a decreasing rate. Put differently, this means that the higher the intital level of environmental quality, the smaller is the increase in utility associated with any additional improvement in the quality of the environment. 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). 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 $F_2(Y) = \int_0^Y F(t)dt$.

Ranking Soils on New York Farms

To rank soils on New York farms, we used a sample of 142 farms across the state for which the cropland on the farms has been identified on a number of county soil maps. About 20,700 acres of cropland on these farms were planted to corn. Nitrogen runoff and leaching on the land in corn were estimated for the 30-year period using the equations in Table 2. Soils 5 data were used to determine the soil characteristics and weather data were from typical weather stations in the general region of the farms. Nitrogen fertilization rates for individual soils were based primarily on the formulas found in Cornell Recommends (1992), a publication distributed by the extension service, and the optimal rates determined from the corn yield/fertilizer response functions in Peterson and Boisvert (1996). Thus, for an individual soil, any variation in nitrogen leaching over the 30 years is strictly due to differences in weather. Average runoff and leaching per acre (weighted by the area of the various soils) in any given year vary across farms because of differences in soils and local weather conditions.

The analysis involves ranking the combined runoff and leaching distributions (using a FORTRAN program by Anderson *et al.*, 1977) for each of the 142 farms, as well as ranking the weighted average per acre runoff and leaching potential for all the soils aggregated into three regions (Figure 1).[2] These regions follow the boundaries of some farm management regions used in Cornell Dairy Farm Business Summary (Smith, *et al.*, 1992). Within regions, soils were also placed into two groups according to their corn yield potential to identify any systematic relationship between yield and runoff and leaching potential. The two yield groups are: high - greater than 125 bu/ac and low - less than 125 bu/ac.

It is difficult to know if these distributions of soils from the sample of farms are 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. The distributions of cropland by hydrologic group in the sample are much more consistent with the NRI data for the other two regions.

The Rankings

The results of the stochastic dominance analysis are quite interesting. Based on the combined average runoff and leaching potential, only three of the 142 farms are SSD efficient. The implication of this result is that cropland on farms across New York is so heterogeneous that ranking farms on any consistent basis in terms of the nitrogen runoff and leaching potential of the soils is nearly impossible. Therefore, from a policy perspective, it is unlikely that prescriptions to reduce nitrogen leaching could be tailored specifically by general farm characteristics.

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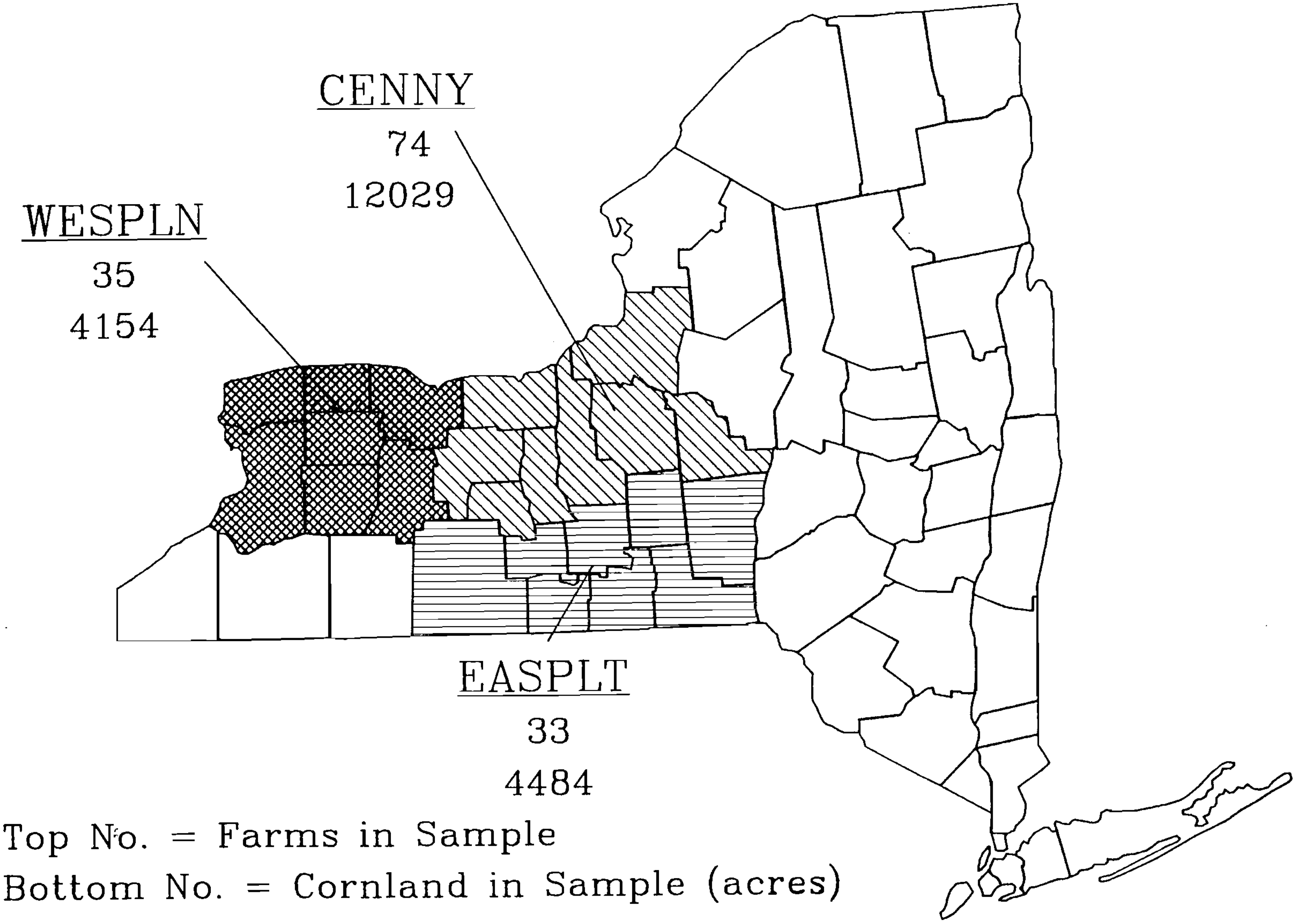
[2] Before the data for each of the 30-year distributions on nitrate runoff and leaching are entered into the program, the observations are ranked from high to low, and are then multiplied by -1, translating -z into Y.

Figure 1. Three Farming Regions in New York State



Top No. = Farms in Sample
Bottom No. = Cornland in Sample (acres)

Table 4. Average Values of Variables Used in Nitrate Loss Simulations by Region

Variable		CENNY	EASPLT	WESPLN
		Regions		
Soil Characteristics:				
HYDA	Dummy for hydrologic soil group A[†]	0.04	0.21	0.07
		[0.01]	[0.11]	[0.08]
HYDB	Dummy for hydrologic soil group B[†]	0.71	0.38	0.31
		[0.66]	[0.14]	[0.43]
HYDC	Dummy for hydrologic soil group C[†]	0.25	0.41	0.62
		[0.32]	[0.75]	[0.48]
H1	Soil horizon depth (in)	4.72	7.30	6.17
SLP	Average field slope (%)	6.09	6.51	4.83
MINN	Nitrogen mineralized by soil (lb/ac)	71.32	72.01	70.07
KAY	K erodibility factor	0.31	0.30	0.30
ORG	Organic Matter (%)	4.55	4.39	4.74
Weather Characteristics:				
PRECIP	Total annual rainfall (in)	37.69	36.16	37.08
PRSTRM	Rainfall in storms w/in 14 days of planting (in)	0.75	0.73	0.83
FRSTRM	Rainfall in storms w/in 14 days of fertilizer (in)	1.23	1.11	1.41
Management Characteristics:				
LBMAN	Total fertilizer applications (lb/ac)	142.60	132.89	129.92
ROT	Years of corn in 10 year rotation	4.24	4.48	4.40
LAGCORN	Dummy, corn previous year	0.00	0.00	0.00

[†] The proportions of soils in the sample [the 1982 National Resource Inventory] in each of the hydrologic groups.

When the runoff and leaching potential of the soils on these farms is grouped into the three regions (Figure 1), the situation is somewhat different. At the aggregate level, the runoff and leaching potential of the soils in the WESPLN Region dominates the runoff and 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 runoff and leaching is seen in Figure 2, where the distributions generally lie below those for the CENNY and EASPLT Regions. We would be more confident in the existence of this advantage if the dominant distribution were well below the other two. Consequently, the conclusion that the WESPLN Region is dominant appears quite sensitive to our particular sample of soils, and the likelihood that the EASPLT region contains too large a proportion of group A soils. It is difficult to argue on the basis of this evidence alone that the nitrogen runoff and leaching potential is sufficiently different to call for different policy strategies to reduce nitrogen leaching across regions in New York.

A much clearer ranking is found when the soils in each region are grouped by productivity as measured by corn yield. Soils in the lowest yield category dominate the soils in the highest yield categories by SSD in all three regions. This is seen clearly in Figures 3 through 5, where the distributions of nitrogen runoff and leachate in these dominant groups lie strictly below the distributions for the dominated yield groups.

Evaluating the Effects of Restricting Nitrogen Application

This SSD ranking by productivity group may not be a terribly surprising result because nitrogen application rates are higher for higher yielding soils. Since most of these soils are predominately in hydrologic groups A and B, the elasticities in Table 3 can be used to provide a

Figure 2. Distribution of Nitrate Runoff and Leaching in Three New York Regions

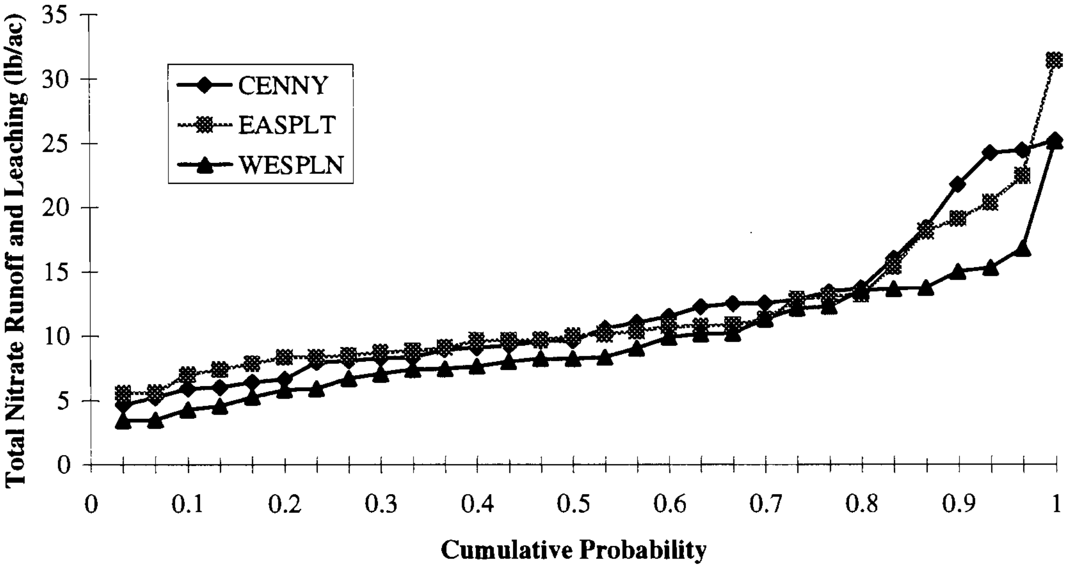


Figure 3. Distribution of Nitrate Runoff and Leaching in Region CENNY by Corn Yield Category

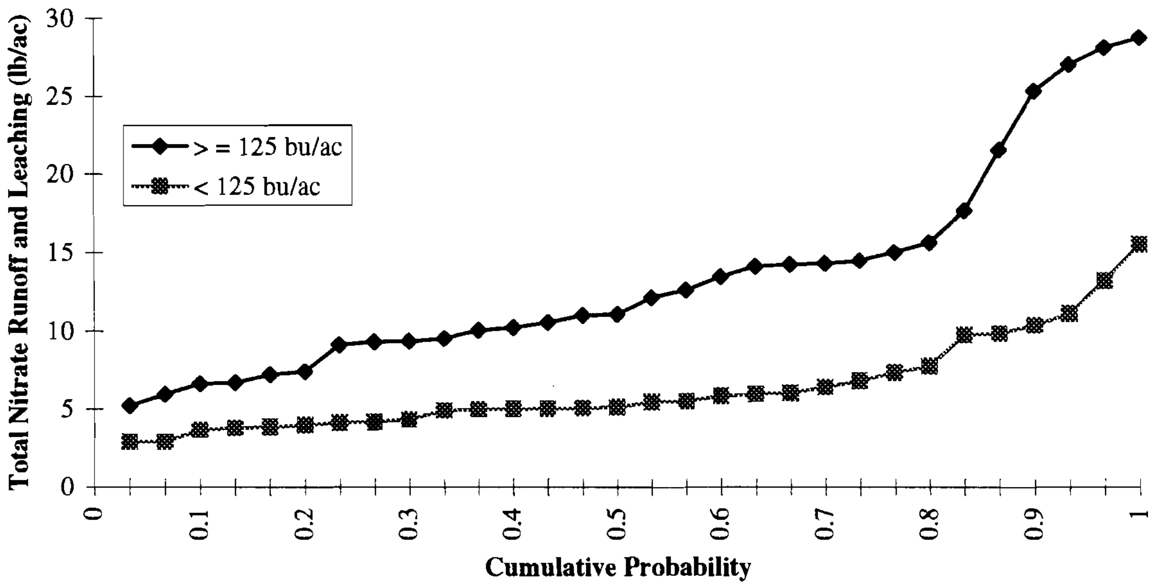


Figure 4. Distribution of Nitrate Runoff and Leaching in Region EASPLT by Corn Yield Category

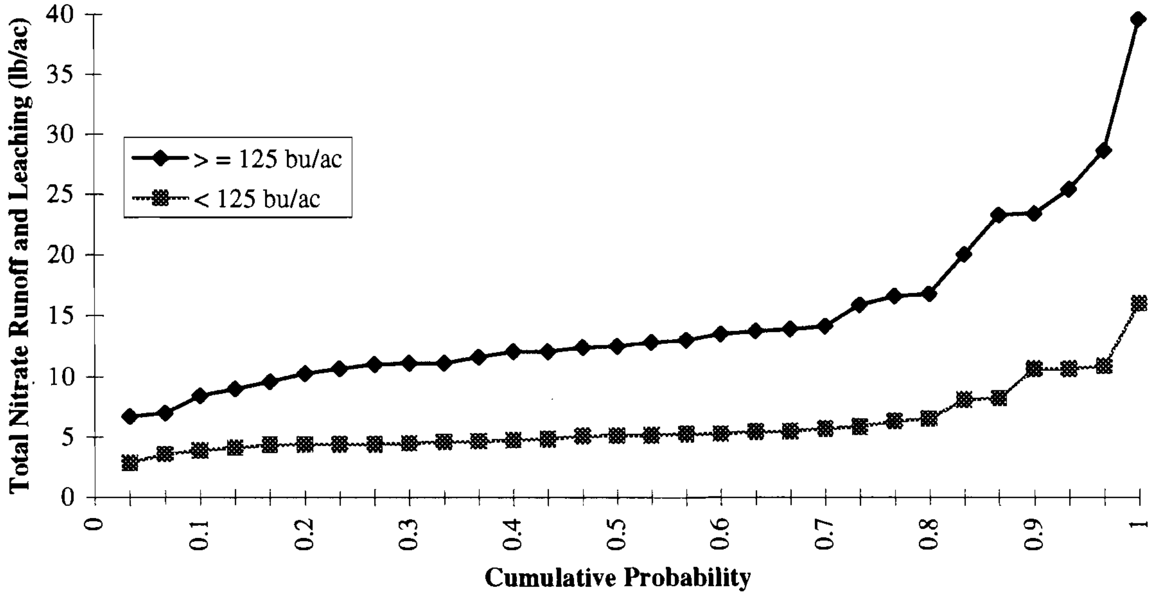
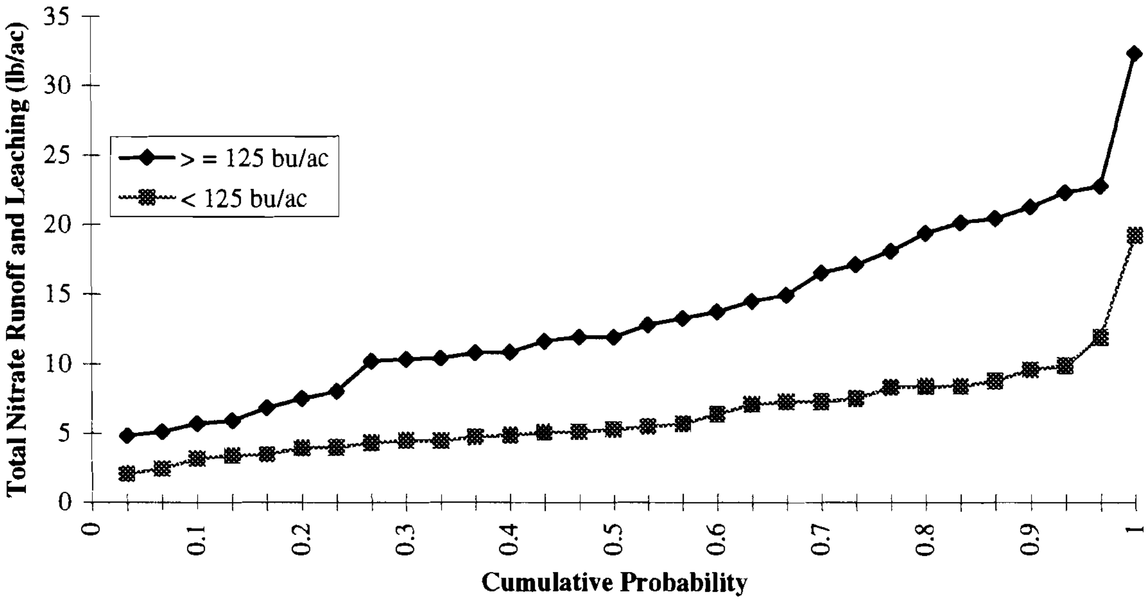


Figure 5. Distribution of Nitrate Runoff and Leaching in Region WESPLN by Corn Yield Category



systematic way to highlight the effect of changes in nitrogen applied and nitrogen runoff and leaching.

To do this, define $T = R + L$, where T is combined nitrate runoff (R) and leaching (L). By the application of Gardner's (1987) methods it is easy to show that by taking the total differential of T and rewriting it in elasticity terms, the elasticity of T with respect to nitrogen applied is $E_{TN} = S_R E_{RN} + S_L E_{LN}$, where S_R and S_L are the shares of R and L in T, and E_{RN} and E_{LN} are the elasticities of runoff and leaching with respect to N, nitrogen applied.

The latter two expressions can be derived from Table 3. The elasticity of R with respect of N is $E_{RN} = E_{R,LBMAN}$. The elasticity of L with respect to N differs by hydrologic group, and the recursive effect of R on L must be accounted for as well. In general this expression is $E_{LN} = E_{L,LBMAN} + E_{L,\,NITRUN} E_{RN}$. Finally, to obtain the percentage change in leaching for a region, one must take the sum of these elasticities, weighted by the proportion of soils in each hydrologic grouping, S_{AB} and S_C. Shares and elasticities by region are in Table 5.

The differences in the elasticities of combined runoff and leaching with respect to nitrogen application are striking. They are highest in the CENNY region; this is explained mostly by the fact that there is a higher percentage of soils in hydrologic groups A and B in this region. This means that policies to encourage a reduction in the application of nitrogen would be somewhat more effective in this region than in the others.

More important, however, is the fact that the elasticities are consistently, and substantially higher for soils where corn yield is above 125 bu/ac. In all three regions these elasticities are well above unity for soils in this group, indicating that as nitrogen application is reduced by one percent, combined runoff and leaching will fall by more than one percent. Since the elasticities

Table 5. Effects of Reducing Nitrogen Application on Nitrate Runoff and Leaching

	Shares of Total Nitrate Loss Due to		Shares of Land By Hydrologic Group			Elasticities of Nitrate Loss Due to N Applied							
Region	Runoff	Leaching	A	B	C	E_{RN}	$E_{L,LBMAN}^{AB}$	$E_{L,NITRUN}^{AB}$	$E_{L,LBMAN}^{C}$	$E_{L,NITRUN}^{C}$	E_{LN}^{AB}	E_{LN}^{C}	E_{TN}
						(Corn Yield > 125 bu/ac)							
CENNY	0.16	0.84	0.05	0.90	0.05	0.63	4.82	-4.25	3.92	-3.41	2.14	1.77	1.88
EASPLT	0.14	0.86	0.31	0.58	0.11	0.63	4.82	-4.58	3.92	-4.57	1.93	1.04	1.67
WESPLN	0.16	0.84	0.16	0.64	0.20	0.63	4.82	-4.40	3.92	-4.30	2.05	1.21	1.68
						(Corn Yield < 125 bu/ac)							
CENNY	0.44	0.56	0.03	0.07	0.90	0.63	4.82	-4.53	3.92	-3.99	1.97	1.41	1.10
EASPLT	0.42	0.58	0.02	0.01	0.97	0.63	4.82	-5.93	3.92	-4.94	1.08	0.81	0.74
WESPLN	0.42	0.58	0.01	0.04	0.95	0.63	4.82	-4.50	3.92	-4.51	1.99	1.08	0.92

for the less productive soils are all below unity, runoff and leaching fall less than in proportion to the reduction in nitrogen application.

From a policy perspective, this result reinforces the conclusion based on the rankings above. That is, by focusing on soils in the highest productivity group, one can target those areas where the potential problems are most severe while at the same time achieving the largest reduction in contamination relative to a given reduction in the use of nitrogen fertilizer. In terms of the policy's effect on agricultural income, the only way it would make sense to target the other soil group is if the ratios of the elasticities of net return with respect to nitrogen application between the high and the low groups were greater than the ratio of the two runoff and leaching elasticities. For this to be true for these regions, the productivity of nitrogen at the margin on the highest yielding soils would have to be between 1.7 and 2.3 times those of the low yielding soils. Based on the yield/nitrogen response relations in Peterson and Boisvert (1996) these ratios of nitrogen productivity between high and low yielding soils are well below unity, averaging 0.68 and ranging between 0.62 and 0.75. Thus, even when differences in soil productivity are accounted for, policies to reduce nitrate contamination should still be targeted towards the higher yielding soils.

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