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OPTIMAL RESIDUAL NITRATE NITROGEN LEVELS FOR IRRIGATED CORN AND EFFECTS OF NITROGEN LIMITATIONS

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ABSTRACT

Optimal use of applied nitrogen on irrigated corn on clay loam soils where accumulation of residual nitrate N occured was insensitive to changes in interest rates and fertilizer/crop price ratio changes. Soil tests are necessary to determine the correct N application. Deviations from the profit maximizing level affect both current and future profits.

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INTRODUCTION

There has been considerable emphasis placed on reducing the cost of crop production because of declining farm prices and the related farm credit crisis. While fertilizer expenditures constitute only 10 to 15 percent of the total variable cost they may present a tempting point for cost cutting. However this requires an awareness of the appropriate fertilizer application rates for various crops and soil types.

The objectives in this paper are to examine the effects of (a) residual nitrate nitrogen levels on the optimal use of applied nitrogen for irrigated corn and (b) fertilizer limitations on producer returns for soils in which nitrogen accumulation has been shown to occur.

EMPIRICAL ESTIMATION OF RESPONSE AND A FERTILIZER CARRY-OVER FUNCTIONS

Several researchers, (eg., Carter (1974); Roberts (1980); Hooker et. al. (1983)), have reported accumulations of residual nitrate nitrogen in sufficient quantities to affect crop yields. Onken et. al. (1972, 1985) found the best regression fit for crop response to applied N was obtained when residual NO_3^--N was included as a separate explanatory variable. The authors found the marginal rate of substitution between applied and residual N to be influenced by the amount of residual NO_3^--N, the depth of the soil measurement, and the maximum grain yield.

Following Onken et. al. (1985), a second-order polynominal function was used in this study to approximate the response of corn to applied and residual NO_3^--N in the soil profile. The amount of NO_3^--N in the top six inches of the soil profile was used in the response function because of the correspondence with the measurements made by farmers in taking soil samples. Onken and Sunderman (1972) reported that measurements of NO_3^--N in the top surface of the soil are sufficient to measure the N supplying capacity of the soil. The fit of the response function in Table 1, was not substantially improved when measurements of residual NO_3^--N at other soil depths were used. The time series-cross section (PROC TSCS) routine in SAS was used for the response function estimation. This routine was used to compensate for non-independence of the error terms since the same treatments were applied to the same plots between 1976 and 1981. The signs of the coefficients for the response function were as expected including negative signs for the quadratic terms and for the interaction term between applied and residual NO_3^--N. At the 5 percent level the t values indicate the individual regression coefficients with the exception of the intercept coefficient were significantly different from zero. The TSCS procedure does not provide an estimate of the R^2 but the estimate of the R^2 from the OLS routine for the same response model was 0.74.

Since residual NO_3^--N is a factor of production, any systematic change in the amount of residual nitrate nitrogen which is caused by crop management is important. The relevant management question is whether or not current Nitrogen application rates affect future residual resident soil Nitrate values. In this study the amount of residual NO_3^--N in the top six inches of the soil profile was related in a linear form to the amount of N applied the previous year and to the amount of residual NO_3^--N in the same profile the previous year. The regression coefficients of Table 2 indicate that 12.25 pounds of residual NO_3^--N would be present each year from natural causes while each pound of N applied in one year would add .04

TABLE 1. Estimated Regression Coefficients for corn yield response function

Variable	Coefficient	Standard Error	t value
		Corn Yield Response	
Constant	19.6318	12.65	1.55
N_2	1.10665	.1249	8.86*
N^2	-2.8279×10^{-3}	$.5632 \times 10^{-3}$	-5.02*
$NO_3^- -N$	3.2339	.5497	5.88*
$(NO_3^- -N)^2$	-1.87493×10^{-2}	$.4529 \times 10^{-2}$	-4.14*
$N(NO_3^- -N)$	-4.73736×10^{-3}	$.1300 \times 10^{-2}$	-3.64*

*Coefficients significant at .1 percent level

TABLE 2. Estimated Regression Coefficients for Residual NO_3^--N Carry-Over

Variable	Coefficient	Standard Error	t value
	Residual NO_3^--N Carry-over		
Constant	12.254	2.566	4.78**
Nt-1	.042	.0172	2.43*
$(NO_3^-$ N)t-1	.212	.0402	5.27**
	F value = 18.01	$R^2 = .36$	

*Coefficients significant at the 5 percent level

**Coefficients significant at the .1 percent level pounds to the top six inches of the soil profile in the following year. Each additional pound of residual NO_3^--N would add .21 pounds of residual NO_3^--N to the same top six inches the following year. The t values indicate the regression coefficients for the carry-over function were significantly different from zero even though the regression explained only 36 percent of the variation in residual nitrate levels. Alternative specifications and explanatory variables failed to markedly improve the results so the simple linear form was used in the study. However soil nitrates are subject to leaching so year to year weather variations can be expected to affect the amount of residual nitrogen in the crop root zone.

ECONOMICS OF FERTILIZER USE WITH SOIL TEST AND CARRY-OVER INFORMATION

The presence of the carry-over function means that the amount of N applied in one year affects the amount of residual NO_3^--N and consequently the rate of corn yield response from applied nitrogen in subsequent periods. The appropriate economic analysis as shown by Stauber et. al. (1973), Kennedy et. al. (1973) and Dillon (1977) is therefore dynamic rather than static. However an analysis of the static system is useful to certain producers and provides a point of comparison for the dynamic analysis.

STATIC SINGLE PERIOD ANALYSIS The producer who only looks one year ahead, such as a tenant with a one year lease (assuming marginal nitrogen costs and output returns are shared in the same proportion), would be most interested in the amount of applied nitrogen which would maximize single period profits. Single period profits are maximized by applying the amount of nitrogen which equate the marginal product of applied nitrogen to the per pound price of nitrogen divided by the discounted, harvest cost adjusted price of corn. The exact equation for calculating the marginal productivity of applied fertilizer is the first derivative of the response function shown in Table 1. The marginal physical product of nitrogen (in bushels) is

$$MPPn = 1.107 - .00565\ N - .0047\ (NO_3^{-}\text{-}N).$$

The quantity of residual NO_3^--N in the soil profile is determined by soil test. The market price of corn is adjusted by subtracting any per bushel harvesting, storage and selling costs. The corn price would then be discounted from the time of sale back to the date of the fertilizer purchase.

The sloping lines in Figure 1 are plotted from the MPP of applied N equation by inserting the indicated levels of residual NO_3^--N and then calculating the MPPn with various levels of applied N. The horizontal lines in Figure 1 represent the range of fertilizer/corn price ratios. Figure 1 indicates the variation in the optimal use of nitrogen from changes in corn and nitrogen prices to be less than 25 pounds per acre when the planning horizon is one year. The change in optimal level of applied nitrogen due to a 20 pound change in NO_3^--N values under constant prices is also less than 25 pounds. These results indicate that amount of N which should be applied in the short-run is as sensitive to changes in the soil test values as it is changes in prices within the ranges used in this study.

MULTIPERIOD DYNAMIC ANALYSIS. The optimal levels of applied nitrogen when considering multiple year effects were determined by maximization of the discounted value of nitrogen applications over a 10 year planning horizon. The model can be specified as, maximize L(Nt, Rt, Ht) =

$$\sum_{t=1}^{T} B_t[Py\ Y(N_t, R_t) - PnN_t] + \sum_{t=2}^{T} H_t(S(N_{t-1}, R_{t-1}) - R_t) + H_1(Ro - R_1)$$

$$N_t, R_t > 0, \text{ all } t,$$

Where T = the length of the planning horizon, 10 years

B_t = the discount factor for year t

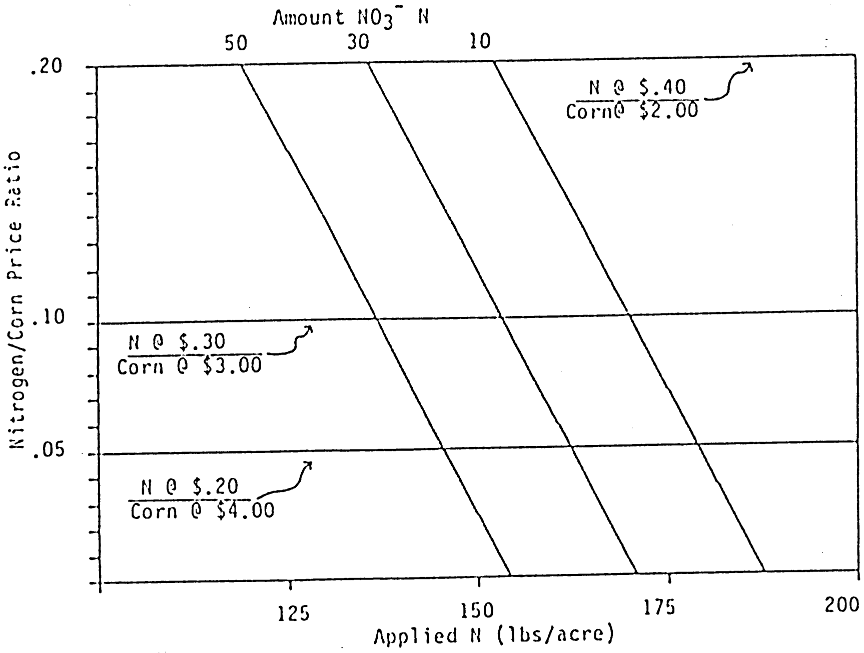

Figure 1. Applied Nitrogen for Maximum One-Year Profits With Alternative Nitrogen/Corn Prices and Residual NO_3^--N Levels in the Top Six Inches of the Soil Profile.

Py	= the price of the crop less per bushel harvest discounted to date of fertilizer purchase
Pn	= the price of applied nitrogen
R_t	= amount of residual NO_3^--N in the top soil profile in year t. Ro is given by the inital test
$Y(N_t,R_t)$	= yield of corn a given by the amount of applied and residual N
$S(N_{t-1}m\ R_{t-1})$	= amount of residual NO_3^--N
H_t	= Lagrangian multiplier for year t.

A ten year planning horizon was used for optimization to minimize the effect of the ending conditions on optimal nitrogen levels during the first years of the planning horizon. In practice, weather variabilities would dictate that the producer should retest the soil each year and reoptimize over a new planning horizon. The corn yield in each year was calculated from the response function in Table 1. The level of residual NO_3^--N for the first year was set at 10, 30, or 50 pounds to simulate the results of a soil test. The amount of residual NO_3^--N in each succeeding year was determined by the use of the carry-over equation shown in Table 1. The Box Complex (1967) routine was used to carry out the calculations for the dynamic optimization.

The projected nitrogen application rates, residual NO_3^--N values and resulting corn yields for producers with an initial soil test of 10 or 30 pounds of NO_3^--N are shown in Figure 2. Regardless of the initial soil test in each of the four economic scenarios shown in Figure 2 the optimal residual soil nitrate level converges to an equilibrium level between 24 and 25 pounds. Consequently the equilibrium nitrogen application rates varied between 157 and 174 pounds per acre and the resulting corn yields ranged from 172 to 175 bushels, respectively.

However the initial nitrogen application following the soil test is of most importance. Table 3 indicates that initial nitrogen application rate to maximize long run returns is 10-15 pounds of N per acre greater than the rate to maximize returns for a single year. The carry-over equation indicates the general trend of

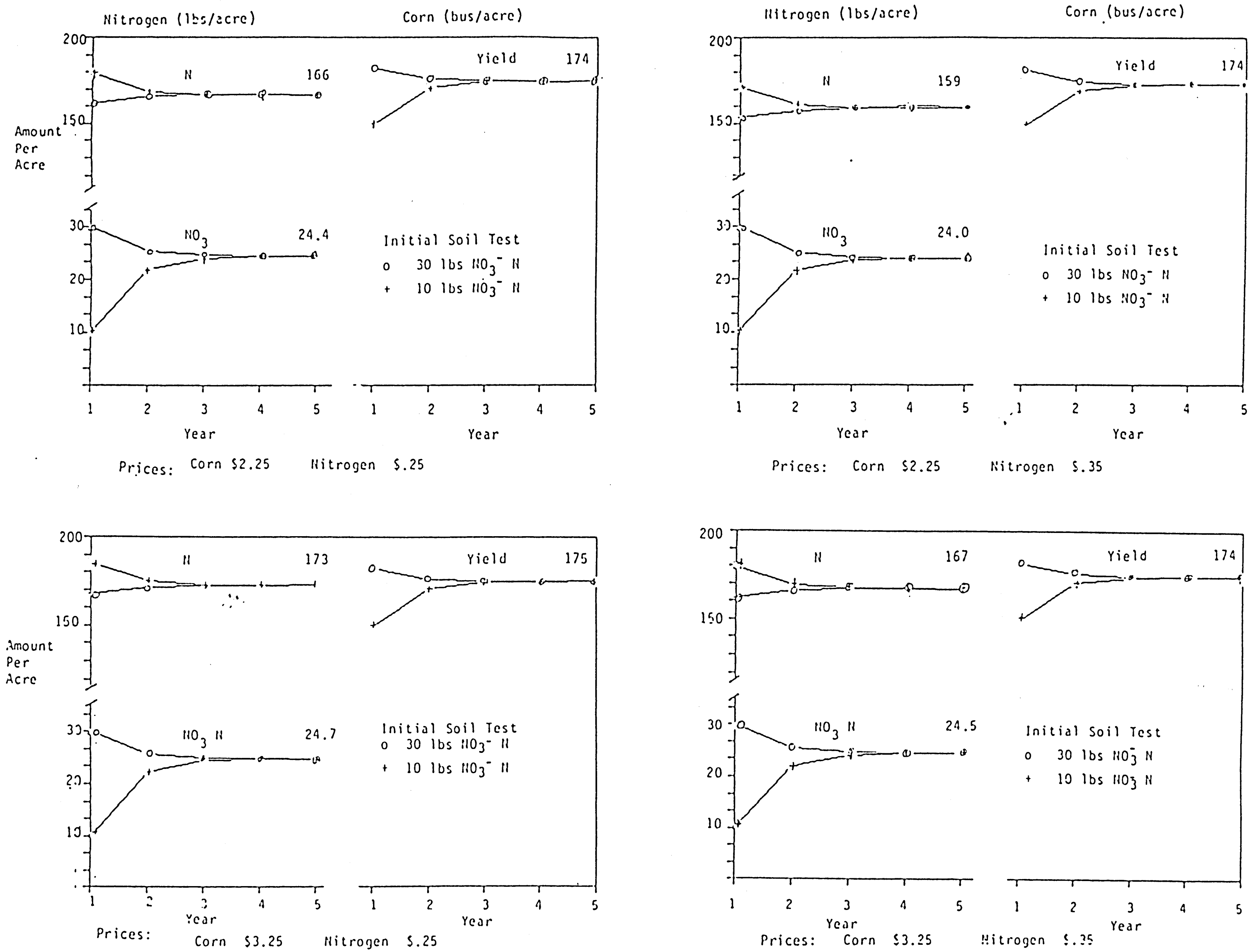

Figure 2. Derived Optimal Rates of Applied and Residual Nitrate Nitrogen Levels With Resulting Corn Yields Over a Five Year Period When the Initial Residual Nitrate Level was 10 and 30 Pounds Per Acre.

TABLE 3. Profit Maximizing Nitrogen Recommendations for the First Year of a 10 Year Planning Horizon and Single Year Profit Maximizing Nitrogen Recommendations.[a]

Corn price ($/bu)	Price N ($/lb) .25 Planning Period 1 Yr	.25 Planning Period 10 Yr	.30 Planning Period 1 Yr	.30 Planning Period 10 Yr	.35 Planning Period 1 Yr	.35 Planning Period 10 Yr
Soil Test = 10 lbs NO_3^--N per acre						
			pounds N per acre			
2.25	166	180	162	175	158	171
2.75	170	183	166	180	163	177
3.25	173	186	170	182	167	180
Soil Test = 30 lbs NO_3^--N per acre						
			pounds N per acre			
2.25	149	162	145	158	141	153
2.75	153	165	150	162	146	158
3.25	156	168	153	165	150	162

[a]Annual Discount Rate is 12 percent.

residual soil nitrates but is not a sufficiently good predictor to replace the annual soil test.

The equilibrium quantities of applied N, residual NO_3^--N and resulting corn yields in Table 4 are taken from the fifth year of the optimization process. These values indicate that under the parameters of the response and carry over functions in this study, the long run nitrogen application rates for corn on Pullman clay loam soils are nearly invariant to economic variables.

EFFECTS OF NITROGEN LIMITATIONS ON RETURNS, CORN YIELDS AND RESIDUAL SOIL NITRATES

Producers may apply less than optimal quantities of fertilizer because of a lack of knowledge of the appropiate level of fertilizer and/or because of expenditure limitations. This section examines effects of applying less than the optimal quantity of nitrogen fertilizer on irrigated corn produced on Pullman clay loam soils in the Texas High Plains. The price of corn grain at harvest time was assumed to be $3.25 per bushel or about $3.00 per bushel when discounted to the date of fertilizer purchase. The cost of one pound of nitrogen fertilizer applied was $.30 and the discount rate was 12 percent. The restrictions on applied nitrogen were considered "slight" to "moderate" where no more than 150 pounds could be applied and "severe" where no more than 100 pounds of N per acre could be applied. The duration of the restrictions was assumed to be one, two, or three years. The effects of the restrictions on net returns, corn yields, and residual soil nitrate values over a five year period are summarized in Table 5 and Figure 3. Figure 3 shows the changes over a five year period in levels of nitrogen applied, subsequent soil nitrate levels and expected corn yields for the cases where 150 and 100 pound nitrogen limits were imposed for a two year period. It was assumed that as soon as the restrictions on applied N were removed that the producer again followed a policy of

TABLE 4. Equilibrium Levels of Applied Nitrogen, Residual Soil Nitrate and Corn Yields with Alternative Corn Prices, Nitrogen Costs and Interest Rates.

	Equilibrium Quantities								
	Applied Nitrogen			Residual Nitrogen			Corn Yield		
Corn price ($/bu)	Nitrogen ($/lb)			Nitrogen ($/lb)			Nitrogen ($/bl)		
	.25	.30	.35	.25	.30	.35	.25	.30	.35
	--------lbs per acre----------			------lbs per acre------			----lbs per acre----		
				interest = 8%					
2.25	167.5	163.7	160.1	24.5	24.3	24.1	174.2	173.6	173.1
2.75	170.9	167.8	164.5	24.7	24.5	24.3	174.5	174.2	173.8
3.25	173.3	170.7	167.9	24.8	24.7	24.5	174.8	174.5	174.2
				interest = 12%					
2.25	166.7	162.5	158.8	24.5	24.2	24.0	174.1	173.5	172.8
2.75	170.1	167.0	163.9	24.6	24.5	24.3	174.5	174.1	173.7
3.25	172.4	170.0	167.2	24.7	24.6	24.5	174.7	174.5	174.1
				interest = 16%					
2.25	165.4	161.4	157.5	24.4	24.2	24.5	173.9	173.3	172.6
2.75	169.0	166.2	162.3	24.6	24.4	24.2	174.3	174.0	173.5
3.25	171.7	168.7	166.0	24.7	24.6	24.4	174.6	174.3	174.0

TABLE 5. Effect of Restricting Applied Nitrogen to 100 or 150 Pounds Per Acre for One, Two, or Three Years For Irrigated Corn On Pullman Clay Loam Soils.

	Initial Soil Test													
	10 Pounds							30 Pounds						
	Optimal Level	Amount Less Optimal Max Applied N(lbs/acre)						Optimal Level	Amount Less Optimal Max Applied N(lbs/ acre)					
		100 Length of Rest.			150 Length of Rest.				100 Length of Rest			150 Length of Rest.		
Year		1 yr	2yr	3yr	1 yr	2 yr	3 yr		1 yr	2 yr	3 yr	1 yr	2 yr	3 yr
	Applied Nitrogen (pounds per acre)													
1	183	-83	-83	-83	-33	-33	-33	165	-65	-65	-65	-15	-15	-15
2	172	4	-72	-72	1	-22	-22	169	2	-69	-69	1	-19	-19
3	170	1	4	-70	1	2	-20	170		3	-70		1	-20
4	170	-1	1	4				170		1	3			1
5	170	-1	-1					170			1			
	Yield of Corn (bus/acre)													
1	149	-21	-21	-21	-4	-4	-4	182	-14	-14	-14	-1	-1	-1
2	171	-6	-24	-24	-2	-4	-4	176	-4	-21	-21	-1	-3	-3
3	174	-1	-6	-23		-2	-4	175	-1	-5	-22		-1	-3
4	174		-1	-6			-2	174		-1	-6			-2
5	174			-1				174			-1			
	Net Return (dollars/acre)													
1	$394	$-40	$-40	$-40	$-2	$-2	$-2	$498	$-23	$-23	$-23	$1	$1	$1
2	462	-18	-50	-50	-7	-7	-7	478	-13	-41	-41	-3	-2	-2
3	472	-3	-19	-49	-1	-6	-5	475	-2	-17	-46	-1	-4	-4
4	473		-3	-18		-1	-5	474		-3	-18		-1	-5
5	474			-3			-1	474			-3			-1

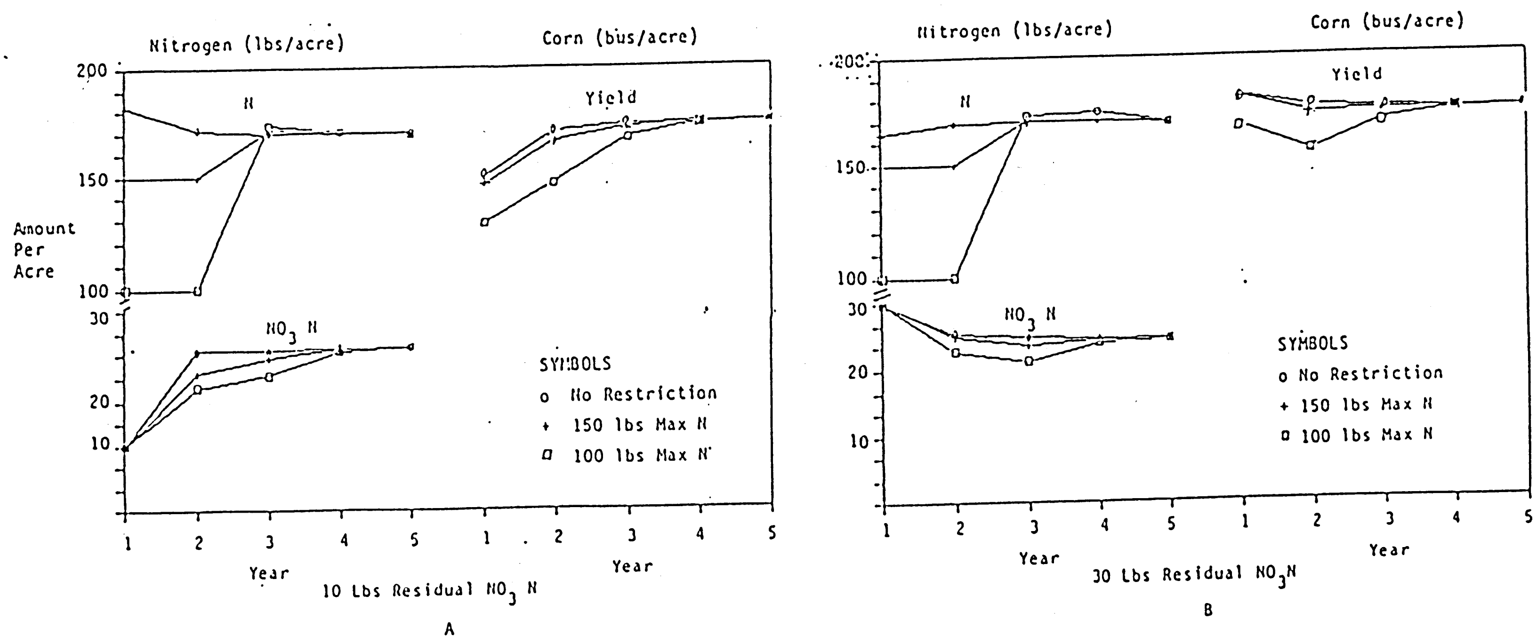

Figure 3. Effect of Limiting Applied Nitrogen to 100 and 150 Pounds Per Acre for Two Years Initial Residual NO_3 N Level 10 or 30 Pounds Per Acre.

maximizing long run returns. The no restriction line in Figure 3, represents the actions the producer would take if he were aware of the level of NO_3^--N nitrogen and applied the optimal amount of N each year to maximize the long run profits.

With 10 pounds of residual NO_3^--N in the top soil profile, the producer with no nitrogen limitation would apply 182 pounds the first year and would expect to apply 172 pounds the second year. The producer with a two-year limitation of 100 pounds of applied N, still had some buildup of residual NO_3^--N, but at a slower rate than producers who were less limited in the amount of nitrogen they could apply. The resulting corn yields for the producer with 10 pounds of NO_3^--N in the top soil profile who faced a severe N limitation increased over time but remained below the yields for producers with moderate or no limitations. After the lifting limitations in the third year (eg. credit became available), it was optimal for the producer who had applied only 100 pounds per acre for the first two years to apply more fertilizer than producers with lesser restrictions. However the third year yield for the severely restricted producer remained below those of producers with lesser restrictions. Under the assumed prices, when the producer had 30 pounds of residual NO_3^--N in the top soil profile, it was optimal for some mining of the residual NO_3^--N to occur. However the effect of the nitrogen limitations (Figure 3B) was to force this mining of residual NO_3^--N to occur at a rate which was faster than was otherwise desirable. With 30 pounds or more residual NO_3^--N, and a limit of 100 pounds of applied N, there was a small loss in yield the first year followed by a much larger loss the second year. Similarly, the yield following the lifting of the restrictions remained below the yields of producers who faced lesser restrictions.

The per acre differences in the level of applied N, residual Nitrate N, corn yields and producer profits are further detailed in Table 5. When a producer with 10 pounds of residual NO_3^--N in the top soil profile applied only 100 pounds of N, he was applying 83 pounds less than the optimal 183 pounds of N per acre. As a result his projected yield was 21 bushels per acre less than the optimal yield of 149 bushels. Consequently his returns over fertilizer cost were reduced by $40 per acre from what they would have been if the optimal quantity of 183 pounds had been applied. In column 1, in the second year the producer would optimally apply slightly more N than would the producer who was unrestricted the first year. However his yield was still 6 bushels less and his per acre profit would be $18 less than that of the unrestricted producer. That is the income reductions for the restricted producer continued for one period after the restriction was removed.

When the fertilizer limitation was 150 pounds per acre the income effects were more subtle. In the first year the producer restricted to 150 pounds actually increased income by one dollar over that of the unrestricted producer. This resulted from a one year reduction in fertilizer costs of $4.50 per acre and a revenue reduction of only $3.50. However the projected NO_3^--N for the restricted producer was less for the unrestricted producer, so in the second year the restricted producer faced a $3.00 per acre loss as compared to the unrestricted producer. The results in Table 5 indicate that a slight to moderate reduction in nitrogen application would have only a small impact on net income. the results also indicate that any income reductions will continue for at least one year after the time when fertilizer limitations are in effect.

A summary of the effects of nitrogen limitations lasting one, two or three years (Table 6) shows that even the slight to moderate nitrogen limitations resulted in discounted revenue reductions which were at least 50 percent greater than any savings in fertilizer cost. That is, a producer could afford to borrow money at very high rates of interest to bring nitrogen applications to their optimal long run level.

The exception was when the top soil profile initially contained 50 pounds or more NO_3^--N. In this case the unrestrained optimal nitrogen application was less than the 150 pound moderate limitation.

In summary, the long run demand for nitrogen on corn on Pullman clay loam soils was found to be fairly insensitive to changes in crop prices, fertilizer costs and interest rates. The long run profit maximizing nitrogen application rate was 20-30 pounds above the static short term profit maximizing rate. On an annual basis, having a soil test is extremely important in determining the appropriate fertilizer level. Even small reductions in nitrogen under optimal long run rate resulted in substantially greater reductions in revenue than in nitrogen cost. Income reductions resulting from nitrogen limitations will extend at least one year after the restrictions have ended because of reduced soil nitrate values.

TABLE 6. Discounted Differences in Fertilizer Expense, Value of Corn Produced, and Profits From A Limited Nitrogen Use Program.[a]

	INITIAL SOIL TEST NO_3^- N					
	10		30		50	
Years Limitation In Effect	Max Nitrogen (lbs/acre) 100	150	Max Nitrogen (lbs/acre) 100	150	Max Nitrogen (lbs/acre) 100	150
	(dollars/acre)					
	Reduction in Fertilizer Cost					
1	24	9	19	4	14	0
2	48	15	37	9	31	3
3	60	20	54	14	48	8
	Reduction in Revenue					
1	82	18	55	6	33	0
2	145	28	112	14	85	5
3	198	37	164	22	137	13
	Reduction in Profits					
1	59	9	36	2	19	0
2	102	13	75	5	54	2
3	138	16	112	8	90	5
	Reduced Revenue/Nitrogen Cost Saved					
1	3.4	2.0	2.9	1.5	2.4	-
2	3.4	1.9	3.0	1.5	2.7	1.7
3	3.3	1.8	3.0	1.6	2.9	1.6

a Calculated as the difference between the discounted amount under the optimal fertilizer program and the discounted amount under the restricted nitrogen over a five year period.

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