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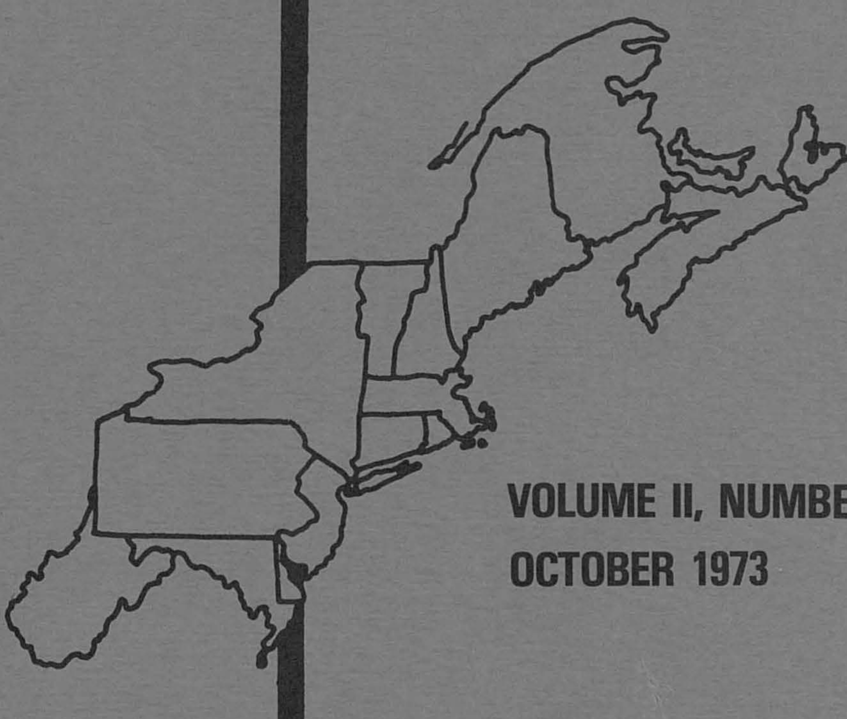

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AN ANALYSIS OF OPTIMUM USE WITH MINIMUM POTENTIAL LOSS OF NITROGEN FERTILIZER ON CORN

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A major environmental problem is the loss of recreational and asthetic values for bodies of water resulting from accelerated eutrophication. 1/ Eutrophication is only part of the concern over increased nitrate levels. More important, several streams have been found to have nitrate concentrations above U. S. Public Health Service Drinking Water Standards of 45 mg/l. [6] Given agriculture's use of nutrients, agriculture's contribution to the nitrogen and phosphorus content of water needs to be evaluated.

Study Objectives

It is alleged that increased fertilizer use has measurably increased the nitrogen content of surface and subsurface waters. While a general association exists, there is insufficient data and information on the fate of inorganic nitrogen compounds to provide valid estimates of nitrogen transfer from fertilizer to ground and surface waters [4, 13, 7]. The difficulty in obtaining such estimates is a direct result of the highly complex behavior of nitrogen in soil. Besides the application of fertilizer nitrogen, consideration must be given to soil organic matter and its rate of mineralization, fixation of atmospheric nitrogen, nitrogen in rainfall, crop utilization of nitrogen, assimulation of nitrogen by micro-organisms, leaching of nitrogen and denitrification. Even if a relationship between the transfer of nitrogen from fertilizer use to ground and surface waters could be determined, one is still faced with the questions of (1) the influence of the nutrient on other uses of that water and (2) the relative importance of fertilizer to the other sources of nitrogen.

Considering the solubility of nitrogen, suggested alternatives for reducing nitrate losses associated with fertilizer use are:

1. Development of fertilizer having a slower release of nutrients to enable more complete utilization of nutrients by the plant.

1/ Eutrophication is a natural process whereby solids and nutrients are accumulated in a body of water. This process makes the lake shallower and increases its nutrient content thereby increasing the total biological productivity of that body of water.

2. Timing the application of fertilizer nitrogen to correspond with the period of maximum uptake by the crop.

3. Adjust the quantity of fertilizer nitrogen applied to match the ability of the crop to take up the nitrogen.

4. Maintain an actively growing crop on the land as much of the time as possible.

5. Reduce the amount of nitrogen fertilizer used.

This paper concentrates on the alternative of timing nitrogen applications to that period when uptake by the crop is at maximum. The objective is to evaluate the effects of spring plow down and summer sidedress applications of nitrogen fertilizer on corn. Specifically, this study stresses the economic implications of the method 2/ of nitrogen application on corn by determining the optimum level of nitrogen use for the alternative methods of application, the related pollution potential for specified levels of nitrogen, the return over nitrogen cost for specified levels of nitrogen, and the price of fertilizer which would limit fertilizer use to 100 lbs/ac.

Data Sources

The economist in developing optimizing models for evaluating actual or proposed policies is frequently hard pressed to obtain the needed coefficients. Part of the problem lies in the range of coefficients that are usually needed. All to frequently plant scientists fail to devise experiments with gradient input levels that will be useful for later economic analysis. For example, in developing yield response data for nitrogen fertilizer the gradient input levels of nitrogen are frequently too far apart, particularly at the higher levels of nitrogen application. The method of determining the alternative levels of nitrogen appears to be to double the preceding level. Thus, the levels of nitrogen may be 30, 60, 120 and 240 pounds. These levels of nitrogen, particularly between 120 and 240, omit the probable decision points on the amount of nitrogen used. Therefore, from the economist's viewpoint, a few less replicates and an increase in the gradient input levels of fertilizer would be useful.

Another segment of the data problem concerns our rapidly changing technology. For example, yield response data to nitrogen fertilizer looks vastly different today than 10 to 15 years ago. Even if the same magnitude of fertilizer was used today, the yield response would be different because of the different mixes of pesticides, hybrid corn, machinery input and timing sequence. Therefore, to keep input-output relationships known within the frame of current technology requires on-going projects so that these relationships are valid for present economic analysis. Because of these problems, relevant input-output relationships even for highly researched subjects,

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2/ In this paper, the method of nitrogen application refers to fall, spring and summer applications of nitrogen.

such as nitrogen input and corn output, are difficult to obtain.

Five studies, four non-irrigated and one irrigated, were found in the literature relating to method of nitrogen application, i.e., fall, spring, summer sidedress, and different nitrate input levels with corn yield [16,14,11,8,10]. The five studies or sets of data are referred to as the Aurora, Herendeen, DeKalb, Nebraska and Ontario data.

Estimation of Production Functions

Data obtained from these five studies were used to estimate production functions for corn. In estimating these functions, the primary objective was to determine the impact of method of application, for given levels of nitrogen application, upon corn yield. The model, however, is complicated by the fact that data were taken over a number of years and from a number of different locations. This means the data re influenced by the weather for the different years and soil differences for the different locations, each of which affect the coefficients obtained by regression analysis. The objective is to determine the effect of the method of application on yield net of the location effects.

There are two general alternatives in using regression analysis to estimate functions where there are class differences such as the locations and method of application effects encountered in this data. One is to estimate separate equations for each group of observations. A second alternative is to use dummy variables in a single regression equation (covariance models) to allow for differences among classes while using all of the observations. 3/

The problem of analyzing location and method of application effects from the set of data may be stated in the following way. The observations are on nitrogen and yield for I locations (i = 1,..I). The location classes are to account for the soil differences discussed earlier, which may affect both the intercept and slope coefficients of the nitrogen-yield function. The impact of the method of application on yield, for a given location, affects only the slope coefficients; the yield must be identical for both "methods of application" when no nitrogen is applied.

The general model is:

$$(BU/A)_{ij} = \alpha_o + \alpha_i + \beta_j + \gamma_{ij} X_{ij} + \delta_{ij} X_{ij} + \lambda_{ij} X^2_{ij} \quad (1)^{4/}$$

$$+ {}_{ij}$$

where

BU/A = yield, bushels per acre

3/ For a review of the use of dummy variables and their application in agricultural economics, see Tomek [15] or Ben-David and Tomek [3].

4/ Searle [12, p. 360] defines the model used.

X = nitrogen application, lb. per acre,

α_i = parameters of the location effects,

β_j = parameters of the method of application.

γ_{ij} = parameters of interaction of location and application method,

$\delta_{ij}, \lambda_{ij}$ = parameters of nitrogen variables, which change with location and application.

i = 1, 2, ... I location effects

j = 1, 2 application effects (sidedress or spring application)

e_{ij} = error term of model.

Based on the logic outlined above, we specify $\beta_j = 0$. Thus, the equations estimated have zero-one dummies to estimate the α_i, and slope dummies are used to permit changes in the slope parameters. Because of the large number of observations and locations, particularly for the Herendeen and Nebraska data, separate equations were estimated for the methods of application to simplify the model. Thus, the parameters of nitrogen variables which change with application method and the parameters of interaction for location and application method are not needed in the actual model used.

The Herendeen data are used to illustrate how the dummy variables for locations were used in the estimation of production functions for the method of application. The equation estimated is:

$$(BU/A)_j = \alpha_0 + \sum_{i=1}^{12} \alpha_i L_{ij} + \delta_0 X_j + \sum_{i=1}^{12} \delta_i L_{ij} + \lambda_0 X_j^2 + \sum_{i=1}^{12} \lambda_i L_{ij}^2 + e_j \qquad (2)^{5/}$$

where j = (1,...,13) locations,

i = (1,...,12) an index to define the dummies.

$I_{ij} = \begin{cases} 1 \text{ when } i=j \\ 0 \text{ otherwise} \end{cases}$ intercept dummies for location

$L_{ij} = I_{ij}X$, slope dummies for location

$L_{ij}^2 = I_{ij}X^2$, slope dummies for location

BU/A and X defined in (1).

The above equation can be interpreted as a regression of bushels per acre on nitrogen fertilizer with the intercept and slope varying from class to class.

5/ To get away from linear dependency in the matrix of observations of independent variables, some restriction must be placed on α_i, δ_i and λ_i associated with the dummy variables. For a detailed explanation of these possible restrictions see references [15 or 3].

Under this model, the intercept for all thirteen location classes is:

$$a_0 + \frac{1}{13}(a_1 + a_2 + \ldots a_{12}).$$ 6/ Similarly, the slope coefficients for X and X^2 for all location classes are:

$$\delta_0 + \frac{1}{13}(\delta_1, \delta_2 + \ldots + \delta_{12}) \text{ and } \lambda_0 + \frac{1}{13}(\lambda_1 + \lambda_2 + \ldots + \lambda_{12}).$$

These represent intercept and slope coefficients for spring application of nitrogen for the Herendeen data. Therefore, the regression equation for the spring application of nitrogen is equal to the intercept plus the slope plus the squared term for nitrogen applied. The estimated coefficients for spring and sidedress applications of nitrogen are presented in the Appendix, Table 4. The regression equation for spring application of nitrogen taken from Table 4, is:

$$BU/A = 72.9 + .457X - .00177X^2. \qquad (3)$$

A similar approach was used in estimating equations for spring and sidedress applications of nitrogen for each of the five sets of data. 7/ A summary of the estimated regression coefficients for the alternative times of nitrogen application (spring and sidedress) for the five sets of data are presented in Appendix Table 4. 8/

Having estimated production equations for the various times of nitrogen application, the optimum level of nitrogen application can be computed for each data set for a given combination of corn and fertilizer prices. As an example, consider the spring production equation estimated from the Herendeen data and solve for the optimum level of nitrogen application with the price of corn at a $1.50 per bushel and the price of nitrogen at $.10 per pound. The marginal product of nitrogen application is the first derivative of equation (3).

$$\frac{d\ BU/A}{dX} = .457 - .00354X \qquad (4)$$

Taking this additional yield per acre per pound of nitrogen fertilizer and setting it equal to the price ratio of nitrogen and corn one obtains the level of fertilizer at which the additional return per pound of fertilizer will equal the additional cost.

6/ As stated in a footnote 5, equation 2, the general model cannot be estimated directly. The restriction to allow this estimation is to set $a_{13} = 0$, then a_0 represents the intercept for class 13. That is, the class effect of a_{13} set = 0 appears in the constant term.

7/ For DeKalb and Nebraska, an equation for fall application of nitrogen was also established but not reported, since these locations included a fall application of nitrogen in addition to the spring and sidedress application.

8/ These regression equations for the method of nitrogen application give an estimate of yield for various levels of nitrogen, with phosphorus and potassium at a constant level.

$$(.457 - .00354X) = \frac{\$.10}{\$1.50} \qquad (5)$$

$$X = 110$$

This suggests that the optimum level of spring application of nitrogen, for the given production function and prices of corn and nitrogen, is approximately 110 pounds per acre.

Similar analysis can be used to determine the price of fertilizer needed to restrict fertilizer use to a given level. For example, let's assume that we want to limit the level of nitrogen applied to 100 pounds per acre for the spring application. Using equation five above, the price of fertilizer which would limit use to 100 lb/ac. is obtained as follows:

$$(.457 - .00354{*}100) \quad \$1.50 = p_f \qquad (6)$$

$$p_f = 15 \text{ cents.}$$

Given the price of corn, assuming farmers are profit maximizers and are operating on the production function estimated from the Herendeen data, then the price of fertilizer would have to be approximately 15 cents per pounds to limit use to 100 pounds per acre.

An analogous procedure was used to solve for the optimum levels of nitrogen and the price of fertilizer required to restrict nitrogen use to 100 pounds for each of the alternative methods of application for each of the five sets of data. Two prices for corn and for fertilizer were assumed, a $1.10 and a $1.50 per bushel and $.06 and $.10 per pound, respectively. Taking the results from the two price combinations with greatest spread in prices, i.e., $1.50 and $.06 vs. $1.10 and $.10, the difference in the optimum level of spring and sidedress nitrogen for the five sets of data ranged from 15 to 31 lbs. per acre and 8 to 15 lbs. per acre, respectively. The price of fertilizer to restrict use to 100 lbs. per acre for spring and sidedress, with corn at $1.50, ranged from 15 to 60 cents per lbs. and 24 to 62 cents per lbs. respectively. 9/ This suggests that a considerable change in the price of nitrogen must occur to affect fertilizer use.

Estimating Potential Nitrogen Losses

The additional yield from the application of nitrogen fertilizer, which was estimated above, represents only one aspect of society's concern with the use of nitrogen fertilizer. The other concern is with the loss of nitrogen to surface and ground waters associated with the application of nitrogen fertilizer. One component in the estimation of the potential nitrogen losses is estimating the nitrogen uptake by the corn plant. Using the Herendeen study

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9/ The range for sidedress does not include Herendeen where the required price was -.03 cents.

for which nitrogen in corn grain is reported, the percentage of nitrogen in corn grain was estimated using the same model used in estimating yield functions. The results obtained from the model presented in equation 1 and the F statistic are reported in Table 1.

Table 1
Estimated Coefficients for Percent Nitrogen in Corn Grain for Herendeen Data

Crop and Method of Application	Regression Coefficients							
	a_o	a_1	δ_o	δ_1	λ_o	λ_1	R^2	$S_{y.x.}$
Corn Grain (Spring)	1.49 (29.69) 1/	.02	.00170 (5.80)	* 2/	*	*	.55	0.15
Corn Grain (Sidedress)	1.38 (23.07)	.09	.00411 (4.32)	*	.00001 (2.05)	+ 3/	.56	0.14

1/ The values in parentheses are the t-statistics.
2/ The model is reduced by the component parts found to be nonsignificant at the ninety-five percent level using the F statistic. Asterisked (*) coefficients indicate the coefficients deleted from the model.
3/ The computer program was unable to invert sums of squares and cross-products matrix. The probable reason is the high collinearity among regressors which is aggravated by the small number of observations.

Taking the appropriate coefficients from Table 1, the estimated equations are:

Spring

$$\%NCOR = 1.51 + .00170X \quad (7)$$

Sidedress

$$\%NCOR = 1.47 + .00411X - .000010X^2 \quad (8)$$

From the above equations, one can estimate the percent nitrogen in corn grain for various amounts of spring and sidedress applications of nitrogen. 10/ Then the pounds of nitrogen removed in the corn grain per acre is determined by multiplying the percent nitrogen in grain times the pounds of grain produced per acre for the level of fertilizer applied. For the Herendeen data, the percent nitrogen in grain and the pounds of grain produced per acre are estimated for 50, 100 and the optimum pounds of nitrogen per acre. Multiplying these two numbers together for the three specified levels of nitrogen applied

10/ The nitrogen in corn grain was also reported for the Ontario and Nebraska study. The estimated equations for the percent nitrogen in grain for these two studies indicated a lower nitrogen content for corn grain than the Herendeen data. This results in a lower estimate of the nitrogen removed in grain and therefore a large estimate of nitrogen loss, assuming other factors equal.

one obtains the pounds of nitrogen removed in the corn grain per acre. The results of these calculations for the Herendeen data are presented in Table 2.

Table 2
Calculated Nitrogen Removed in Corn Grain and Estimated Nitrogen Loss For Herendeen Data, Assuming it is Harvested as Shelled Corn

Time of Application	Lbs. Nitrogen/AC		
	50	100	Optimum 1/ (110)
Spring			
1) Yield (bu/A)	91.3	100.9	108.8
2) % Nitrogen in Corn Grain	1.59	1.68	1.70
3) Nitrogen Removed in Grain (lbs/A) 2/	81	95	104
4) Loss of Nitrogen 3/	24	50	49

1/ Optimum level is estimated from the production function for Herendeen with the $P_c = 1.50$ and $p_f = .10$.

2/ The bushels per acre times 56 lbs./bu. gives the lbs. of corn produced. This times percent nitrogen in grain gives the lbs. of nitrogen per acre removed in the grain.

3/ See text for method of estimating nitrogen loss.

As stated earlier, these estimates of the pounds of nitrogen removed in corn grain per acre are but one component in determining the loss of nitrogen. A mass balance equation for determining the loss of nitrogen per acre may be stated in the following way: Loss of nitrogen equals beginning nitrogen plus nitrogen in rain, plus mineralization, plus fertilizer nitrogen, minus crop uptake, minus immobilization, minus volatilization, minus ending nitrogen inventory.

$$\text{LOSSN} = \text{BEGN} + \text{RAINN} + \text{MIN} + \text{FERTN} - \text{CROPN} - \text{IMMOB} - \text{VOLAT} - \text{ENDN}$$

In this equation, the beginning and ending nitrogen inventory can be obtained through soil analysis as in the Herendeen study. The Herendeen soil analysis for nitrogen indicates that the beginning and ending nitrogen inventories are likely to be similar. Therefore, in this analysis, it is assumed that the beginning and ending inventory of nitrogen are the same. The estimated nitrogen in rainfall, of 5 pounds per acre, under humid-temperate climate was obtained from Buckman and Brady [5, p. 428]. An estimate of the amount of nitrogen delivered from the soil by mineralization was obtained by taking the estimated pounds of nitrogen per acre times the average annual rate of delivery of nitrogen. The pounds of nitrogen in the furrow slice per acre was obtained from Buckman and Brady [5, p. 22].

The estimate for the average annual rate of delivery of nitrogen from the soil was obtained from Woodruff [17, p. 211]. Taking the 3000 lbs. of nitrogen per acre from Buckman and Brady times the average delivery rate of 2 percent from Woodruff, one obtains a measure of 60 lbs. of nitrogen delivered by mineralization. By summing the rainfall nitrogen, the mineralization and the fertilizer applied, the amount of nitrogen available for crop use in a given year is obtained.

Knowing the amount of nitrogen available, the next step was to estimate the amount of nitrogen removed by various processes. The nitrogen removed in the crop for Herendeen has already been estimated above and can be taken from Table 2. An estimate of immobilization is not needed because the mineralization rate of 2 percent is mineralization net of immobilization. Mineralization and immobilization occur simultaneously and the net quantity of inorganic nitrogen produced is governed by leaching, denitrification and particularly microbial assimilation [1]. Nitrogen losses to volatilization occurs as ammonia or as gaseous nitrogen losses, the latter is termed denitrification. Nelsen and Uhland [9] suggest that ammonia volatilization appears to be a minor factor under eastern conditions. This suggests that the volatilization losses in the eastern part of the U. S. are mainly due to denitrification. An estimate of volatilization losses was obtained from Buckman and Brady [5, p. 419] and Allison [2, p. 225]. They indicate that results from lysimeter studies show that perhaps 20 percent of the nitrogen added to soils was not accounted for by crop removal and drainage. They assumed that this is lost by volatilization. Taking 20 percent of the amount of nitrogen applied, an estimate of volatilization losses is obtained.

Using these estimates of the various processes acting upon nitrogen in the soil, one can compute the loss of nitrogen to ground and surface water for the various methods and levels of nitrogen applications. The estimate of losses for spring application of nitrogen for Herendeen data are presented in Table 2. These calculations of losses implicitly assume that the rate of mineralization, immobilization, and volatilization do not change with the various methods and levels of nitrogen application.

Results and Conclusion

Using the yield, nitrogen in corn grain, and loss functions developed above, estimates of these and the return over the cost of nitrogen fertilizer were made. A summary of these computations is presented in Table 3.

Given these results, several trends exist in the data for increasing levels of nitrogen and for spring compared to sidedress application of nitrogen. First, the yield efficiency of spring versus sidedress generally decreases as level of nitrogen applied increases. The yield efficiency of spring compared to sidedress application of nitrogen at 50 lbs, 100 lbs. and the optimum rate ranges from 63 to 102 percent. 11/

11/ The yield efficiency is obtained by dividing the yield per lb. of nitrogen for spring by the yield per lb. of nitrogen for sidedress.

Table 3

Summary of Yield, Crop Removal of Nitrogen, Nitrogen Loss and Return Over Cost for For Alternative Methods and Amounts of Nitrogen Applications.

Location and Method of Application	Nitrogen Applied	Yield	Nitrogen 1/ In Grain	Nitrogen 2/ In Grain	Use Eff.	Nitrogen Loss	Return Over Nitrogen Cost	Yield Eff. of Spring vs Sidedress
	lb/ac	bu/ac	%	lbs/ac	%	lbs/ac	$	%
Herendeen (sp)	50	91.3	1.59	81	162	24	132	99
	100	100.9	1.68	95	95	50	141	102
	110 3/	101.8	1.70	104	95	49	152	94
Herendeen (sd)	50	92.4	1.66	86	172	19	134	
	100	98.6	1.78	98	98	47	138	
	85 3/	98.3	1.75	96	113	37	139	
Aurora (sp)	50	81.2	1.59	72	144	33	117	95
	100	99.0	1.68	93	93	52	138	94
	183 3/	113.8	1.82	116	63	85	152	89
Aurora (sd)	50	85.8	1.66	80	160	25	124	
	100	105.6	1.78	105	105	40	148	
	168 3/	118.3	1.88	125	74	74	161	
DeKalb (sp)	50	96.2	1.59	86	172	19	139	94
	100	119.6	1.68	113	113	32	169	94
	225 3/	147.8	1.89	156	69	89	199	88
DeKalb (sd)	50	102.6	1.66	95	190	10	149	
	100	127.6	1.78	127	127	18	181	
	203 3/	152.6	1.59	162	80	65	209	

Table 3. Continued

Location and Method of Application	Nitrogen Applied	Yield	Nitrogen 1/ In Grain	Nitrogen 2/ In Grain	Use Eff.	Nitrogen Loss	Return Over Nitrogen Cost	Yield Eff. of Spring vs Sidedress
Ontario (sp)	50	83.7	1.59	75	150	30	121	95
	100	101.1	1.68	95	95	50	142	91
	249 3/	129.0	1.93	139	56	125	169	71
Ontario (sd)	50	88.0	1.66	82	164	23	127	
	100	110.6	1.78	110	110	35	156	
	174 3/	126.3	1.89	134	77	70	172	
Nebraska (sp)	50	91.1	1.59	81	162	24	132	89
	100	105.0	1.68	99	99	46	147	89
	180 3/	116.8	1.82	119	66	90	157	63
Nebraska (sd)	50	102.4	1.66	95	190	10	149	
	100	117.5	1.78	117	117	28	166	
	116 3/	119.3	1.82	122	105	36	167	

1/ This assumes that the percent nitrogen in grain computed from the Herendeen data, as a function of amount and method of nitrogen application, is representative of the other studies. While similar functions computed from the Ontario and Nebraska data indicates the percent nitrogen in grain is lower, the trend should be the same, so that even though the losses would be higher the general conclusions drawn from the above data would not change.

2/ Lbs. per acre of corn equals bushels per acre times 56 lbs. per bushel, at 15 percent moisture.

3/ The optimum level of nitrogen assumes $P_c = 1.50$ and $P_f = .10$.

The results also show that the percent nitrogen in grain (which is based only on the Herendeen data) increases with the amount of fertilizer applied. In addition, the percent nitrogen in grain for a given level of fertilizer applied is higher for sidedress application than for spring applications of nitrogen.

This increase in the percent nitrogen in corn grain means a greater increase in the nitrogen removed in the grain, up to the optimum, than if this percentage remains constant. Also, the increased percent of nitrogen in grain for sidedress over spring applications results in more nitrogen removed in grain with sidedress for a given level of nitrogen application. While the percent nitrogen in grain increases with increased levels of nitrogen, 12/ the efficiency of the corn plant in using the nitrogen applied decreases with the level of nitrogen applied, 13/ but is better for sidedress than for spring application.

Turning to the estimated losses of nitrogen, the general tendency of nitrogen losses to increase with the amount of fertilizer applied is clear. A smaller loss of nitrogen for sidedress compared to spring applications is also apparent. These two conclusions follow logically from (1) the decreased efficiency in the use of nitrogen as nitrogen application increase, (2) the smaller decrease in nitrogen use efficiency with sidedress, and (3) the assumption that the amount and method of application does not significantly affect the processes of mineralization, immobilization and volatilization. Therefore, the smaller decrease in nitrogen use efficiency with sidedress also results in a decrease in the estimated loss of nitrogen compared to spring at the optimal level of application, ranging from 11 to 55 lbs. per acre.

In addition to the decrease in the estimated loss of nitrogen with sidedressing, it appears that a small increase in returns over the cost of the fertilizer also exists with sidedressing. Perhaps, there is an additional cost for sidedressing. These additional costs would be an increase in the cost of application and/or opportunity cost for labor during the haying season. The additional application cost is at most 1 to 2 cents per pound of nitrogen and would decrease with the amount applied. However, if granular fertilizer is used for spring application and anhydrous for sidedress, the sidedress application could cost less per pound of nitrogen. Furthermore, the opportunity cost for labor may be less than the increased return from getting the corn in 1 or 2 days earlier because no nitrogen was applied before planting.

In conclusion, it appears that sidedress application would offer at least equal returns to spring application of nitrogen and that the estimated loss of nitrogen would be less.

12/ This is at least true from the data used up to 224 lbs. of nitrogen per acre.

13/ Use efficiency is equal to lbs. of nitrogen removed by corn grain divided by lbs. of nitrogen applied.

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Table 4.

Estimated Regression Coefficients for Alternative Methods of Nitrogen Application On Corn For Each Set of Data.

Data set and method of application	a_o	a_1 1/	δ_o	δ_1 1/	λ_o	λ_1 1/	R^2	$S_{y.x}$
			Regression Coefficients					
Aurora Grain (Spring)	56.6 (18.19) 2/	+ 3/	.558 (7.79)	+ 3/	-.00134 (5.00)	+ 3/	.46	22.1
Aurora Grain (Sidedress)	57.3 (19.54)	+ 3/	.659 (9.76)	+ 3/	-.00176 (6.95)	+ 3/	.51	20.9
Herendeen Grain (Spring)	64.5 (16.05)	8.4	.525 (7.81)	-.068	-.00177 (6.03)	* 4/	.67	17.6
Herendeen Grain 5/ (Sidedress)	62.1 (13.93)	9.5	.645 (7.33)	-.082	-.00293 (6.00)	*	.74	16.2
Ontario Grain (Spring)	80.3 (15.46)	-19.1	.470 (4.78)	*	-.00081 (2.07)	*	.74	16.1
Ontario Grain (Sidedress)	73.1 (14.13)	-17.4	.743 (7.58)	*	-.00194 (4.97)	*	.75	16.1
DeKalb Grain (Spring)	74.7 (16.59)	-8.6	.669 (15.34)	*	-.00134	*	.71	20.2
DeKalb Grain (Sidedress)	75.2 (19.80)	-6.1	.754 (20.51)	*	-.00169 (14.40)	*	.77	17.1
Nebraska Grain (Spring)	117.5 (23.27)	-45.4	.131 (1.77)	.299	-.00101 (3.31)	*	.84	14.3
Nebraska Grain (Sidedress)	118.7 (20.78)	-45.4	-.037 (0.202)	.763	-.00002 (0.019)	-.00281	.86	13.3

1/ The intercept and slope coefficients to account for differences in the various locations are a_1, δ_1 and λ_1, respectively. The regression equation is $a_o + a_1 + (\delta_o + \delta_1)X + (\lambda_o + \lambda_1)X^2$.

2/ The t- values are the number in parentheses.

3/ Aurora is a single location so there are no location dummies.

4/ See footnote 2, Table 1.

5/ The coefficients for the Herendeen sidedress functions are questionable in that the higher levels of nitrogen applied in the spring were never applied as sidedress, except for one location.