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FERTILIZER USE IN MINNESOTA CORN PRODUCTION

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In the last three decades, nitrogen fertilizer application in agriculture has changed from an occassional use to a major management practice in most cropping operations. The reason stems from the fact that nitrogen fertilizer is one of the most profitable investments in crop production. Nitrogen fertilizer is relatively inexpensive and has been described as the most limiting nutrient in corn production (Overdahl et al., 1980).

Between 1960 and 1988, the use of nitrogen fertilizer in United States agriculture increased from about 2.7 million to 12 million tons in 1981, before dropping to about 10.5 million tons in 1988 (Figure 1). Similarly, average application rate per acre soared from about 60 pounds per acre to almost 140 pounds per acre between 1965 and 1988. However, nitrogen has been identified

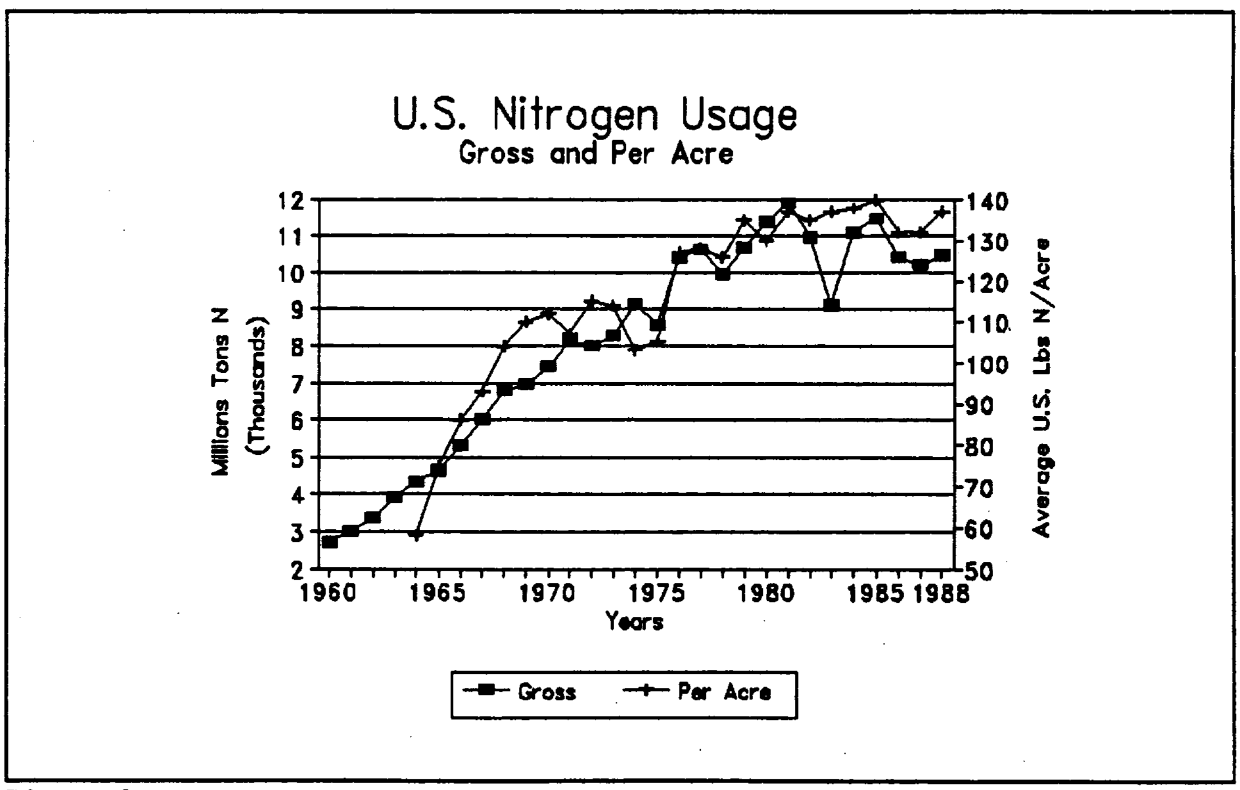

Figure 1

as a major source of groundwater contamination because nitrate-nitrogen is very soluble and leaches into groundwater very easily. As a result, Several measures for controlling nitrogen application in agriculture are being contemplated.

This paper examined the potential implications of adopting a tax strategy as the policy choice to curb nitrogen application in corn production in Minnesota. We focused on corn for two reasons; corn is important because of its economic value (contributing over $1 billion annually), and corn production is highly dependent on nitrogen fertilizer. The issue was analyzed from three perspectives: First, fertilizer price elasticities in corn production were derived. Generally, elasticity estimates provide insights into the potential response of producers to changes in price. Second, the response function for nitrogen fertilizer was estimated and the sensitivity of the optimal level to changes in price was examined. And finally, risk implications of reducing nitrogen fertilizer in corn production were analyzed.

Fertilizer Price Elasticities

The duality cost function approach was employed to estimate the parameters of the production function in corn production. This choice was largely motivated by availability of data and problem of multicollinearity among the input variables in conventional production approaches. For brevity, we postulate the dual minimum cost function as:

$$(1) \quad C = C^*(w_1, \ldots, w_m, Y)$$

where:

C^* = the minimum cost function for corn production

$w_1, \ldots, w_m$ = price of inputs used in corn production

Y = the parametrically assigned output level.

Let the output level Y be represented as:

$$(2) \quad Y = F(x_i) \quad (i = 1, \ldots m)$$

where $x_i, \ldots, x_m$ are fertilizer, capital, labor, land and other inputs used in production.

The cost function C^* is homogeneous of degree one in input prices and assigns to every combination of input prices the minimum cost corresponding to the cost minimizing input levels x_i. If we assume homotheticity of the production function, the cost function can be written as h(Y)C(W). Furthermore, following Chambers (1988), the assumption of weak seperability of the cost function implies that the cost function can be written as:

$$(3) \quad C(w, Y) = C^*(Y, c_1(Y, w_1), \ldots, c_m(Y, w_m))$$

where $c_1, \ldots, c_m$ are sub-functions possessing the same properties as the cost function. Therefore, like the cost function, the c_i's are increasing and differentiable in input prices. Weak seperability of the cost function implies that the marginal rate of substitution between any pairs of factors in the separated groups are independent of inputs outside the aggregate. This means that the Allen partial elasticities of substitution between a factor in the separable group and some factor outside the group are equal for all factors in the group (Berndt and Christensen (1973)). However, this does not mean that the demand for the composite fertilizer is independent of other inputs in production.

For the present study, we assume that the fertilizer nutrients (nitrogen, phosphorous and potassium) are weakly separable so that the demand for the nutrients is independent of the demand for other inputs. Simultaneously, we assume that there exists a homothetic fertilizer aggregator function so that the dual minimum cost function can be constructed as:

$$(4) \quad C = C^{*}(w_1(w_N, w_p, w_k), w_2, \ldots, w_m, Y)$$

According to Denny and Fuss (1977), the separability assumption of a cost function is consistent with decentralization in decision making or equivalent to optimization by stages. This implies that the cost minimization problem can be decomposed into two stages. In the first stage, the cost of producing a given output Y is minimized, given the inputs used in production. Then in the second stage, given the amount of fertilizer required for production, the decision maker chooses the amount of nitrogen, phosphorous and potassium so as to minimize cost. In this sense, the cost minimization decision of fertilizer consumption can be examined independently of other inputs. Therefore, if the cost of fertilizer nutrients are assumed to be proportional to their consumption, the unit cost function for aggregate fertilizer can be specified as:

$$(5) \quad \frac{C_f^*}{F} = w_1(w_N, w_p, w_k, Y)$$

where C_f^* is the minimum cost of aggregate fertilizer used in production.

Empirical Model

The general transcedental logarithmic (translog) production model is used in this analysis. Specifically, we have a second order approximation to an arbitrary cost function of the form:

$$(6) \quad \ln(\frac{C_f^*}{F}) = \beta^o+\beta_y \ln Y+\sum_i \beta_i \ln w_i+.5\sum_i \sum_j \beta_{ij} \ln w_i \ln w_j+\sum_i \beta_{iy} \ln w_i \ln_y+\varepsilon$$
$$(i,j = N,P,K)$$

The derived demand function for an input x_i is obtained by Shephard's Lemma (Christensen, Jorgenson, and Lau, (1971) (1973)) as:

$$(7) \quad \frac{\delta \ln C^*}{\delta \ln w_i} = S_i = \alpha_i+\sum_j \beta_{ij} \ln w_j+\beta_{iy} \ln Y$$
$$(i,j = N,P,K)$$

where:

$$(8) \quad S_i = \frac{w_i x_i(w_1,\ldots,w_m,Y)}{C(w_1,\ldots,w_m,Y)} \quad i = 1,\ldots,m$$

Note that S_i is the share of input i in the total cost of fertilizer. The shares must sum to unity so we have

$$(9) \quad \sum_{i=1}^{m} \frac{w_i x_i}{C(w,y)} = 1$$

when m-1 of the share equations are estimated. The estimated share equations can be written explicitly as:

$$(10) \quad S_N = \alpha_N + \beta_{NN} \ln w_N + \beta_{NP} \ln w_P + \beta_{NK} \ln w_K + \beta_{Ny} \ln Y + \varepsilon$$

$$(11) \quad S_P = \alpha_P + \beta_{PN} \ln w_N + \beta_{PP} \ln w_P + \beta_{PK} \ln_K + \beta_{Py} \ln Y + \varepsilon$$

$$(12) \quad S_K = \alpha_K + \beta_{KN} \ln w_N + \beta_{KP} \ln w_P + \beta_{KK} \ln w_K + \beta_{Ky} \ln Y + \varepsilon$$

The duality approach implies the imposition of the following restrictions;

$$(13) \quad \sum_i \alpha_i = 1; \quad \sum_i \beta_{i,j} = 0; \quad \sum_j \beta_{i,j} = 0; \quad \beta_{i,j} = \beta_{j,i} \quad i \neq j$$

These conditions are the "adding up conditions", the linear homogeneity conditions, and the symmetry condition, respectively. The symmetry and the homogeneity conditions imposed on the share equations were tested using the Lagrangean multiplier test. The derived values were below the critical values thus satisfying the hypothesis of homogeneity and symmetry.

Binswanger (1974) noted that when cross equations restrictions are imposed, ordinary least squares estimators are not efficient even if the equations have the same number of explanatory variables. In addition, the error terms $\epsilon_{i,j}$ may be correlated due to errors in farmers' expectation or due to the incidence of weather. Therefore the technique of seemingly unrelated regression (SUR) with restricted generalized least squares was applied to the share equations simultaneously. The linear dependence implicit from the "adding up" and the "homogeneity" conditions implies that one of the share equations is redundant and should be eliminated from the estimation. The parameters of the eliminated equation were calculated using the homogeneity conditions. The following equivalent sets of cross equation restrictions were imposed for the symmetry condition as a result of dropping one of the share equations.

$$(14) \quad \beta_{NP} = \beta_{PN}; \; \beta_{KN} = -(\beta_{NN} + \beta_{NP}); \; \beta_{PK} = -(\beta_{PN} + \beta_{PP})$$

The demand elasticities and the Allen partial elasticities of substitution can be computed with the regression coefficients as:

Own elasticity of demand:

$$(15) \quad \eta_{ii} = \frac{\gamma_{ii}}{S_i} + S_i - 1 \quad (for\ all\ i)$$

Cross-elasticity of demand:

$$(16) \quad \eta_{ij} = \frac{\gamma_{ij}}{S_i} + S_j \quad (for\ all\ i \neq j)$$

Own-elasticity of substitution:

$$(17) \quad \sigma_{ii} = \frac{\gamma_{ii}}{S_i} - \frac{1}{S_i} + 1 \quad (for\ all\ i)$$

Cross-elasticity of substitution:

$$(18) \quad \sigma_{ij} = \frac{\gamma_{ij}}{S_i S_j} + 1 \quad (for\ all\ i,j;\ i \neq j)$$

where $\gamma_{i,j}$ and $\gamma_{i,i}$ are the estimated coefficients and S_i is the share of input i in production.

Data Description

The data for nitrogen, phosphorous and potassium used in corn production in Minnesota were constructed as the product of the average application rate per acre, the percentage of corn acres receiving the plant nutrient, and the total corn acres planted per year (see appendix A). The data were developed for the years 1966 through 1990. Information was gathered from various issues of Fertilizer Outlook Situation reports and Agricultural Resources Input Situation reports published by the USDA.

The data for corn acreage was gathered from various issues of Minnesota Agricultural Statistics. Fertilizer price data were taken from various issues of Agricultural Prices Annual Summaries, also published by the USDA. The price of nitrogen was calculated as the average national price of all nutrients--ammonium nitrate, anhydrous ammonia, nitrogen solution (30 percent), ammonium sulphate and urea. The average United States price of concentrated super-phosphate (44-46% P_2O_5) was used as the price of phosphorous fertilizer, while the national average price of potash (60% K_2O) was used as the price of potassium fertilizer. All prices were adjusted to 1966 price.

Anhydrous ammonia is the most commonly used source of nitrogen fertilizer and it contains about 82 percent of nitrogen. Attempts were made to use the price as a proxy for the price of nitrogen fertilizer but the result was not significantly different from the result attained by using the adjusted average price.

Estimation Results and the Derived Elasticities

In this section, we present the results of the estimated share equations from applying the framework to the translog cost function. Table 1 presents the parameter estimates derived from the SUR technique with restrictions. The R-square for the estimated system of equations is .94. The R-square in a system equation is difficult to interpret (Vroomen and Larson (1990), and Boyle (1982)). However Boyle argued that we can make some inferences about the goodness of fit of the system equations from the R-squares of the single equations.

The R-squares for the share equations in single estimations are .81, .92, and .84 for nitrogen, phosphorous and potassium, respectively. Therefore, based on the high R-squares from the single equations, we can establish a fair degree of confidence in the results. The standard errors are presented in the middle column of Table 1 and the t-ratios indicate that all the parameters except one are statistically significant.

Using the derived parameter estimates, the ordinary own and cross-price demand elasticities are presented in Table 2. The elasticities are calculated for each observation and at the share mean. The mean own price elasticities for nitrogen, phosphorous, and potassium are -0.35, -0.10, and -0.07, respectively. Using nitrogen as an example, this implies that for every 10 percent increase in the price of nitrogen, the demand for nitrogen fertilizer decreases by 3.5 percent.

Over the years, the elasticity estimates for nitrogen fertilizer in corn production in Minnesota have been inelastic with very little variability. The estimates range from -0.30 to about -0.39 between 1966 and 1990. Similar results were obtained for phosphorous and potassium during the same period. The cross-price elasticity between nitrogen and phosphorous fertilizer is positive. The mean cross-price elasticity is 0.18 suggesting that for every 10 percent increase in the price of phosphorous, the demand for nitrogen fertilizer increases by only 1.8 percent. This indicates a limited substitutability between nitrogen and phosphorous fertilizers in corn production. A similar relationship was also obtained between nitrogen and potassium. The cross-price elasticity between phosphorous and potassium fertilizer is negative. This suggests a complementary relationship between phosphorous and potassium in corn production. The results are consistent with other studies of fertilizer plant nutrient elasticities.

Table 1 Parameter estimates of the Translog Cost Function with Restrictions

	Coefficients	Standard Error	T-ratio
α_{NN}	-0.8	0.27	-2.7
α_{PP}	1.4	0.27	5.1
α_{KK}	0.4	0.20	2.1
b_{NN}	0.09	0.03	2.6
b_{NP}	-0.03	0.03	-1.0
b_{NK}	-0.06	0.02	-3.0
b_{NO}	0.09	0.02	4.4
b_{PP}	0.16	0.03	5.2
b_{PK}	-0.13	0.02	-7.5
b_{PO}	-0.09	0.02	4.1
b_{KK}	0.19	0.02	9.5

Table 2 Estimates of Elasticity of Demand and Elasticity of Substitution

YEAR	b_{NN}	b_{NP}	b_{NK}	b_{PP}	b_{PK}	b_{KK}
66	-0.37824	0.250541	0.127699	-0.1837	-0.11696	-0.04228
67	-0.36975	0.256802	0.112944	-0.18501	-0.13559	-0.0069
68	-0.37688	0.237182	0.139699	-0.17582	-0.12397	-0.05652
69	-0.36467	0.228529	0.136139	-0.16635	-0.15564	-0.03895
70	-0.3805	0.202594	0.177901	-0.14872	-0.13106	-0.09642
71	-0.37796	0.202409	0.175548	-0.14724	-0.13822	-0.09287
72	-0.38744	0.242912	0.144525	-0.1824	-0.09313	-0.07469
73	-0.38663	0.213228	0.173403	-0.16198	-0.10643	-0.09812
74	-0.35811	0.228696	0.129409	-0.16482	-0.1694	-0.02196
75	-0.35288	0.24611	0.106768	-0.17617	-0.17292	0.027869
76	-0.35955	0.215071	0.144476	-0.15309	-0.17369	-0.04602
77	-0.31981	0.114371	0.205442	0.092102	-0.42031	-0.09068
78	-0.33372	0.133734	0.19999	0.010758	-0.33607	-0.0908
79	-0.34113	0.128218	0.212908	0.023147	-0.33299	-0.10231
80	-0.32978	0.095226	0.23455	0.175272	-0.46882	-0.11147
81	-0.33875	0.104319	0.234434	0.119428	-0.41066	-0.11323
82	-0.32448	0.113826	0.210657	0.090617	-0.41182	-0.09598
83	-0.34748	0.167033	0.180451	-0.08038	-0.24538	-0.07947
84	-0.33045	0.162567	0.167887	-0.0631	-0.28669	-0.05734
85	-0.30792	0.156581	0.151336	-0.03943	-0.33918	-0.02148
86	-0.32597	0.183579	0.142389	-0.10149	-0.2665	-0.0175
87	-0.33237	0.175713	0.156652	-0.09007	-0.2642	-0.04368
88	-0.35134	0.168297	0.183044	-0.08476	-0.23533	-0.08372
89	-0.34242	0.163361	0.179058	-0.07047	-0.26135	-0.07567
90	-0.35079	0.155995	0.194795	-0.05923	-0.25474	-0.09315
Elasticity at mean	-0.35265	0.182512	0.170143	-0.10984	-0.21529	-0.07197
Std Error*	(0.0674)	(0.0674)	(0.0449)	(0.1200)	(0.0800)	(0.066)

* = SE(bij)/si

Comparison with Other Plant Nutrient Studies

Table 3 compares own-price elasticities estimated in the current study with those of previous studies. The own-price elasticities of the current study fall within the range of those obtained from other plant nutrient studies. A comparison of these estimates with those obtained in the Corn Belt for corn production confirms the consistency of these results.

Vroomen and Larson (1990) obtained estimates of -0.23 and -0.02 as the minimum own-price elasticities of demand for nitrogen and phosphorous in the Corn Belt area, and estimates of -0.85 and -1.27 as the maximum own-price elasticities of demand for both nutrients, respectively.

Similarly, in their study of nutrient plant elasticities of demand for corn production in the United States, Denbaly and Vroomen (1991) obtained estimates of -0.23, -0.02, and -0.16 as the short run price elasticities of demand for nitrogen, phosphorous and potassium in corn production, and -0.48, -0.30 and -0.27 for the long run price elasticities of demand for these plant nutrients, respectively. Generally, the estimtes of this study are consistent with other studies and so can be accepted with some degree of confidence.

Table 3 Comparison of Previous Estimates of Own-Price Elasticities with Those of the Current Study.

Study	Period	Area	Own-Price Elasticities N	P_2O_5	K_2O
Current Study	1966-90	Minnesota (Corn):	-0.35	-0.11	-0.07
Heady & Yeh[a]	1926-56	United States	-0.45	-0.45	-0.40
Carman[a]	1955-76	11 Western States:			
		Minimum	-0.20	-0.29	-0.21
		Maximum	-1.84	-2.38	-3.27
Roberts & Heady	1952-76	United States:			
		Corn	-1.15	-1.13	-1.30
		Wheat	-0.23	-0.74	-0.24
		Soybeans	-0.20	-0.84	-0.96
Gyawu et al[a]	1960-80	United States	-0.30	-0.09	-0.78
Roberts[a]	1965-84	Tennessee	-0.08	-0.29	-0.17
Vroomen & Larson	1964-89	Corn Belt (Corn):			
		Minimum	-0.23	-0.02	-
		Maximum	-0.85	-1.27	-
Denbaly & Vroomen	1964-89	United States (Corn):			
		Short Run	-0.23	-0.02	-0.16
		Long Run	-0.48	-0.30	-0.27

"a" is aggregate crop demand for N,P,K

The Yield Response Function

The second phase of this analysis involves the estimation of a nitrogen yield response function in order to determine the optimal level of nitrogen application in corn production. The sensitivity of the optimal levels to changes in price was examined and analyzed.

The data used in this effort are experimental plot data from the Agricultural Experimental Station of the University of Minnesota at Lamberton (see appendix B). The data are a subset of data for continuous corn production collected over a period of 31 years. The sources of nitrogen fertilizer were ammonium nitrate and urea, and data for the period 1981 through 1991 were used. The experiment was designed to determine differences in the rates and timing of application between the two types of nitrogen fertilizer. The rates of application were 0, 40, 80, and 160 pounds per acre, respectively, and the experiment was replicated four times in a randomized block design with the treatments repeated annually on the same plots. The treatments were carried out in the fall.

The corn price and the input prices used were either based on the projections provided by Fuller et al. (1992) for the Lamberton area or calculated as the ratio of the price per ton to the percent of the plant nutrient times a factor of 20 for urea (Doane Information Services, 1981, p 220).

Empirical Model

The quadratic functional form was employed for the estimation of the response function for corn. This was due to the fact that the quadratic functional specification provided the best fit in terms of R-square and t-ratios of all the functional forms investigated.

Recently, the use of the quadratic and the Von Liebig function for estimating response function has been criticized. Frank et al. (1990) have suggested the use of the Mitschelich-Baule functional specification as an appropriate alternative. According to them, the Mitschelich-Baule is more flexible regarding the degree of isoquant convexity and accommodates cases of near perfect factor substitution (σ-∞) to cases of near zero factor substitution (σ-0). Hence the function allows for factor substitutability and in addition imposes a plateau growth. In constrast, the Von Liebig functional form also imposes a growth plateau, but a zero elasticity of substitution is assumed for all levels of inputs. The quadratic funtion does not allow for plateau growth on the output-- it exhibits a diminishing marginal productivity for all inputs. Conversely, Heady et al. (1955) criticized the Mitschelich-Baule specification on the basis that it does not adequately describe the fertilizer-input crop-output relationship under all situations because it is too restrictive and does not allow for diminishing total returns. Consequently, it may not be appropriate for experiments with high rates of fertilization.

Table 4 Regression Estimates Using Nitrogen Fertilizer as Ammonium Nitrate

Variables	Coefficients	Standard error	R^2
Constant	90.93	4.19	.82
N	.63	.07	
N^2	-.002	.0004	
d1	-39.31	5.31	
d2	-11.48	5.31	
d3	-70.65	5.40	
d4	-46.30	5.31	
d5	-18.48	5.31	
d6	-29.17	5.31	
d7	1.60	5.31	
d8	-64.13	5.31	
d9	-15.29	5.31	
d10	-2.80	5.31	

d's are the yearly dummy variables.

Table 5 Regression Estimates Using Nitrogen Fertilizer as Urea

Variables	Coefficients	Standard error	R^2
Constant	92.09	4.06	.85
N	.784	.067	
N^2	-.003	.0004	
d1	-35.69	5.15	
d2	-9.20	5.15	
d3	-77.74	5.15	
d4	-47.39	5.15	
d5	-15.05	5.15	
d6	-30.14	5.15	
d7	-.631	5.15	
d8	-68.82	5.15	
d9	-17.06	5.15	
d10	-1.49	5.15	

d's are the yearly dummy variables.

The equations in Table 4 and 5 represent the quadratic functional forms for ammonium nitrate and urea, respectively. The standard errors are presented in column 3 while the "d" variables are the yearly dummies added to capture the annual effect of weather conditions on yield. In both equations, the year 1991 was used as the reference dummy. The R^2s indicate that nitrogen fertilizer explained about .82 and .85 percent of the variability in corn production for the two nitrogen sources. The optimum level of nitrogen application was derived for both types of nitrogen fertilizer by assuming profit maximization, and the sensitivity of the optimum levels to changes in price was examined. With corn priced at $2.25 per bushel and nitrogen fertilizer priced at $0.21 per pound, the optimum level of nitrogen fertilizer used as ammonium nitrate was 144 pounds per acre, while the optimum level of nitrogen used as urea was 120 pounds per acre.

Tables 6 presents the results of changing the price of nitrogen fertilizer from the initial price of $0.21 per pound. Using ammonium nitrate as an example,

Table 6 The Effect of Price Increases on Nitrogen Application and Net Profit per Acre of Corn Production (Lamberton data)

Type	Price	% increase Price	Pounds	% decrease Nitrogen	Yield Bushel	% decrease Yield	Total Rev	Net Revenue	Change In Net Rev
Ammonium Nitrate	0.21	-	144.00	-	143.00	-	321.80	291.50	-
	0.23	10.00	141.80	1.50	142.90	0.09	321.50	288.80	--2.90
	0.25	20.00	139.30	3.30	142.60	0.28	320.90	285.60	-6.10
	0.27	30.00	136.80	5.00	142.30	0.50	320.20	282.90	-8.90
	0.42	100.00	119.00	17.40	139.60	2.40	314.10	264.12	-27.60
Urea	0.21	-	120.00	-	144.70	-	325.60	300.40	-
	0.23	10.00	118.00	1.70	142.50	1.50	320.60	293.30	-7.10
	0.25	20.00	116.80	2.70	142.40	1.60	320.40	290.80	-9.60
	0.27	30.00	115.00	4.20	142.20	1.70	320.00	288.37	-11.80
	0.42	100.00	104.00	13.30	140.50	2.90	316.10	272.50	-27.90

Net Revenue = Total Revenue - Nitrogen Cost.

if we assume a 30 percent increase in the price of nitrogen fertilizer, Table 6 shows that the optimal level of nitrogen fertilizer will decrease from the profit maximizing level of 144 pounds per acre to 136.8 pounds per acre, a 5 percent decrease. Similarly, a 100 percent increase in the price of nitrogen fertilizer used as ammonium nitrate will decrease the quantity used to 119 pounds per acre, a decrease of 17.40 percent. In both cases, the percent decrease in the quantity used is much smaller than the percent increase in price.

By the same fashion, a 30 percent increase in the price of nitrogen fertilizer applied as urea will decrease quantity used to 115 pounds per acre, a 4.2 percent decrease. Also, a 100 percent increase in the price of nitrogen fertilizer indicates a decrease of 16 pounds per acre (13 percent) in the quantity used. Consistently, the results indicate that the percent decrease in the quantity of nitrogen fertilizer was less than the percent increase in price.

An examination of the change in profit indicates a substantial adverse effect on farmers' profit as a result of increasing nitrogen prices. For instance, a 30 percent increase in the price of nitrogen fertilizer applied as ammonium nitrate reduced profit by about $9.00 per acre, while a 100 percent increase in price decreased profit per acre by about $28.00 per acre. Similarly, a 30 percent increase in the price of nitrogen fertilizer used as urea resulted in a $12.00 decrease in profit per acre, while a 100 percent increase in the price resulted in a decrease of $28.00 per acre.

The impact on profit from imposing a quantitative restriction was investigated by restricting nitrogen application to some target levels and holding the price constant. The results indicate that at 119 pounds of ammonium nitrate nitrogen fertilizer, the decrease in profit from the profit maximizing level was only $2.39 per acre. Similarly, an evaluation of profit at 104 pounds of urea per acre without a change in the price will decrease profit by about $6.00 per acre. Results indicate that quantitative restrictions are generally a better policy than a tax policy. While the decrease in quantity used from a tax measure was very limited, the impact on producers profit was significant.

The Impact of Tax Policy on a Hypothetical Farm Situation

Table 7 re-inforces the substantial adverse effect on farm profits from raising the price of nitrogen fertilizer. Cost estimates for continuous corn production at Lamberton as provided by Fuller et al. (1992) were used. At a cost of $0.21 per pound of nitrogen fertilizer as ammonium nitrate, net profit per acre (including the value of government programs) was $28.24. A 30 percent increase in the price of nitrogen reduced the net profit to $19.64, while a 100 percent increase decreased the net profit to $0.75 per acre.

The same adverse effects were observed using nitrogen applied in the form of urea. At $0.21 per pound of nitrogen as urea, net profit per acre including the value of government program was $36.62. Raising the price of nitrogen fertilizer by 30 percent resulted in a $25.52 net profit, while a 100 percent increase decreased the net profit to $9.06 per acre.

Table 7 Evaluation of Farm Profits Using Hypothetical Farm Budget Data

	<u>Budget 1</u>	<u>Budget 2</u>	<u>Budget 3</u>
Revenue	314.10	320.20	322.00
Govt. Payment	37.00	37.00	37.00
Total	351.10	357.20	359.00
Variable Costs (excluding nitrogen fertilizer):			
	102.00	102.00	102.00
Drying	12.62	12.82	12.83
Fixed Costs	185.75	185.75	185.75
Nitrogen Fert	50.00	36.99	30.20
Net Profit	0.75	19.64	28.24

Nitrogen Application Rates (from ammonium nitrate):

Budget 1—119 pounds/acre @ $.42/lb

Budget 2—137 pounds/acre @ $.27/Ib

Budget 3—144 pounds/acre @ $.21/Ib

Risk Implications of Reducing Nitrogen Fertilizer in Corn Production

In this section, the risk implications of reducing nitrogen fertilizer application in corn production are considered. Producers' risk attitudes have long been recorgnized as an important variable in farm production (Robison and Barry, 1987). The neglect of this fact in policy deliberations may lead to inappropriate conclusions.

Batie and Taylor (1989) argued that economic analysis comparing only the expected value of net returns is insufficient, and that variability in yields and net returns must be evaluated as well. Fertilizer is a risk increasing input because fertilizer increases the probability of high yield when rainfall is adequate and timely, but it also increases the probability of low yield when rainfall in inadequate and chemical burning occurs (Leathers and Quiggin, 1991). Therefore, increased use of fertilizer increases both the expected yield and the yield variability. For a risk increasing input, income variability may be reduced by reducing the amount used. Consequently, the impact of tax policies on a risk averse decision maker may be exergerated if the risk effects are not considered.

Time series experimental data for nitrogen fertilizer from Lamberton experimental station for ammonium nitrate and urea were used in this analysis. The functional specification suggested by Just and Pope was used to estimate the production parameters. The functional form comprised of two general functions and can be represented as:

$$(19) \quad Y = f(x) + h^{\frac{1}{2}}(x)\varepsilon \quad E(\varepsilon)=0, \quad V(\varepsilon)=1$$

This specification allows the effects of the mean and the variance of output to be independent. For consistency, a quadratic functional form was used. So we have:

$$(20) \quad y_t = (\alpha+\alpha_1 x+\alpha_2 x^2)+(\beta+\beta_1 x+\beta_2 x^2)\varepsilon$$

where y_t is corn yield per acre and x the input used in production. In general form, the function is written as:

$$(21) \quad y_t = f(x_t,\alpha)+\varepsilon_t^*, \qquad E(\varepsilon_t^*)=0,\ E(\varepsilon_t^*,\varepsilon_s^*)=0 \quad (For\ all\ t\neq s)$$

where $\epsilon_t^* = h^{1/2}(x_t,\beta)\epsilon_t$, $E(\epsilon_t)=0$, $E(\epsilon_t,\epsilon_s)=0$ for all $t\neq s$.

The function above is heteroscedastic because the variance is dependent on the level of input used. An efficient estimate from this specification could be derived by a weighted non-linear least squares regression of Y_t on x_t using $h^{-1/2}(x_t,\beta)$ as the weight. Table 8 presents the parameter estimates for the three-stage estimation for nitrogen fertilizer used as ammonium nitrate. The more efficient parameters of the third stage estimation were used in a programming model to examine the impact of policy variables on producers' risk attitudes.

Table 8 Estimates of the Production Function for Ammonium Nitrate

(a) First stage: Estimates of the deterministic component

	Coefficient	standard error	t-ratio
constant	90.93	4.19	21.70
N	0.630	0.069	9.13
N^2	-0.002	0.0004	-5.00

(b) Second stage: Estimates of the stochastic component

constant	3.05	0.18	17.20
N	-0.006	0.006	-1.00
N^2	0.00003	0.00003	1.00

(c) Third stage: Estimates of the deterministic component

constant	36.40	2.73	13.34
N	0.74	0.13	5.85
N^2	-0.003	0.001	-3.00

To examine the effect of policy variables on producers' risk attitude, we assume price and yield risk and specify profit per acre as:

$$(22) \quad \pi = PY - \sum_i r_i x_i \quad (i = 1, \ldots, m)$$

where: π = profit

P = random output price

r_i = cost of input i per acre

Y = random yield per acre, and

x_i = input i used per acre

Note that $Y = f(x_i) + h^{1/2}(x_i)\epsilon$ for $i = 1,\ldots,m$, ϵ is stochastic and $\epsilon \sim N(0,1)$, $E(P) = P$, and $E(\epsilon) = 0$. Taking the expectation of the profit function we get:

$$(23) \quad E(\pi) = Pf(x_i) - \sum_i r_i x_i$$

The variance of profit when price and yield are normal, random and independently distributed (Mood et al., 1974) is:

$$(24) \quad V(\pi) = Y^2\sigma_p^2 + P^2\sigma_y^2 + \sigma_p^2\sigma_y^2$$

The price and quantity are assumed to be independently distributed for an individual producer so that the covariance term is zero. Following Robison and Barry (1987), we approximate the certainty equivalent of profit per acre as:

$$(25)\quad CE = E(\pi) - \frac{\lambda}{2} Var(\pi)$$

where λ is the Arrow-Pratt absolute risk aversion coefficient, $E(\pi)$ and $var(\pi)$ are expected profit and variance of profit respectively. $\lambda>0$ is a measure of risk aversion while $\lambda=0$ denotes a risk neutral case. By substitution, we get:

$$(26)\quad Max\ CE = Pf(x_i) - \sum_i r_i x_i - \frac{\lambda}{2}(f(x_i)^2 \sigma_p^2 + P^2 h(x_i) + \sigma_p^2 h(x_i))$$

From the first order conditions we derive:

$$(27)\quad \frac{\delta CE}{\delta x_i} = P\frac{\delta f(x_i)}{\delta x_i} - r_i - \frac{\lambda}{2}(2\frac{\delta f(x_i)}{\delta x_i}\sigma_p^2 + P^2\frac{\delta h(x_i)}{\delta x_i} + \sigma_p^2\frac{\delta h(x_i)}{\delta x_i}) = 0$$

This can be written as:

$$(28) \quad p\frac{\delta f(.)}{\delta x_i} = r_i+\frac{\lambda}{2}(2\frac{\delta f(.)}{\delta x_i}\sigma_p^2+p^2\frac{\delta h(.)}{\delta x_i}+\sigma_p^2\frac{\delta h(.)}{\delta x_i})$$

Equation 28 states that producers will use inputs until the marginal value product (mvp) equals the cost of input r_i plus the risk term measured by the interaction of various moments of the price and yield distributions and weighted by producers' risk attitude. The ratio of the input prices can be equated to the ratio of the mvp of yield less the risk term. So we get:

$$(29) \quad \frac{r_i}{r_j} = \frac{p\frac{\delta f(.)}{\delta x_i}-\frac{\lambda}{2}(a_i)}{p\frac{\delta f(.)}{\delta x_j}-\frac{\lambda}{2}(a_j)} \quad (for\ all\ i \neq j)$$

where a_i and a_j are the risk terms as described earlier.

From Equation 29, we notice that the level and the proportions of the input used are affected by the input price, the variance of output price, the output level, the marginal products, the risk aversion and the marginal contributions of the inputs to output variance. For the risk neutral case, the derivative of the certainty equivalent is derived as:

$$(30) \quad \frac{\delta CE}{\delta x_i} = p\frac{\delta f(x_i)}{\delta x_i}-r_i = 0 \quad (for\ i=1,...,m)$$

The ratio of the input prices can therefore be equated to the ratio of the mvp as:

$$(31)\quad \frac{r_i}{r_j} = \frac{p\frac{\delta f(x_i)}{\delta x_i}}{p\frac{\delta f(x_j)}{\delta x_j}} \quad (for\ all\ i \neq j)$$

In this case, the risk term does not appear in the equation and therefore does not affect the decision. The impact of policy variables designed to change input use will therefore differ depending on the decision maker's risk attitude. By varying λ, optimal input levels for different risk attitudes could be determined. Thus the effect of taxing nitrogen or restricting the quantity used can be evaluated under different scenarios.

Results

Optimal input levels were determined by solving Equation 26 for different values of λ using the General Algebraic Modeling System (GAMS). λ values were assumed to be 0, .008, .010, .012, .014, and .020. Table 9 shows that the profit maximizing level of nitrogen fertilizer used as ammonium nitrate was 108 pounds per acre. Expected return under this condition was $164.37. For increasing risk levels (i.e. $\lambda > 0$), reductions were observed with nitrogen application levels. This supports the fact that fertilizer is a risk increasing input in production.

Table 9 Effect of Adjusting λ under Initial Nitrogen Fertilizer Price as Ammonium Nitrate

λ	Nitrogen (lbs/acre)	Expected Return[a] ($/acre)
0	108.0	164.37
.008	107.0	157.30
.010	106.7	155.54
.012	106.4	153.80
.014	106.1	152.00
.020	105.1	146.73

a = Expected Return = Total Revenue - Nitrogen Cost

Table 10 Effect Taxing Nitrogen Fertilizer

% Tax	λ	Nitrogen (lbs/acre)	Expected Return[a] ($/acre)
30	0	103.8	158.0
	.012	101.6	147.5
	.020	99.9	140.6
100	0	92.9	143.3
	.012	89.7	133.2
	.020	87.1	126.5

a = Expected Return = Total Revenue - Nitrogen Cost

At λ=.020, nitrogen fertilizer used as ammonium nitrate was 105 per acre and the expected net return was $146.73. In general, risk averse producers were found to use less than the profit maximizing level. Similar relationships were observed using nitrogen fertilizer applied as urea.

Effect of Taxing Nitrogen Fertilizer

The price of nitrogen fertilizer used as ammonium nitrate was increased by 30 and 100 percent and Equation 26 was solved for risk levels of 0, .012, and .020. The results (see Table 10) show that the response of producers to tax measures were sensitive to farmers' risk attitude. At a 30 percent tax rate, while the risk neutral individual was using about 104 pounds of nitrogen fertilizer as ammonium nitrate, the extremely risk averse individual was using about 100 pounds per acre.

Similar relationships were observed when nitrogen fertilizer was taxed 100 percent. While the risk neutral individual was using 93 pounds of nitrogen fertilizer per acre, the extremely risk averse producer was using about 87 pounds per acre. The problem of achieving a target level of fertilizer application is obvious since producers' response to tax measures depends partly on their risk attitudes. Olson and Eidman (1992) noted that most farmers' risk measures lie between –0.0001 and 0.005. For the present case, this implies that the decrease in the quantity used as a result of a 30 percent increase in price was only 4 pounds per acre (3.7 percent), while the decrease as a result of a 100 percent increase in price was only 15 pounds, (i.e. 14 percent decrease). The same relationships were observed using nitrogen fertilizer applied as urea.

Effect of Quantitative Restriction

The effect of quantity restrictions on the use of nitrogen fertilizer was investigated by placing different upper bounds on the quantity used and solving Equation 26 for the selected three risk levels.

Table 11 shows that the costs to the farmer by placing restrictions on the input used were much lower than the cost from imposing a taxation measure, regardless of the risk attitude. Casler and Jacobs (1979) suggested that the shadow price of placing restrictions on the input used could be interpreted as the amount of tax that would be required to achieve that level of application. Therefore to achieve a 90 pound usage level of nitrogen fertilizer using quantitative restriction, for the risk neutral producer, the marginal cost was \$0.25 per acre as opposed to a tax of \$20.00 per acre that resulted in a 93 pound per acre usage level.

Similarly, a 90 pound usage level for nitrogen fertilizer in the form of ammonium nitrate, for the extremely risk averse producer could be achieved at a cost of \$0.18 per acre as against a tax measure of \$18.00 per acre in order to achieve a comparable amount. The same relationships were observed for the different levels of risk aversion. Generally, quantitative restrictions as a policy choice for reducing nitrogen fertilizer are more favorable than the taxation measures since the target levels could be achieved at lower costs to producers. The same relationships were observed using nitrogen fertilizer applied as urea.

Table 11 Effect of Quantitative Restrictions on Nitrogen Fertilizer Application.

λ	Nitrogen (lbs/acre)	Expected Return[a] ($/acre)	Marginal Cost of Restriction ($/acre)
0	106	164.3	.03
0	100	163.9	.112
0	90	162.1	.25
0	85	160.7	.32
.012	106	153.8	.006
.012	100	153.5	.08
.012	90	152.0	.21
.012	85	150.9	.27
.020	106	146.7	0
.020	100	146.6	.06
.020	90	145.4	.18
.020	85	144.4	.24

a = Expected Return = Total Revenue - Nitrogen Cost

Conclusion

The economic ramifications of a tax policy in order to change producers' behavior in corn production were examined and analyzed. Consistently, the results indicated that quantitative restrictions were more effective in curbing nitrogen fertilizer usage in corn production than taxation measures. The price elasticity of nitrogen fertilizer was found to be -0.35, suggesting that for 10 percent increase in the price of nitrogen fertilizer, the quantity demanded would decrease by only 3.5 percent.

The sensitivity analysis of the optimum level of nitrogen fertilizer showed that for each percent increase in the price of nitrogen fertilizer, the percent decrease in the quantity demanded was much smaller than the percent increase in price. For example, a 100 percent increase in the price of nitrogen fertilizer used as ammonium nitrate resulted in a 17 percent decrease in the quantity used. Similarly, a 100 percent increase in the price of nitrogen fertilizer used as urea reduced usage by only 13 percent.

An examination of the risk effects of reducing nitrogen fertilizer in corn production showed that producers' risk attitudes were sensitive to taxation measures. The results indicate that risk averse decision makers tend to use less than the profit maximizing level of nitrogen fertilizer. Consequently, producers response to such policy strategy depends to a large extent on their risk attitudes. Using nitrogen fertilizer applied as ammonium nitrate, at 100 percent tax, the risk neutral producer was using 93 pounds while the extremely risk averse decision maker was using 87 pounds per acre. A similar relationship was observed using nitrogen fertilizer applied as urea.

Conversely, quantitative restrictions as a policy choice proved to be superior to taxation measures as the target levels could be achieved at lower cost to producers. For a risk neutral farmer, a 90 pound usage level of nitrogen fertilizer applied as ammonium nitrate was achieved at a cost of $0.25 per acre as opposed to a cost of $20.00 per acre using tax measures. Similarly, a 90 pound usage level was achieved for the extremely risk averse producer at a cost of $0.18 per acre as against an $18.00 per acre cost from adopting a tax measure. The cost of administration of quantity restriction or the combination of both policies as an alternative policy choice was not considered in this analysis. The incorporation of such costs or the mix of both policies are necessary to fully evaluate these policy variables.

Finally, caution should be used in interpreting the results of this study. Experimental plot data were used to analyze the effects of a tax policy in corn production. In actual farm situations, farmers may react differently to tax policy, since they may be able to cushion the adverse effects by changing to alternative enterprise or adopting alternative farming practices. Further studies that incorporate all these possibilities are necessary to provide more insight into the potential response of producers to these policy strategies.

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APPENDIX

Table A. Data Used in Estimating Price Elasticity for Nutrients Used in Minnesota Corn Production.

Year	Acres (1,000's)	N Applied (000 tons)	P Applied (000 tons)	K Applied (000 tons)	N Price[a] Index	P Price[a] Index	K Price[a] Index
1966	5313	2467.4	2056.1	1764.4	1.000000	1.000000	1.000000
1967	6069	3858.9	3009.1	2460.8	0.977053	1.003658	0.963099
1968	5400	4399.9	3231.9	3129.3	0.869565	0.936585	0.900369
1969	4835	4088.0	2523.9	2465.9	0.785024	0.902439	0.857933
1970	5220	4757.5	2929.5	3325.1	0.785024	0.923170	0.966789
1971	6572	5930.6	3588.3	3688.2	0.797101	0.934146	1.070110
1972	5650	4724.5	3290.2	2935.3	0.809178	1.024390	1.088560
1973	6200	5656.1	3550.5	3991.6	0.905797	1.146341	1.162361
1974	6940	5391.5	3745.6	4111.0	1.968599	1.939024	1.586715
1975	7000	5924.4	3728.8	3934.8	2.210144	2.475609	1.808118
1976	7200	7299.3	4163.0	4615.0	1.690821	1.951219	1.752767
1977	6900	6989.9	3594.7	4761.2	1.835748	1.243902	1.752767
1978	7000	5914.2	3210.4	3981.6	1.787439	1.353658	1.808118
1979	6900	6900.2	3832.8	4688.1	1.980676	1.475609	2.140221
1980	7250	7151.6	3265.8	4994.3	2.403381	1.707317	2.546125
1981	7700	7915.2	3851.7	5553.4	2.584541	1.902439	2.841328
1982	7300	7778.1	3353.2	4554.5	2.403381	1.975609	2.767527
1983	5100	4947.0	2178.7	2995.7	2.210144	2.573170	2.509225
1984	7250	8004.0	3298.8	4486.3	2.379227	2.682926	2.564575
1985	7300	7767.2	2989.4	4080.7	2.258454	2.426829	2.214022
1986	6300	6403.9	2721.6	3320.1	1.932367	2.268292	2.011070
1987	5400	6207.3	2302.0	2878.2	1.823671	2.439024	2.306273
1988	5700	6457.0	2667.6	3223.4	2.041062	2.597560	2.896678
1989	6200	6916.1	2703.8	3320.1	2.101449	2.646341	2.915129
1990	6700	7419.6	3075.3	3975.8	2.065217	2.475609	2.822878

a) Scaled for 1966 = 1. (Average National Price/Ton)

Table B.1. Data for Nitrogen Application for Ammonia, Lamberton, MN, 1981-1991.

Year	Corn Yield (bu/acre)	N Applied (lbs/acre)	Year	Corn Yield (bu/acre)	N Applied (lbs/acre)
1981	74.7	0	1984	43.8	0
1981	61.2	0	1984	60.1	0
1981	51.9	0	1984	51.8	0
1981	60.2	0	1984	69.7	0
1981	77.7	40	1984	68.1	40
1981	90.4	40	1984	72.2	40
1981	74.3	40	1984	48.4	40
1981	67.2	40	1984	78.3	40
1981	85.0	80	1984	63.0	80
1981	77.0	80	1984	114.4	80
1981	95.9	80	1984	53.1	80
1981	100.6	80	1984	57.2	80
1981	67.1	160	1984	102.2	160
1981	104.6	160	1984	102.2	160
1981	96.8	160	1984	103.2	160
1981	96.8	160	1984	81.9	160
1982	71.0	0	1985	76.1	0
1982	78.1	0	1985	70.6	0
1982	60.4	0	1985	57.5	0
1982	70.8	0	1985	79.5	0
1982	96.9	40	1985	78.4	40
1982	94.2	40	1985	110.9	40
1982	82.0	40	1985	70.1	40
1982	92.8	40	1985	89.6	40
1982	139.2	80	1985	96.6	80
1982	127.9	80	1985	143.6	80
1982	129.5	80	1985	93.0	80
1982	131.2	80	1985	121.7	80
1982	131.5	160	1985	113.0	160
1982	133.9	160	1985	149.0	160
1982	151.0	160	1985	110.2	160
1982	136.4	160	1985	154.9	160
1983	34.5	0	1986	70.7	0
1983	29.5	0	1986	49.4	0
1983	26.9	0	1986	37.2	0
1983	28.6	0	1986	57.5	0
1983	41.4	40	1986	64.5	40
1983	40.9	40	1986	82.7	40
1983	43.8	40	1986	57.2	40
1983	44.6	40	1986	91.5	40
1983	42.1	80	1986	77.8	80
1983	73.1	80	1986	122.9	80
1983	52.5	80	1986	84.8	80
1983	51.7	80	1986	105.2	80
1983	72.9	160	1986	120.6	160
1983	72.2	160	1986	128.7	160
1983	51.9	160	1986	144.2	160
			1986	148.8	160

Table B.1. Data for Nitrogen Application for Ammonia, Lamberton, MN, 1981-1991 (Continued).

Year	Corn Yield (bu/acre)	N Applied (lbs/acre)	Year	Corn Yield (bu/acre)	N Applied (lbs/acre)
1987	98.9	0	1990	82.3	0
1987	90.1	0	1990	78.5	0
1987	79.2	0	1990	74.2	0
1987	96.3	0	1990	79.0	0
1987	132.4	40	1990	123.8	40
1987	124.9	40	1990	124.9	40
1987	109.0	40	1990	111.2	40
1987	113.4	40	1990	116.3	40
1987	135.0	80	1990	120.0	80
1987	131.8	80	1990	128.5	80
1987	127.4	80	1990	119.0	80
1987	131.2	80	1990	142.9	80
1987	144.9	160	1990	127.7	160
1987	141.0	160	1990	140.1	160
1987	140.6	160	1990	145.7	160
1987	139.9	160	1990	151.6	160
1988	51.2	0	1991	76.8	0
1988	40.0	0	1991	85.3	0
1988	30.8	0	1991	61.6	0
1988	48.0	0	1991	83.7	0
1988	71.0	40	1991	97.0	40
1988	54.3	40	1991	115.8	40
1988	72.2	40	1991	83.3	40
1988	58.6	40	1991	111.5	40
1988	48.6	80	1991	122.2	80
1988	65.3	80	1991	146.8	80
1988	63.6	80	1991	135.7	80
1988	35.1	80	1991	142.7	80
1988	48.9	160	1991	164.0	160
1988	61.5	160	1991	154.2	160
1988	90.1	160	1991	172.9	160
1988	45.1	160	1991	156.9	160
1989	69.6	0			
1989	70.3	0			
1989	59.5	0			
1989	87.6	0			
1989	102.5	40			
1989	101.9	40			
1989	110.4	40			
1989	107.8	40			
1989	119.5	80			
1989	117.7	80			
1989	98.2	80			
1989	136.2	80			
1989	124.0	160			
1989	122.8	160			
1989	111.5	160			
1989	126.2	160			

Table B.2. **Data for Nitrogen Application for Urea, Lamberton, MN, 1981-1991.**

Year	Corn Yield (bu/acre)	N Applied (lbs/acre)	Year	Corn Yield (bu/acre)	N Applied (lbs/acre)
1981	74.7	0	1984	43.8	0
1981	61.2	0	1984	60.1	0
1981	51.9	0	1984	51.8	0
1981	60.2	0	1984	69.7	0
1981	65.5	40	1984	65.3	40
1981	97.1	40	1984	80.1	40
1981	73.2	40	1984	65.5	40
1981	112.1	40	1984	79.3	40
1981	93.7	80	1984	62.1	80
1981	101.8	80	1984	94.5	80
1981	100.9	80	1984	70.3	80
1981	111.0	80	1984	79.5	80
1981	116.9	160	1984	99.3	160
1981	77.2	160	1984	120.7	160
1981	85.1	160	1984	79.3	160
1981	111.1	160	1984	85.2	160
1982	71.0	0	1985	76.1	0
1982	78.1	0	1985	70.6	0
1982	60.4	0	1985	57.5	0
1982	70.8	0	1985	79.5	0
1982	121.7	40	1985	83.6	40
1982	119.6	40	1985	128.9	40
1982	108.9	40	1985	94.5	40
1982	126.2	40	1985	111.3	40
1982	127.4	80	1985	89.9	80
1982	134.1	80	1985	151.3	80
1982	129.5	80	1985	108.3	80
1982	134.5	80	1985	118.0	80
1982	144.5	160	1985	142.7	160
1982	130.7	160	1985	145.5	160
1982	130.3	160	1985	110.2	160
1982	129.8	160	1985	156.0	160
1983	34.5	0	1986	70.7	0
1983	29.5	0	1986	49.4	0
1983	26.9	0	1986	37.2	0
1983	28.6	0	1986	57.5	0
1983	43.2	40	1986	68.2	40
1983	41.3	40	1986	105.1	40
1983	38.7	40	1986	63.9	40
1983	41.0	40	1986	76.9	40
1983	33.6	80	1986	86.1	80
1983	54.0	80	1986	119.6	80
1983	51.3	80	1986	113.4	80
1983	44.5	80	1986	128.0	80
1983	70.4	160	1986	98.8	160
1983	65.5	160	1986	137.2	160
1983	59.7	160	1986	113.6	160
1983	58.1	160	1986	156.8	160

Table B.2. Data for Nitrogen Application for Urea, Lamberton, MN, 1981-1991 (Continued).

Year	Corn Yield (bu/acre)	N Applied (lbs/acre)	Year	Corn Yield (bu/acre)	N Applied (lbs/acre)
1987	98.9	0	1990	82.3	0
1987	90.1	0	1990	78.5	0
1987	79.2	0	1990	74.2	0
1987	96.3	0	1990	79.0	0
1987	121.8	40	1990	122.6	40
1987	111.1	40	1990	119.2	40
1987	112.1	40	1990	130.0	40
1987	118.6	40	1990	124.7	40
1987	131.1	80	1990	161.2	80
1987	123.5	80	1990	139.1	80
1987	141.7	80	1990	144.8	80
1987	146.7	80	1990	133.2	80
1987	154.9	160	1990	136.3	160
1987	138.9	160	1990	125.0	160
1987	144.7	160	1990	156.5	160
1987	145.0	160	1990	134.3	160
1988	51.2	0	1991	76.8	0
1988	40.0	0	1991	85.3	0
1988	30.8	0	1991	61.6	0
1988	48.0	0	1991	83.7	0
1988	51.3	40	1991	114.4	40
1988	56.5	40	1991	117.3	40
1988	53.0	40	1991	127.6	40
1988	59.9	40	1991	117.0	40
1988	54.2	80	1991	120.3	80
1988	65.4	80	1991	147.2	80
1988	61.2	80	1991	126.6	80
1988	70.5	80	1991	149.1	80
1988	53.4	160	1991	158.0	160
1988	49.4	160	1991	156.8	160
1988	68.9	160	1991	157.0	160
1988	49.9	160	1991	166.0	160
1989	69.6	0			
1989	70.3	0			
1989	59.5	0			
1989	87.6	0			
1989	79.0	40			
1989	103.2	40			
1989	108.0	40			
1989	122.2	40			
1989	105.5	80			
1989	121.9	80			
1989	111.7	80			
1989	146.8	80			
1989	138.8	160			
1989	116.6	160			
1989	128.0	160			
1989	123.1	160			

Table B.3. Data for Nitrogen Application for Ammonia, Becker, MN, 1987-1990.

Year	Corn Yield (bu/acre)	N Applied (lbs/acre)
1987	205.8	80
1987	220.5	160
1987	218.9	240
1988	161.2	80
1988	157.6	160
1988	166.7	240
1989	199.5	80
1989	206.2	160
1989	214.1	240
1990	121.2	80
1990	159.0	160
1990	157.1	240

Table B.4. Data for Nitrogen Application for Ammonia, Waseca, MN, 1987-1990.

Year	Corn Yield (bu/acre)	N Applied (lbs/acre)
1987	156.2	0
1987	188.9	80
1987	191.4	160
1988	115.8	0
1988	116.1	80
1988	120.4	160
1989	135.4	0
1989	175.5	80
1989	77.3	160
1990	111.8	0
1990	170.5	80
1990	146.7	160