EFFECT OF UREA AND WHEAT STRAW INCUBATIONS ON SOIL AMMONIUM- AND NITRATE-NITROGEN

By

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AND NITRATE-NITROGEN

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CHAPTER I

INTRODUCTION

Minimum tillage of wheat has raised a number of questions concerning reduced availability of mineral nitrogen. Considerable research has been published concerning nitrogen immobilization-mineralization under field conditions where residue remains on the surface of the soil. The need for information applicable to Oklahoma soils is evident in updating current N fertilizer recommendations for minimum tillage conditions.

Urea has become an important N source for wheat fertilization and information is needed relating the effect of surface application where high amounts of wheat straw residue occur within the first few centimeters of the soil profile.

A preliminary step to updating N recommendations is obtained through laboratory incubation experiments regarding N and residue rates and their effect on the fundamental reactions involved.

CHAPTER II

EFFECT OF UREA AND WHEAT STRAW INCUBATIONS ON SOIL AMMONIUM- AND NITRATE-NITROGEN

Abstract

A laboratory experiment was conducted to study the effect of urea and wheat straw on N immobilization and mineralization in a Norge loam (Udic Paleustoll). Treatments consisted of a factorial arrangement of four levels of N and residue in a randomized complete block design. Nitrogen and residue rates were 0, 84, 168, 336 and 0, 1800, 3600 and 7200 kg.ha^{-1}, respectively.

Nitrogen immobilization increased significantly with added residue; however, there were no differences between 3600 and 7200 kg.ha^{-1} rates.

Multiple linear regression was used to develop surface response equations for each inorganic N fraction as affected by residue rate. A quadratic regression model was chosen to describe the relationship of extracted NH_4- and NO_3-N to N applied as urea over a twelve week incubation period. Ammonium-N decreased significantly with time regardless of N rate (R^2=0.78), however the prediction equation improved markedly when only the first three weeks were included (R^2=0.96).

Nitrate-N accumulation depended on N rate and decreased with added residue. At N rates of 168 kg.ha^{-1} and lower, NO_3-N increased slightly

the first week then declined to levels lower than observed initially. At a rate of 336 kg N ha^{-1}, NO_3-N increased significantly during the first five weeks for all residue levels. Using conventional techniques, mean recovery of applied urea-N as $(NH_4 + NO_3)$-N averaged over all residue levels were 13, 18 and 55% respectively, for 84, 168 and 336 kg N ha^{-1}. Low recovery was attributed to gaseous losses via ammonia volatilization or denitrification and/or immobilization.

CHAPTER III

LITERATURE REVIEW

Addition of mature plant residues having wide C:N ratios to soil has been shown to increase N immobilization resulting in decreased availability of N for plant uptake (2, 17, 18). Relative amounts of N required to meet the needs of the microflora decomposing the residue largely depend upon the kind of N supplied, nature, location and N content of material undergoing decomposition, moisture, temperature, pH, aeration and time of incubation (1, 2, 10, 12, 14, 15, 17, 18, 22). When low N residue is undergoing decomposition accumulation of mineral N takes place only when N applied is in excess of the needs of the soil microflora (18, 22).

Nitrogen immobilization and mineralization are processes that occur simultaneously; therefore, the use of conventional techniques in determining the components of the inorganic fraction indicate only net changes providing only limited information in actual N turnover (1, 2, 9, 15). Determination of absolute amounts being immobilized apparently requires the use of tracer techniques. Several experiments using ^{15}N have accumulated important information on soil N turnover as affected by residue additions (4, 5, 9, 20). From these and other studies it has been determined that immobilized N is present in an organic form, mainly amino acids, and is not evenly distributed within the native soil organic matter. This immobilized fraction has been reported to act as an organic pool from which net release of N takes place (6, 20). However, correlation of extracted N from a chemically "defined" fraction to a single component that consistently shows improved biological availability upon cultivation has not been very successful (13, 14).

Net release of N tied-up by soil microorganisms will depend upon a number of factors such as moisture, temperature, nature and C:N ratio of organic material undergoing decomposition and salt concentration (1, 14, 15, 23). Significantly higher and faster release of immobilized N has been observed when readily available carbon sources such as glucose are added to soil as opposed to slower release as observed during decomposition of materials such as wheat straw (1). Soil microorganisms during immobilization may tie-up N from ammonium as well as from nitrate, but in the presence of both, ammonium is usually preferred (12, 22).

Nitrogen available for plant uptake is at least partly produced by soil microorganisms even when fertilizer N had been recently applied to soil (22). This observation supports the existence of an interchange of fertilizer N for native soil N during N immobilization and mineralization. Nitrogen immobilization apparently occurs early after fertilizer and/or residue additions and results in an initial period of very rapid decrease in the level of inorganic N which reaches a minimum within two weeks or less (1, 5).

By use of conventional techniques, relative recovery of applied N as extracted inorganic (NH_4+NO_3)-N is often used as a measure of net immobilized-mineralized N. However, significant losses of N under conditions favoring immobilization have been reported (4). Among other competing processes that in addition to N immobilization utilize applied

N are volatilization of ammonia, fixation by clay minerals, denitrification and formation of stable organic complexes by non biological means (5, 11, 16, 21, 24). Figure 1 presents a general diagram of the most important N transformations following urea application to soil.

The objectives of this study were: 1) To determine the effect of urea and wheat straw on soil extractable NH_4- and NO_3-N, and 2) To describe the surface response of NH_4- and NO_3-N as affected by urea-N and residue rates by multiple linear regression equations.

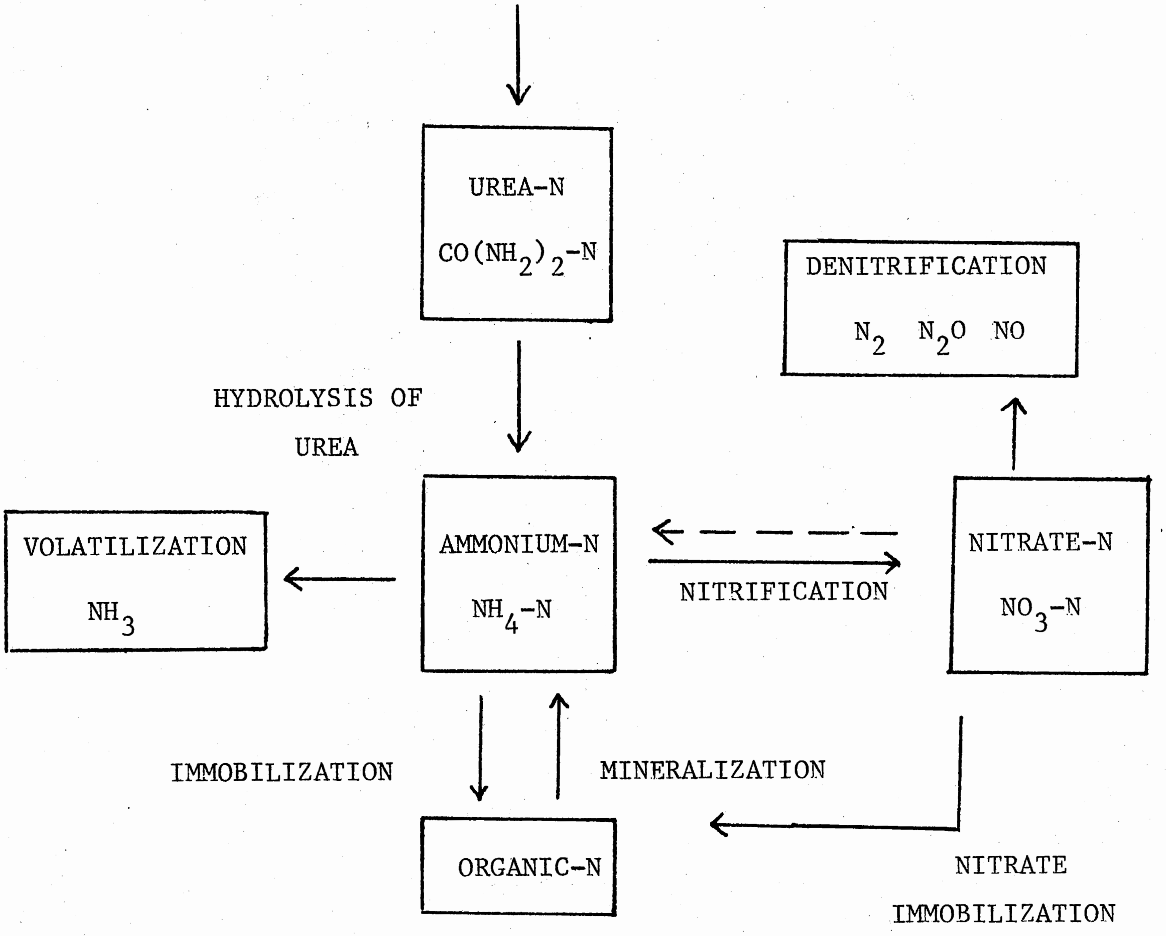


Figure 1. General Soil N Transformations Following Urea-N Application

CHAPTER IV

MATERIALS AND METHODS

A bulk sample (0 to 15 cm) of Norge loam soil was obtained from an experimental field at the Efaw farm at Stillwater, Oklahoma. Prior to incubation the soil was air dried for one week and ground to pass through a 2 mm screen. Standard petri dishes were used as incubation containers. To insure proper and uninterrupted movement of air through the dish, three galvanized paper clips were mounted on the base of each dish to raise its lid, leaving an opening of approximately 5 mm. A fifty gram sample of dry soil was spread in the dish to form a shallow layer about 5 to 10 mm thick. Prior to urea application and wetting of the soil, finely ground wheat straw was thoroughly mixed with the soil in each dish at rates calculated on the basis of weight of soil. Samples were brought to approximately field capacity ($0.28\ kg.kg^{-1}$) and the respective amount of urea was applied as a solution at rates calculated on the basis of weight of soil. Dishes were organized in twelve trays each one containing 16 treatments replicated three times. Trays were incubated in a constant temperature cabinet at $24 \pm 1^{o}C$. One tray was taken for each sampling day. During the incubation period the soil was not allowed to dry. Moisture level was checked by weight every two days and readjusted if necessary. Soil samples were taken at varying lenghts of time then inmediately frozen and kept in the freezer until they were analyzed. After the samples were thawed they were transferred to plastic bottles and 250 ml of 1N Na_2SO_4 solution was added followed by shaking for approximately forty five minutes. Samples were then transferred to buchner funnels mounted in suction flasks and leached with four additional portions of extracting solution. Leachates were transferred to 500 ml volumetric flasks and brought to volume. Aliquots were taken and urea hydrolysis was determined by measuring the decrease in urea concentration during the first 24-48 hours of incubation using the procedure outlined by Douglas and Bremner (7). Ammonium and NO_3-N were determined for all samples using a Technicon Autoanalyzer as described by Henriksen (8) and Selmer-Olsen (19), respectively.

A separate set of soil samples was incubated using small plastic cups containing 30 grams of soil. These were used to determine pH for each sampling date. In this experiment, only N rates were used as treatments with the exception of the last sampling date in which both N and residue levels were used to determine pH for all treatments. At the end of the experiment leached soil samples were saved and total N was determined by Kjedahl using the procedure described by Bremner (3).

A randomized complete block design in a 4x4x12 factorial arrangement of treatments was used. The four N application rates were equivalent to 0, 84, 168 and 336 $kg.ha^{-1}$. Wheat straw application rates were equivalent to 0, 1800, 3600 and 7200 $kg.ha^{-1}$. Soils were extracted at 12 intervals, 1, 2, 4, 5, 7, 12, 21, 28, 36, 52, 73 and 82 days.

CHAPTER V

RESULTS AND DISCUSSION

Urea Hydrolysis

Hydrolysis of urea proceeded at a rapid rate (Figure 2). After one and two days incubation, urea hydrolysis was 88 and 99% complete, respectively. Nitrogen rate did not significantly affect hydrolysis (Table I). Residue application did not affect urea hydrolysis. Urea was applied as a solution after the soil was moistened and this may have had a positive effect since urea solution allowed diffusion throughout the soil.

Another aspect of urea hydrolysis studies has to do with the relative effectiveness of stopping urease activity in the soil system after a given time interval. The technique used to determine urea calls for the addition of 5 mg of phenyl mercuric acetate per liter of extracting solution, which apparently acts as a urease inhibitor during the extracting procedure. In addition the soil samples were frozen after each time interval for a period of approximately 2 days. Relative values of detected urea were based upon the assumption that urease activity was effectively stopped at the given time interval. The disappearance of urea was highly correlated with the increasing amounts of NH_4-N detected over the first two days incubation.

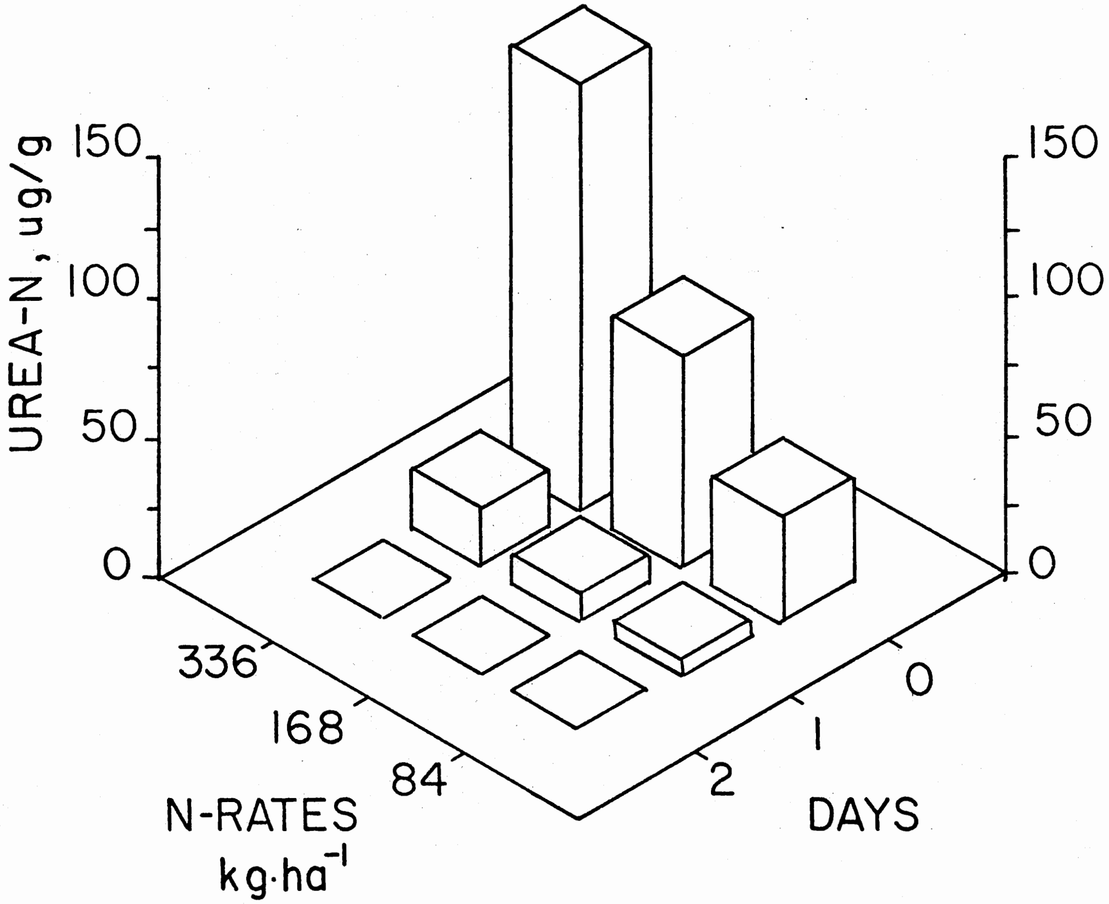


Figure 2. Effect of N Rates and Time on Urea-N in Soil Averaged Over Residue Rates

TABLE I

EFFECT OF N AND RESIDUE RATES ON PERCENT UREA-N HYDROLYSIS

Residue Rate kg.ha^{-1}	Incubation Time					
	One day			Two days		
	N Rate kg.ha^{-1}					
	84	168	336	84	168	336
0	83.7	86.0	85.6	98.7	98.8	98.7
1800	82.7	85.8	86.2	99.2	99.0	98.7
3600	84.6	87.0	84.2	97.2	99.4	99.3
7200	84.6	86.5	87.0	99.3	99.4	99.6

LSD (0.05)=4.9 for comparison between any two treatment means

Effect of N and Residue on NH_4-N

Effect of N rates

Extractable NH_4-N was affected significantly by N rates (Table II). Ammonium-N averaged over residue levels and all sampling dates is illustrated in Figure 3. Highly significant differences of NH_4-N at the 0.01 level were observed among all N levels.

The effect of N rates on extracted NH_4-N averaged over residue rates and sampling dates is presented in Table III. A nearly constant ratio of increasing NH_4-N with increasing N rates suggests that the effect of N rates may be linear within the range of application considered in this experiment. As NH_4-N decreased with time the effect of N rates became less pronounced as observed by the decrease in relative F values for the different incubation times (Table IV). This effect was also observed on the amount of extracted NH_4-N averaged over N and residue treatments for observed incubation intervals (Figure 4). Highly significant differences in NH_4-N were found between the initiation of the experiment and three weeks incubation. Ammonium-N concentration remained unchanged after 21 days incubation. The amount of extracted NH_4-N beyond 21 days appeared to be relatively unaffected by treatments. Ammonium-N concentration averaged over all residue rates decreased with time regardless of N rates (Figure 5). The least drastic change in NH_4-N concentration with time was observed for the 0 rate. The concentration of NH_4-N at the start of the experiment and after seven days were 9 and 2 ug/g of soil, respectively. Averaged over N rates and residue rates NH_4-N decreased at a rate of 3.3 ug/day for a period of 21 days. However, during the first week about 64% of the total N applied disappeared while the remaining 36% decreased over a two week period. This suggests that the rates were quite variable but tended to be higher during the first week of incubation. It also suggests that a nonlinear type of response was present. The disappearance of NH_4-N with time was mainly related to its transformation to nitrate during nitrification. However, other active processes such as loss of NH_3 by volatilization and/or tie-up by immobilization may be responsible for substantial amounts of NH_4-N unaccounted for. failure to recover applied ammonium as nitrate implies that losses of NH_4-N may have taken place by one or both of the pathways mentioned.

Effect of Residue Rates

Extracted NH_4-N as affected by residue addition averaged over N rates and all sampling dates is illustrated in Figure 6. Differences in NH_4-N were found among all residue levels. This suggests that disappearance of NH_4-N with time may be related to an increase in biological activity and consequent N immobilization. The analysis of variance showed an interaction of residue rates x days of incubation. An example of this interaction is illustrated for a N rate of 168 kg. ha^{-1} in Figure 7. A lower amount of extractable NH_4-N with increasing residue over time appears to be the relative effect of this interaction.

Regression Analysis for NH_4-N

Prediction equations for NH_4-N from N rates and incubation time were obtained for different residue additions using multiple linear regression. The highest R^2 values were obtained when quadratic terms were included as well as the interation term. Coefficients for the terms in the equation at the different levels of residue are reported in Table V. The equations were estimated by least squares regression using 144 raw data observations. R^2 values averaged 0.78; however, it was observed that the correlation was improved markedly when only the first three weeks were included. No differences on extractable NH_4-N were observed beyond this time interval. Based on this assumption, an entirely new set of equations was obtained and their coefficients are presented in Table VI.

Since the specification of an underlying functional form is a desirable step in response surface development, these equations appear particularly useful in describing response surface plots. A plotted response surface for the 0 residue rate is presented in Figure 8. A response surface plot may be created for any residue level within the range studied. The plotted model in Figure 8 fails to predict accurate NH_4-N concentrations at the 0 N rate in at least two situations. First, it predicts initial NH_4-N concentrations that are too high compared to the raw data, and second, its predicts negative values after incubation period beyond 10 days and later curves upward with increasing NH_4-N after 20 days incubation. This imposes severe limitations on the predicted values for low N rates.

TABLE II

ANALYSIS OF VARIANCE TABLE - AMMONIUM-N

Source	Degrees of Freedom	F Ratio[@]	OSL
Blocks	2		<.10
Treatments	191		>.005
N Rates	3	8337.5	>.005
Residue Rates	3	22.9	>.005
Days	11	4424.9	>.005
N Rates x Residue Rates	9	3.1	>.005
N Rates x Days	33	1030.9	>.005
Residue Rates x Days	33	9.4	>.005
N Rates x Residue Rates x Days	99	1.9	>.005
Error	382		
Total	575		

@ Error mean square=9.91

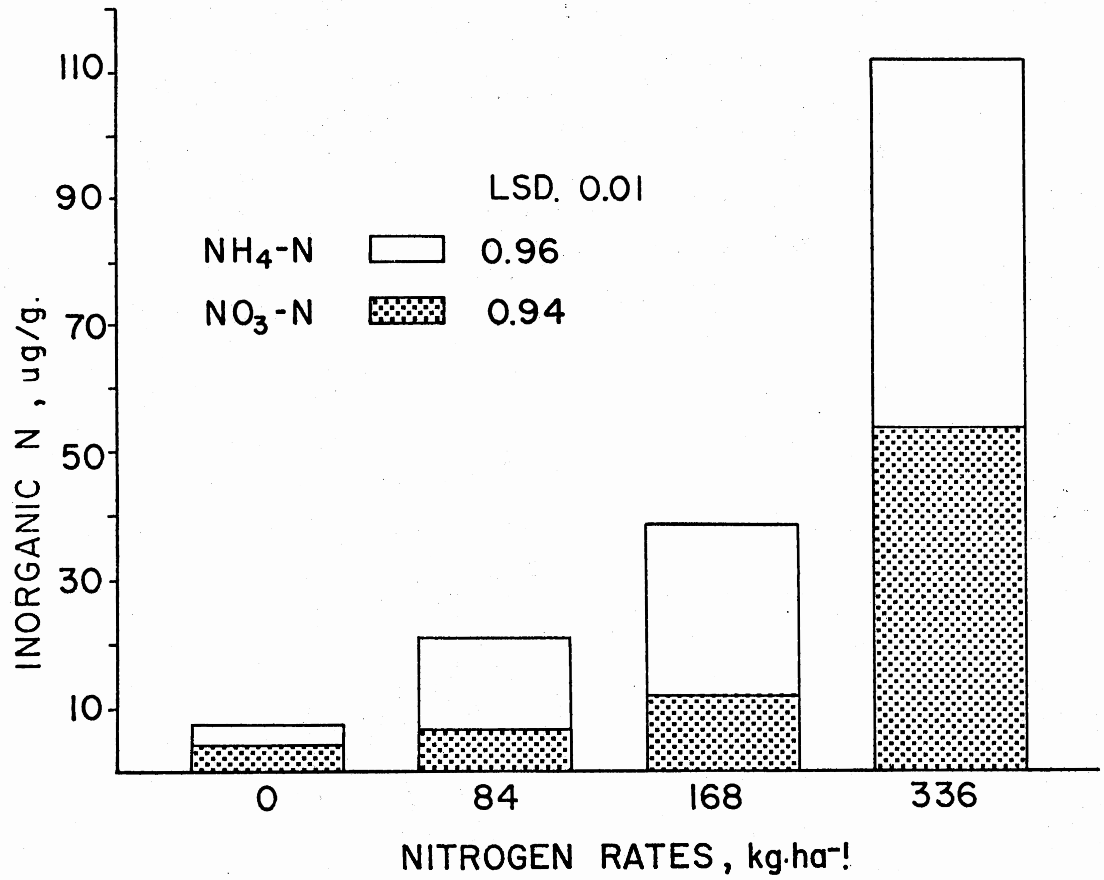


Figure 3. Effect of N Rates on NH_4- and NO_3-N Averaged Over Residue Rates and Time

TABLE III

EFFECT OF N RATES ON EXTRACTED NH_4-N, NO_3-N AND (NH_4+NO_3)-N AVERAGED OVER RESIDUE RATES AND INCUBATION TIME

N applied ug/g	NH_4-N ug/g	Ratio @	NO_3-N ug/g	Ratio	(NH_4+NO_3)-N ug/g	Ratio
0	3.68	-	3.99	-	7.67	-
37.5	14.05	0.37	6.71	0.18	20.76	0.55
75.0	26.58	0.35	11.90	0.16	38.48	0.51
150.0	58.87	0.39	53.63	0.36	112.50	0.75
LSD(0.01)	0.96		0.94		1.34	

@ The ratios on this table were obtained from dividing the amount extracted by the amount applied for each fraction

TABLE IV

SIGNIFICANCE OF N RATES, RESIDUE RATES AND INTERACTION ON EXTRACTED NH_4-N OVER TIME

Incubation days	F Ratio		
	N rates	Residue Rates	Interaction
1	868.0 **	0.1 -	0.2 -
2	4557.9 **	0.3 -	1.0 -
4	4708.4 **	6.9 **	1.2 -
5	2098.4 **	23.9 **	4.1 **
7	908.2 **	58.4 **	10.3 **
12	273.8 **	0.2 -	1.6 -
21	38.5 **	0.4 -	0.5 -
28	11.7 **	0.7 -	1.2 -
36	12.7 **	1.5 -	1.3 -
52	5.0 **	1.7 -	1.3 -
73	0.1 -	0.3 -	1.4 -
82	0.8 -	0.1 -	0.3 -

** Indicates significance at α=0.01
- Not significant at α=0.05

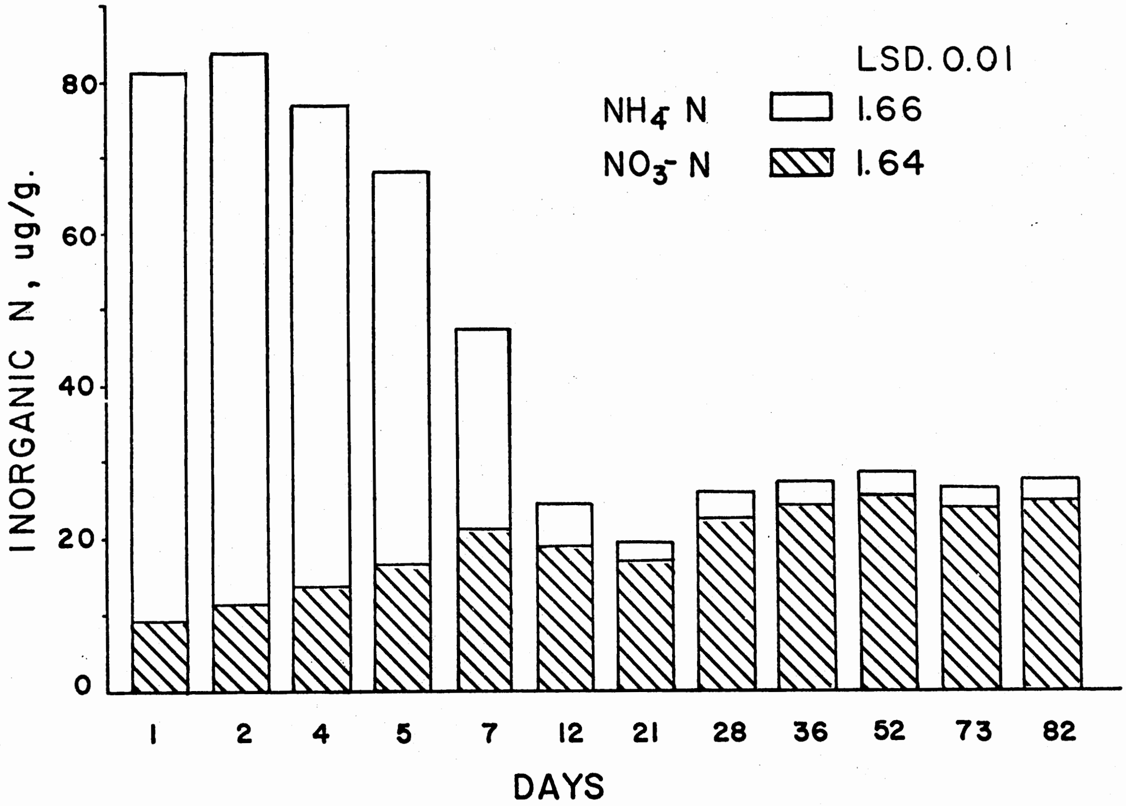


Figure 4. Effect of Incubation Time on NH_4^- and NO_3-N Averaged Over N and Residue Rates

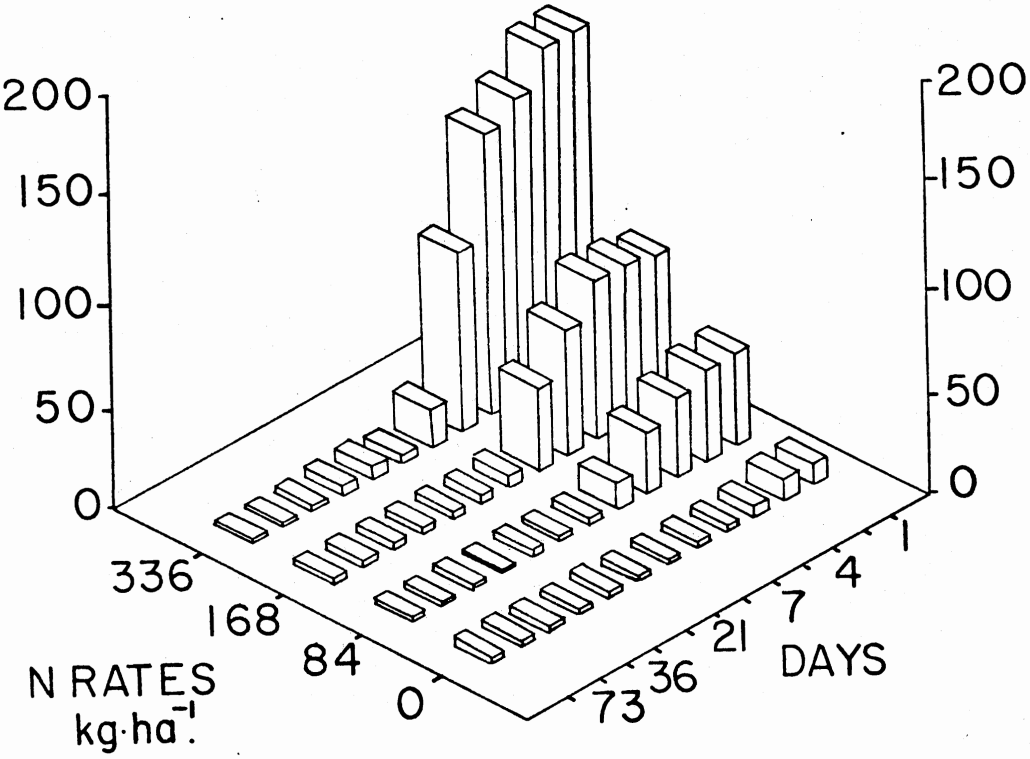


Figure 5. Effect of N Rates and Incubation Time on NH_4-N Averaged Over Residue Rates

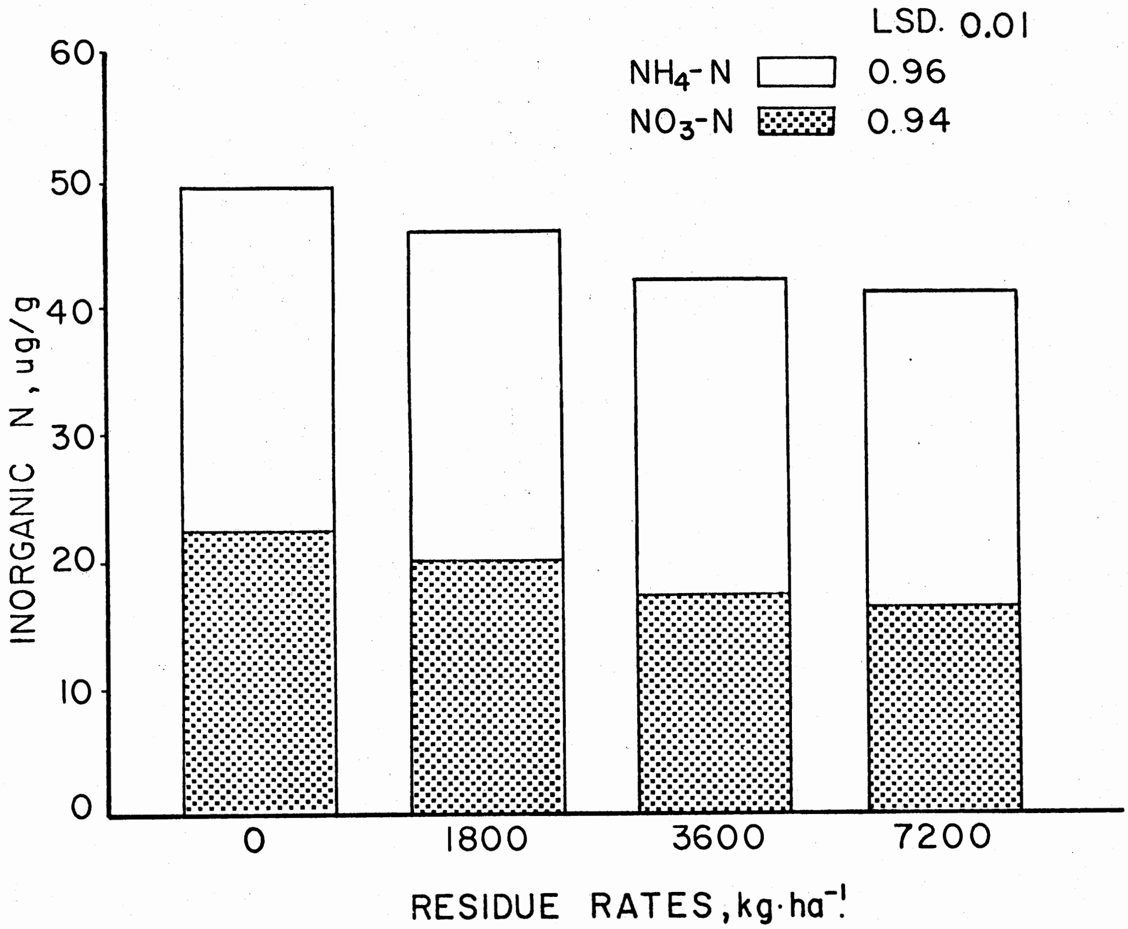


Figure 6. Effect of Residue Rates on NH_4- and NO_3-N Averaged Over N Rates and Time

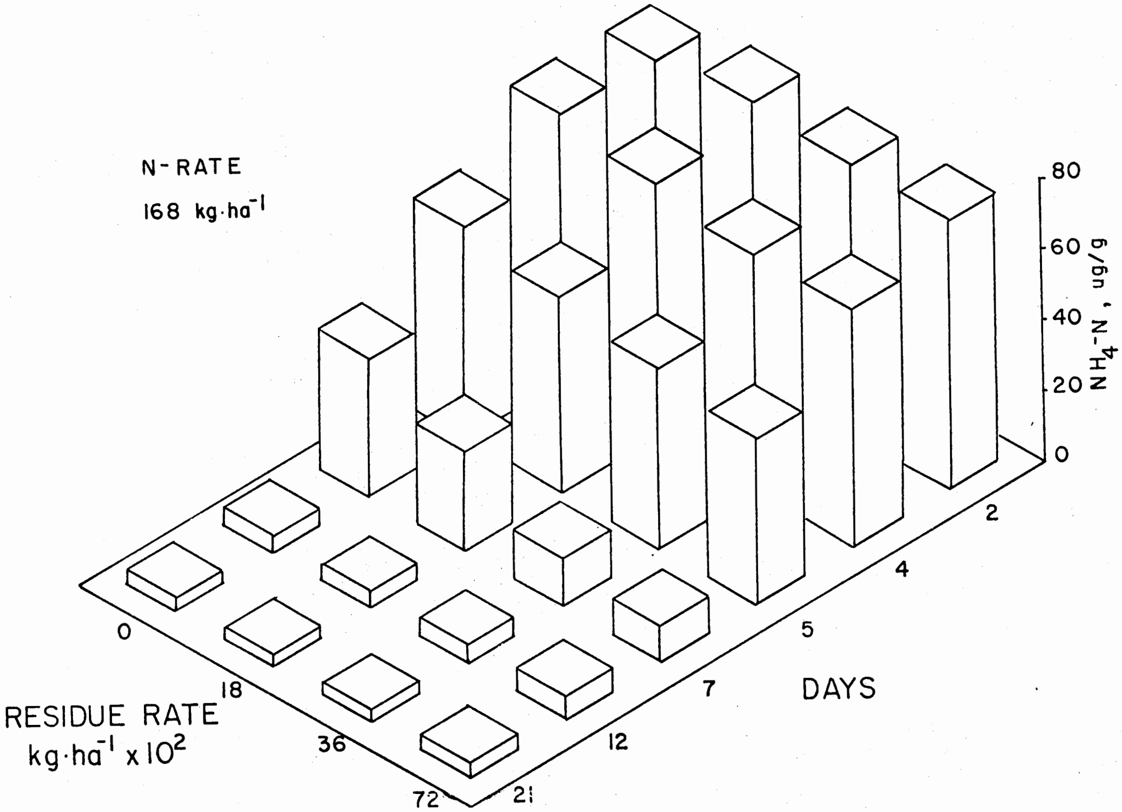


Figure 7. Effect of Residue Rates and Incubation Time on NH_4-N at Selected Sampling Dates

TABLE V

MULTIPLE LINEAR REGRESSION COEFFICIENTS TO PREDICT NH_4-N AT DIFFERENT RESIDUE LEVELS OVER TWELVE WEEKS

Residue Rates kg.ha^{-1}	Coefficients						R^2	Std Error of Estimate
	b_0	b_1	b_2	b_3	b_4	b_5		
0	22.54	0.267	0.00014	-2.247	0.029	-0.053	0.78	21.1
1800	21.48	0.256	0.00016	-2.187	0.028	-0.053	0.76	21.8
3600	20.30	0.239	0.00019	-2.128	0.027	-0.050	0.72	22.6
7200	20.49	0.295	0.00018	-2.091	0.027	-0.050	0.72	22.6

NH_4-N: ug/g; N: Nitrogen Rate, kg.ha^{-1}; T: Time in days

Model: $\widehat{NH_4}\text{-N} = b_0 + b_1N + b_2N^2 + b_3T + b_4T^2 + b_5NT$

TABLE VI

MULTIPLE LINEAR REGRESSION COEFFICIENTS TO PREDICT NH_4-N AT DIFFERENT RESIDUE LEVELS OVER THREE WEEKS

Residue Rates kg.ha^{-1}	Coefficients *						R^2	Std Error of Estimate
	b_0	b_1	b_2	b_3	b_4	b_5		
0	22.03	0.403	0.00022	-5.257	0.228	-0.026	0.96	10.6
1800	22.77	0.389	0.00026	-5.819	0.258	-0.026	0.96	11.1
3600	25.22	0.358	0.00033	-6.770	0.302	-0.026	0.95	12.2
7200	28.12	0.352	0.00030	-7.573	0.338	-0.025	0.94	12.7

* Regression analysis using observed data values for first 21 days

NH_4-N: ug/g; N: Nitrogen Rate, kg.ha^{-1}; T: Time in days

Model: $\widehat{NH_4}\text{-N} = b_0 + b_1N + b_2N^2 + b_3T + b_4T^2 + b_5NT$

$$\hat{Y} = 22.03 + .04\,N + .00022\,N^{2} - 5.26T + 2.56T^{2} - 2.56NT$$

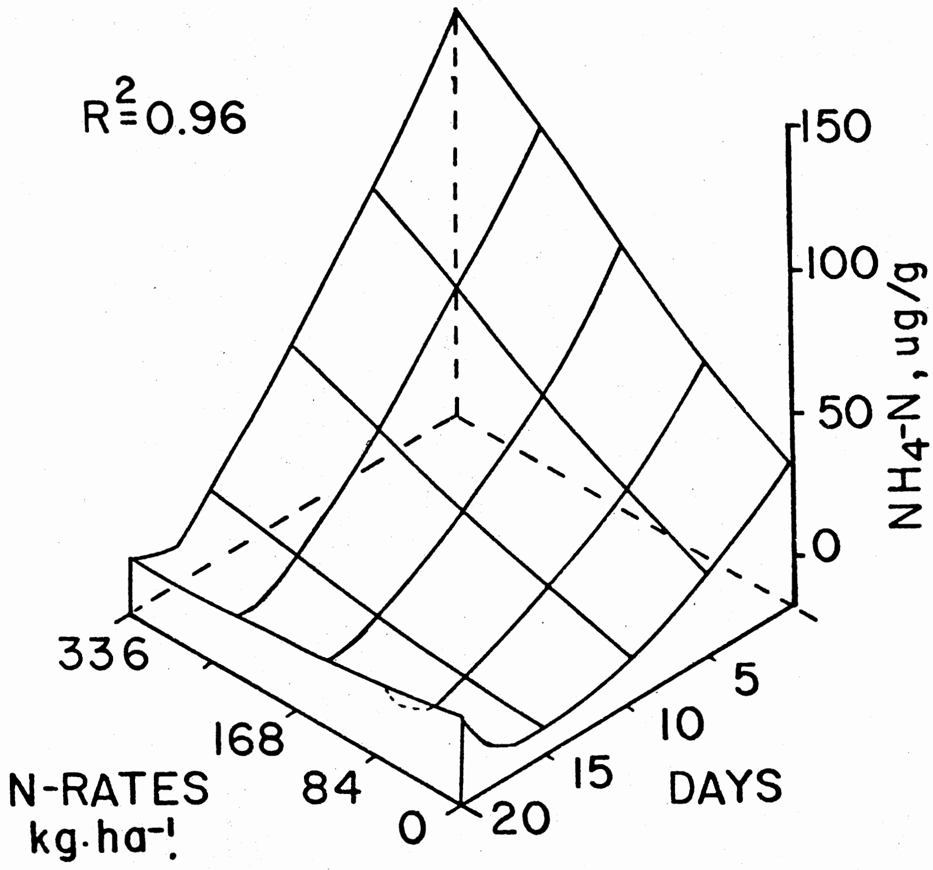


Figure 8. Response Surface of the Effect of Time and N Rate on NH_4-N in Soil Without Added Residue

Effect of N and Residue on NO_3-N

Effect of N Rates

Nitrate-N in soil was significantly affected by N rates (Tables VII and VIII). The highest detected amount corresponded to the 336 kg N ha^{-1} treatment. However, the mean obtained at rates of 84 and 168 roughly corresponded to 1/10 and 1/5 of that obtained at 336 kg N ha^{-1} (Table III). Relative recovery of applied urea-N as NO_3-N was affected at rates of 168 kg N ha^{-1} and lower, suggesting that either gaseous losses and/or N immobilization might be responsible for low recovery. Extracted NO_3-N averaged over N and residue rates increased with time up to five weeks incubation (Figure 4).

The effect of N rates and time on NO_3-N averaged over residue rates is shown in Figure 9. At rates of 168 kg N ha^{-1} and lower there was an increase in extracted NO_3-N over the first week followed by a sharp decrease. No simple explanation for this behavior is offered. However, it is especulated that active nitrification took place over this period, but later was counter balanced by immobilization as the residue started to decompose.

Effect of Residue Rates

The effect of residue rates on extracted NO_3-N averaged over N rates and time is presented in Figure 6. Addition of residue significantly affected the amount of extracted NO_3-N; however, no differences were found between 3600 and 7200 kg.ha^{-1} rates. Analysis of variance for NO_3-N showed interaction of residue and nitrogen rates. Lowest NO_3-N concentrations were observed at rates equal to or less than 168 kg N ha^{-1} with residue levels greater or equal to 3600 $kg.ha^{-1}$. Predominance of immobilization over mineralization would be expected at these rates. Substantial amounts of undecomposed organic matter were probably present in soil prior to incubation. Large pieces were removed by hand; however, small pieces may have remained to provide energy for immobilizing NH_4-N as well as NO_3-N. The effect of the interaction between N rates x residue rates x time is illustrated in Figure 10. It was observed that at a rate of 336 kg N ha^{-1} the presence of residue significantly decreased the amount of NO_3-N but only over the first four weeks of incubation. Beyond this time interval, no differences were observed. A rather different picture is presented for the 168 kg N ha^{-1} rate at which residue addition decreased NO_3-N overall sampling dates.

Regression Analysis for NO_3-N

Using multiple linear regression a prediction equation that included N rates, time, residue levels and their respective interaction terms was obtained. The inclusion of quadratic terms for all the main variables readily increased the prediction value of the equation, yielding, $R^2=0.78$. Coefficients for all the terms of the equation are presented in Table IX.

To provide equations that will allow plotting of response surfaces least squares regression was used to obtain four different equations that related extracted NO_3-N to N rates over time for each residue level. Coefficients for these equations are presented in Table X. An example of a response surface plot for NO_3-N using the equation for 3600 $kg.ha^{-1}$ residue rate is illustrated in Figure 11. The model fails

TABLE VII

ANALYSIS OF VARIANCE TABLE - NITRATE-N

Source	Degrees of Freedom	F Ratio[@]	OSL
Blocks	2	4.2	.05<OSL<.01
Treatments	191		>.005
N Rates	3	8160.6	>.005
Residue Rates	3	113.9	>.005
Days	11	159.2	>.005
N Rates x Residue Rates	9	17.2	>.005
N Rates x Days	33	420.5	>.005
Residue Rates x Days	33	5.2	>.005
N Rates x Residue Rates x Days	99	4.2	>.005
Error	382		
Total	575		

@ Error mean square=9.56

TABLE VIII

SIGNIFICANCE OF N RATES, RESIDUE RATES AND INTERACTION ON EXTRACTED NO_3-N OVER TIME

Incubation days	F Ratio		
	N Rates	Residue Rates	Interaction
1	0.9 -	0.4 -	1.7 -
2	3.3 *	0.4 -	0.6 -
4	26.0 **	8.8 **	0.5 -
5	73.5 **	14.9 **	5.5 **
7	610.3 **	78.6 **	14.8 **
12	623.6 **	26.7 **	8.5 **
21	507.6 **	11.6 **	6.0 **
28	1437.2 **	8.8 **	3.6 **
36	1445.8 **	4.3 *	1.9 -
52	1449.2 **	5.9 **	4.3 **
73	2490.7 **	10.4 **	5.7 **
82	3346.8 **	23.3 **	9.3 **

** Indicates significance at α=0.01
* Indicates significance at α=0.05
\- Not significant at α=0.05

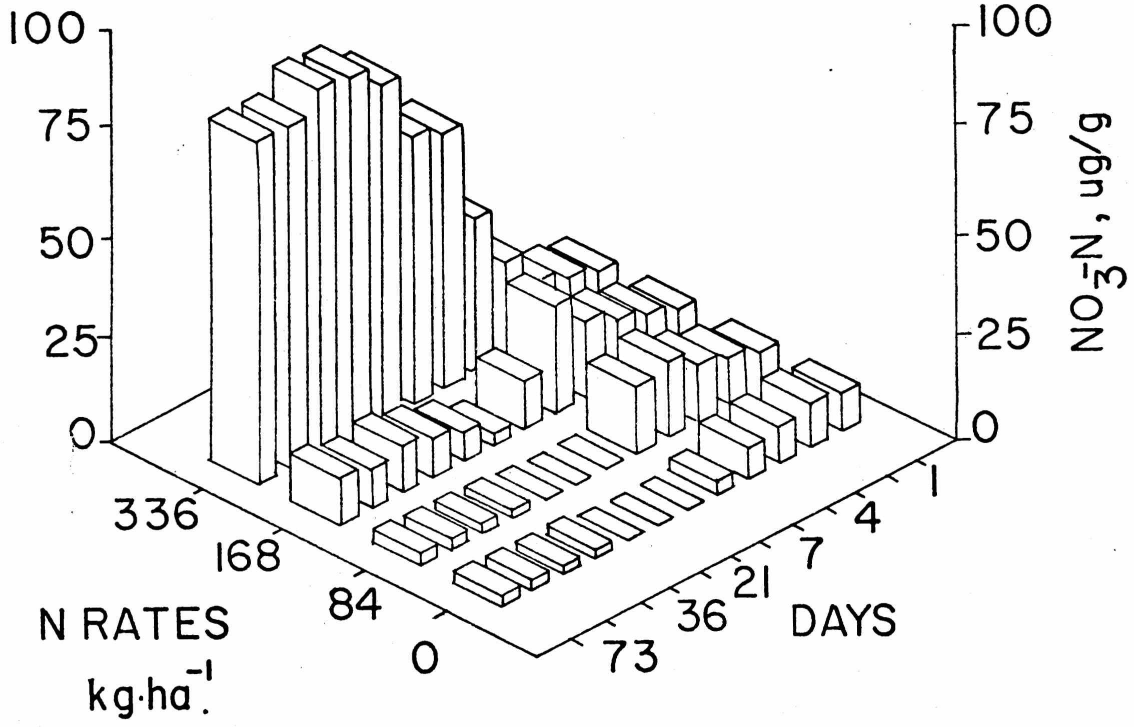


Figure 9. Effect of N Rates and Incubation Time on NO_3-N Averaged Over Residue Rates

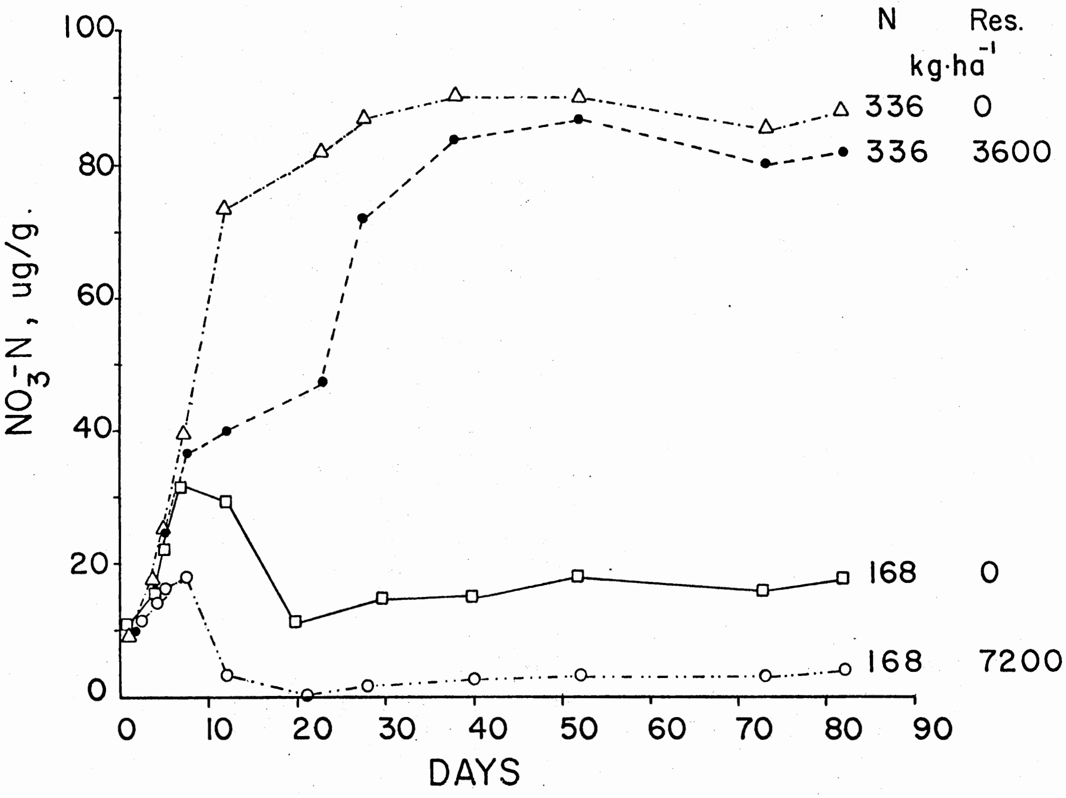


Figure 10. Effect of Two N and Three Residue Rates on NO_3-N Over Time

TABLE IX

MULTIPLE LINEAR REGRESSION COEFFICIENTS TO PREDICT NO_3-N USING N RATES, RESIDUE RATES AND TIME

Parameter	F Ratio	Significance	Coefficient
Constant			$b_0 = 13.56$
N	1304.18	**	$b_1 = -0.12$
N*N	177.29	**	$b_2 = 5.60*10^{-4}$
R	19.57	**	$b_3 = -2.14*10^{-3}$
R*R	4.45	*	$b_4 = 1.91*10^{-7}$
T	68.21	**	$b_5 = 1.65*10^{-3}$
T*T	19.94	**	$b_6 = -4.05*10^{-3}$
N*R	1.96	-	$b_7 = -7.51*10^{-7}$
N*T	3.98	**	$b_8 = 3.25*10^{-3}$
R*T	0.05	-	$b_9 = 6.25*10^{-6}$
N*R*T	0.86	-	$b_{10} = -5.40*10^{-3}$

* Indicates significance at $\alpha = 0.05$; ** Significant at $\alpha = 0.01$; - Not significant at $\alpha = 0.05$

NO_3-N: ug/g; N: Nitrogen Rate, kg.ha^{-1}; T: Time in days

Model: $\widehat{NO_3}\text{-N} = b_0 + b_1N + b_2N^2 + b_3R + b_4R^2 + b_5T + b_6T^2 + b_7NR + b_8NT + b_9RT + b_{10}NRT$

$R^2 = 0.78$; Std error of estimate=19.2

TABLE X

MULTIPLE LINEAR REGRESSION COEFFICIENTS TO PREDICT NO_3-N AT DIFFERENT RESIDUE LEVELS OVER TWELVE WEEKS

Residue Rates $kg.ha^{-1}$	Coefficients						R^2	Std Error of Estimate
	b_0	b_1	b_2	b_3	b_4	b_5		
0	10.46	-0.091	0.00048	0.067	-0.0049	0.0033	0.78	13.2
1800	9.80	-0.115	0.00054	0.039	-0.0042	0.0031	0.78	12.6
3600	10.89	-0.141	0.00057	-0.096	-0.0026	0.0031	0.78	11.8
7200	9.13	-0.158	0.00066	0.017	-0.0037	0.0029	0.80	11.6

NO_3-N: ug/g; N: Nitrogen Rate, $kg.ha^{-1}$; T: Time in days

Model: $NO_3\text{-N} = b_0 + b_1N + b_2N^2 + b_3T + b_4T^2 + b_5NT$

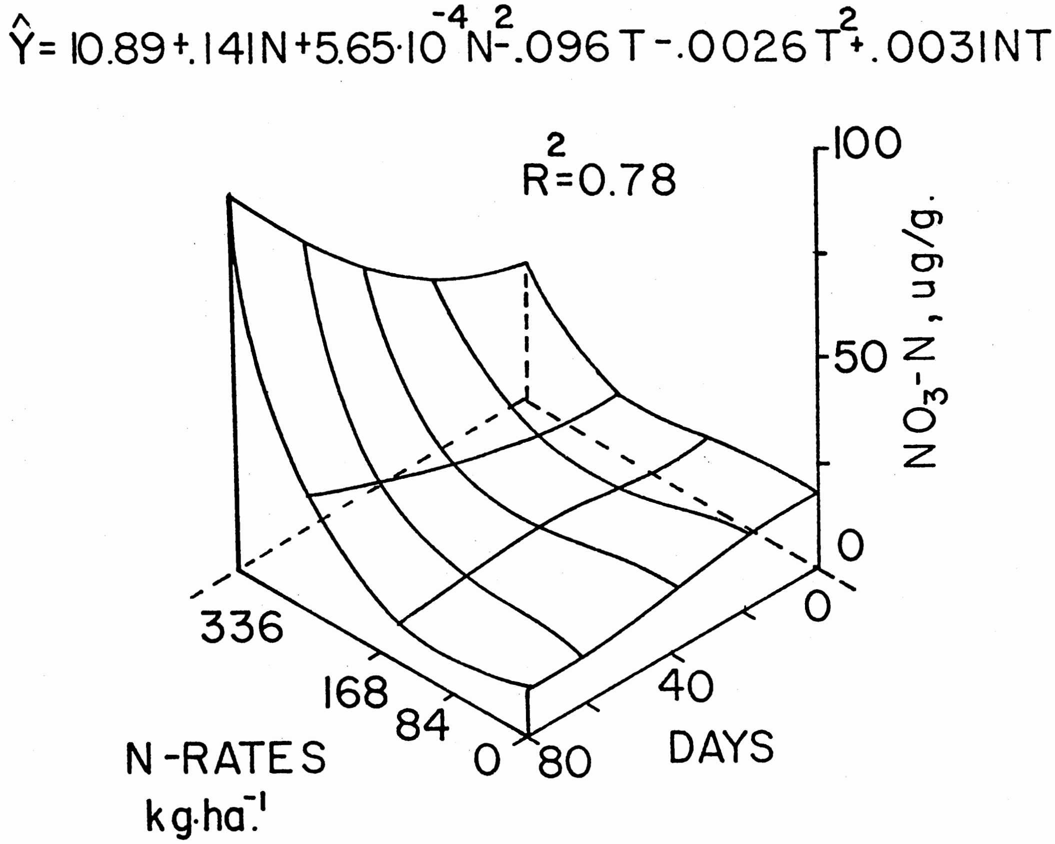


Figure 11. Response Surface of the Effect of Time and N Rate on NO_3-N in Soil Amended With 3600 kg.ha^{-1} Residue

to accurately predict initial NO_3-N concentrations at the early stages of incubation for the highest N rates. Predicted values are too high when compared to the raw data values.

Recovery of Applied Nitrogen

Mean percent recovery of applied N as $(NH_4 + NO_3)$-N for selected days incubation as affected by N and residue rates is reported in Table XI. Approximately 70% of the N applied as urea was unaccounted for by extraction of NH_4-N and/or NO_3-N over the entire incubation period . Recovery of NH_4- and NO_3-N from applied urea-N averaged over N and residue rates is shown in Figure 12. During the first two days while urea hydrolysis was occuring approximately 95% of the applied N was recovered as NH_4-N. As NH_4-N decreased with time, NO_3-N increased. After three weeks NH_4-N reached a minimum while NO_3-N increased up to five weeks. Since no increase in NO_3-N occurred after this date, N unaccounted for was apparently tied-up and/or lost from the system. The container used for incubation did not allow losses of soluble forms by leaching. Failure to recover appied urea-N by either NH_4-N and/or NO_3-N leads to the assumption that immobilization and/or gaseous losses took place as either NH_3 volatilization and/or denitrification.

Nitrogen Immobilization-Mineralization

Immobilization of inorganic N involves its transformation to an organic phase that is not easily detected using conventional techniques. While the N contained in the residue was a limiting factor on the development of the decomposing microflora an increase in inorganic N by fertilizer addition, apparently increased net immobilization. However,

TABLE XI

MEAN PERCENT RECOVERY OF UREA-N AS (NH_4+NO_3)-N FOR SELECTED INCUBATION PERIODS

Incubation days	Nitrogen* and Residue Application Rates kg.ha^{-1}											
	84				168				336			
	0	1800	3600	7200	0	1800	3600	7200	0	1800	3600	7200
7	91.4	72.0	43.5	10.2	88.9	71.6	48.9	35.4	80.6	74.6	66.2	59.3
12	12.1	5.7	5.0	6.1	43.1	21.9	6.0	8.6	60.5	56.1	45.7	46.7
21	4.8	6.5	6.0	5.2	18.6	3.3	3.6	4.3	57.0	48.2	34.4	42.9
28	8.9	9.1	7.1	10.9	22.9	10.2	8.3	5.8	61.0	59.3	50.6	55.4
36	9.0	8.4	8.7	11.0	21.8	20.3	11.3	5.6	62.5	59.2	57.0	56.7
52	10.7	9.6	11.3	12.1	26.6	24.4	12.0	10.7	60.7	57.7	58.9	57.0
73	10.6	11.4	12.3	11.8	24.5	22.2	7.4	6.5	57.6	55.9	53.9	52.7
82	14.6	11.9	14.3	11.2	30.2	23.3	11.3	6.5	58.7	53.9	54.9	53.7

* The amount of applied urea-N plus average of the amount present in the soil for the 0 N rate at a given period of time constitute 100%

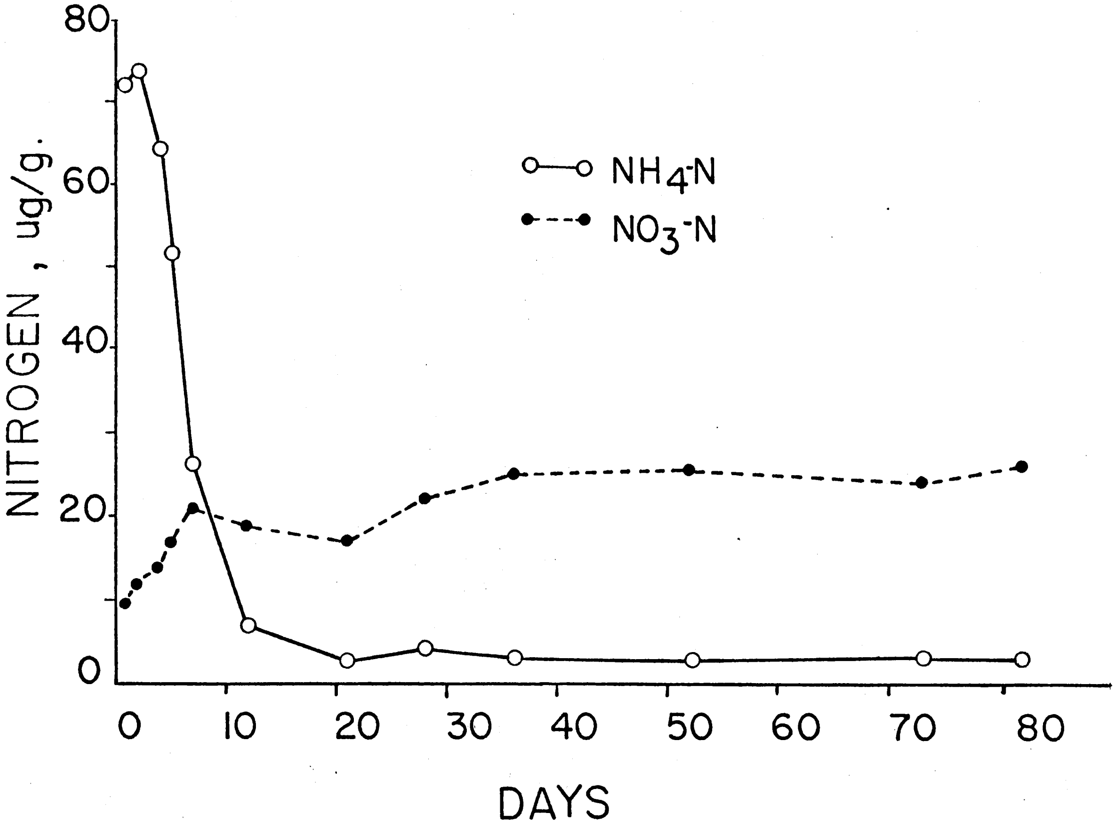


Figure 12. Effect of Incubation Time on Relative Recovery of NH_4- and NO_3-N Averaged Over N and Residue Rates

when the needs of the heterotrophic microorganisms had been met additional N remained unused by the system.

Nitrogen immobilization resulted in a decreased amount of extracted inorganic N. However, nitrogen recovery as NO_3-N was highly dependent on N and residue rate and an important N x residue interaction must not be overlooked. This interaction is clearly illustrated in Figure 10. Apparently between 168 and 336 kg N ha^{-1} there was enough N for the microorganisms decomposing residue that the nitrifying bacteria could compete effectively and nitrification occurred.

Table XII presents the results of total N for leached soil samples. Accuracy of the total N determination using conventional techniques was largely controlled by the degree of accuracy at which the normality and volume of the titrating acid could be determined. The total N content of the soil samples was low enough that no differences could be statistically determined. Percent differences found between 84 and 168 kg. ha^{-1} may be masking 100 ug N/g of soil that cannot be accounted for.

Ammonia Volatilization

Apparently, treated soil samples lost NH_3 during incubation. Young (24) demonstrated that gaseous losses of NH_3 are highly sensitive to the relative values of the diffusion coefficients of NH_4^+ and NH_3.

In this experiment, the diffusion of NH_4^+ was reduced mechanically due to the type of incubation container used. The thin soil layer ($<$ 1 cm) in each dish limited the effective depth of diffusion of NH_4^+ which may have resulted in a high concentration of NH_4-N in the soil solution. The overall rate of NH_3 loss from a soil system at a given temperature and pH is directly proportional to the relative concentration of NH_4-N and as concentration increases NH_3 losses will increase.

This reasoning supports the idea that NH_3 losses may have actually occurred during incubation. However, no tangible inferences can be made as to their extent nor their duration. During the first seven days of incubation, N recoveries were 91, 89 and 81% for N rates of 84, 168 and 336 $kg.ha^{-1}$, respectively, for treatments without residue. Approximately 90% of N was in the form of NH_4-N at this time and apparently volatilization increased with N rate (Table XI). Concentrations of NH_4-N as affected by N and residue rates for selected incubation periods are presented in Figure 13 and 14.

Denitrification

As nitrification takes place, gaseous losses by denitrification may occur if anaerobic conditions are present. An accumulation of NO_2-N is generally considered evidence of this condition. Even though the experimental procedure used allowed the determination of this ion, no differences were obtained. The only evidence of NO_2-N occured at the 336 $kg.ha^{-1}$ treatment, however the values observed were always less than 0.5 ug/g of soil. Concentrations of NO_3-N as affected by N and residue rates for selected incubation periods are presented in Figure 15, 16 and 17.

Effect of N Rates on Soil pH

A significant reduction on soil pH was observed at the end of the experiment for N rates equal or greater than 168 $kg.ha^{-1}$ (Table XIII). The increase on pH observed during the early stages of incubation was apparently a temporary situation and appeared to coincide with high amounts of extracted NH_4-N. As nitrification proceeded and began to accumulate pH decreased in soil incubated with 336 kg N ha^{-1}. The effect of N rates in pH over time is illustrated in Table XIV and Figure 18. At a rate of 336 kg N ha^{-1} soil pH decreased one unit from the check soil. At a rate of 168 kg N ha^{-1} pH decreased approximately 0.1 units. Residue rates had no effect on soil pH at the end of the experiment as observed in Table XIII.

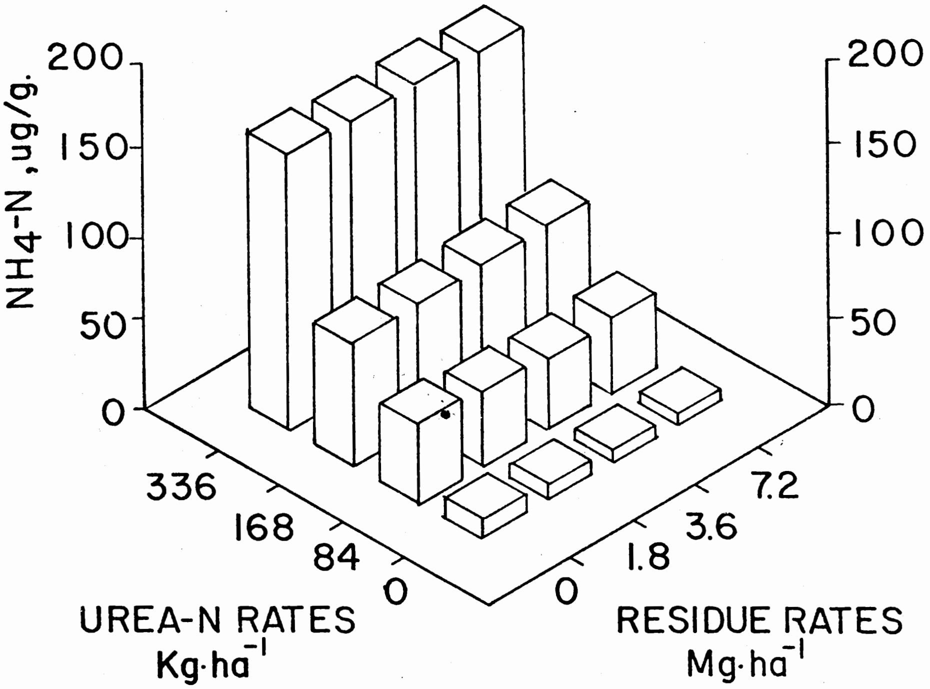
TABLE XII

EFFECT OF N AND RESIDUE RATES ON PERCENT TOTAL NITROGEN FOR LAST DAY OF INCUBATION

N Rates kg.ha^{-1}	Residue Rates kg.ha^{-1}				Mean
	0	1800	3600	7200	
0	0.08	0.07	0.08	0.07	0.08
84	0.08	0.08	0.08	0.09	0.08
168	0.09	0.09	0.09	0.09	0.09
336	0.09	0.09	0.09	0.09	0.09

LSD (0.05)=0.01 for comparison between treatment means
LSD (0.05)=0.01 for comparison between any two residue treatment

1 Day



7 Days

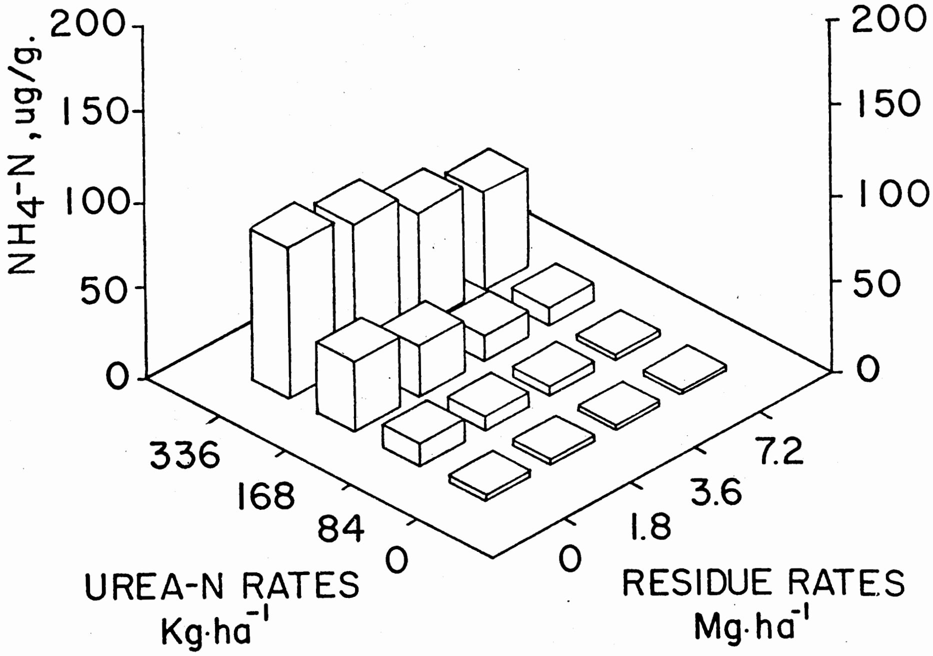
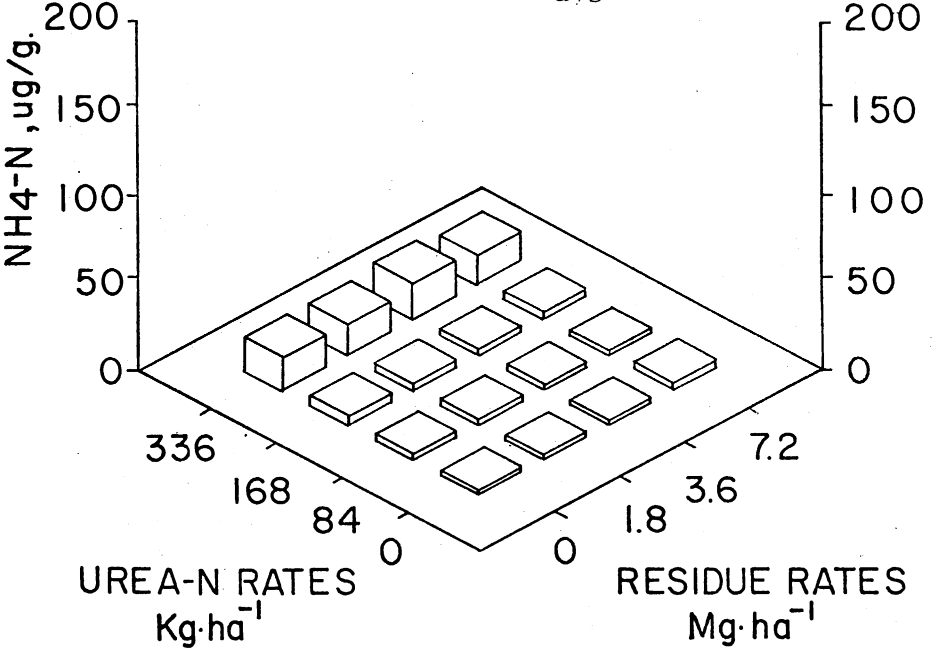
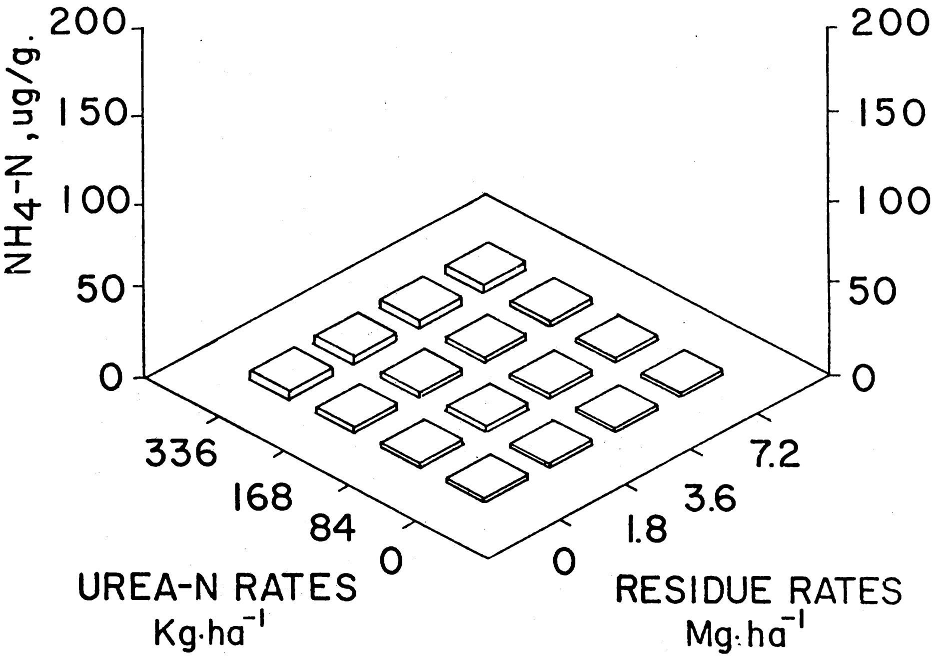


Figure 13. Effect of N and Residue Rates on NH_4-N For One and Seven Days Incubation, Respectively

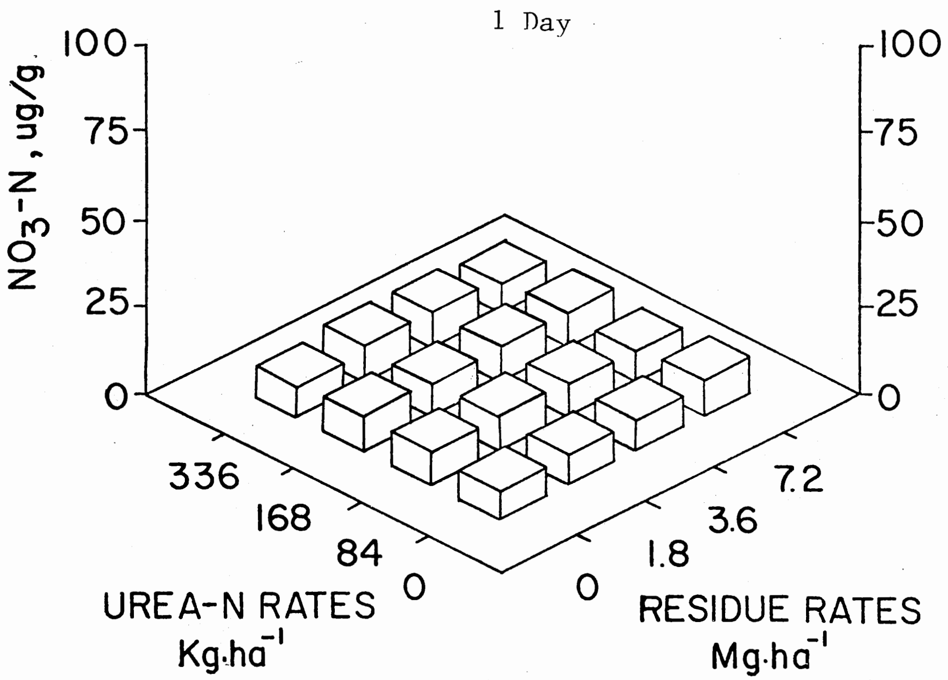


12 Days



21 Days

Figure 14. Effect of N and Residue Rates on NH_4-N For Twelve and Twenty one Days Incubation, Respectively


1 Day

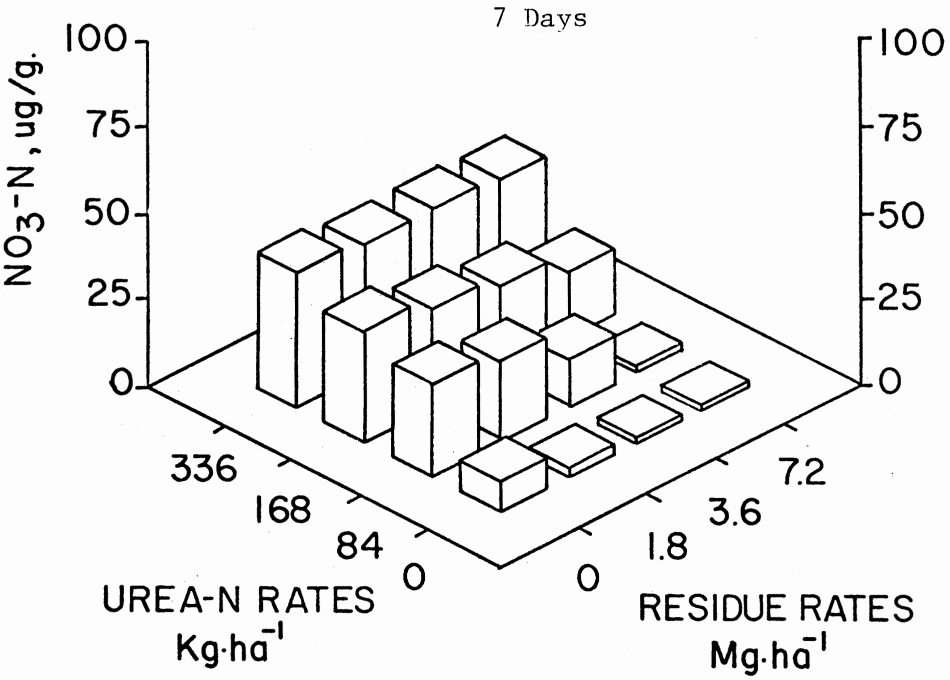
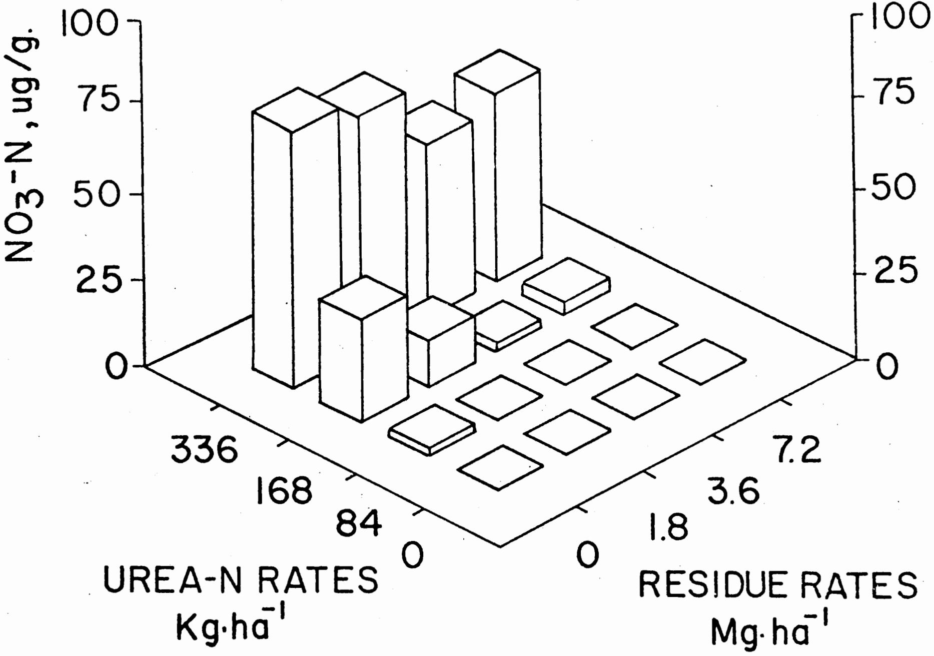

7 Days

Figure 15. Effect of N and Residue Rates on NO_3-N For One and Seven Days Incubation, Respectively

12 Days



21 Days

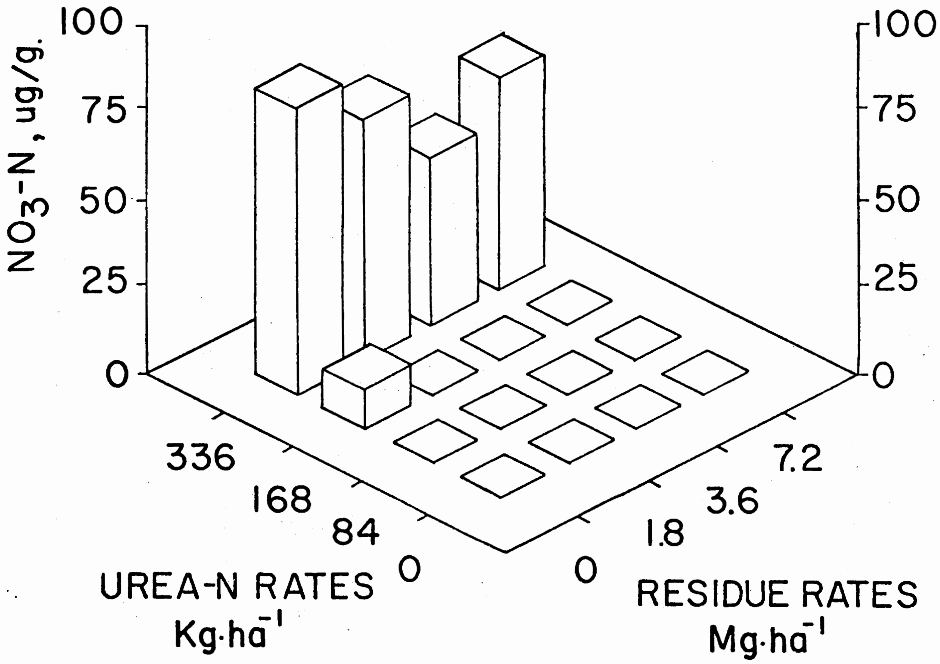
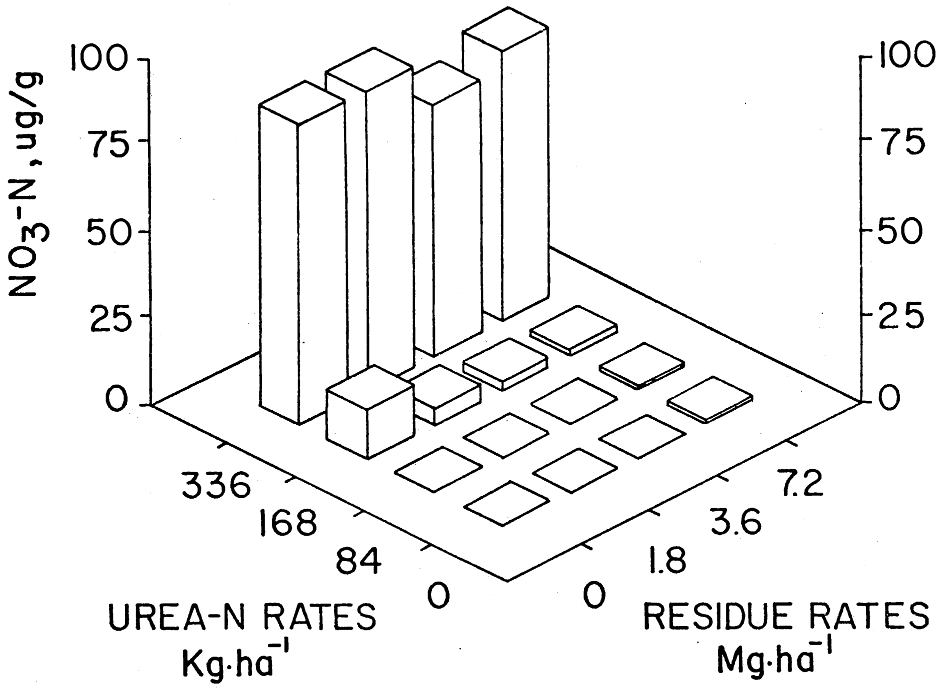


Figure 16. Effect of N and Residue Rates on NO_3-N For Twelve and Twenty one Days Incubation, Respectively

28 Days



36 Days

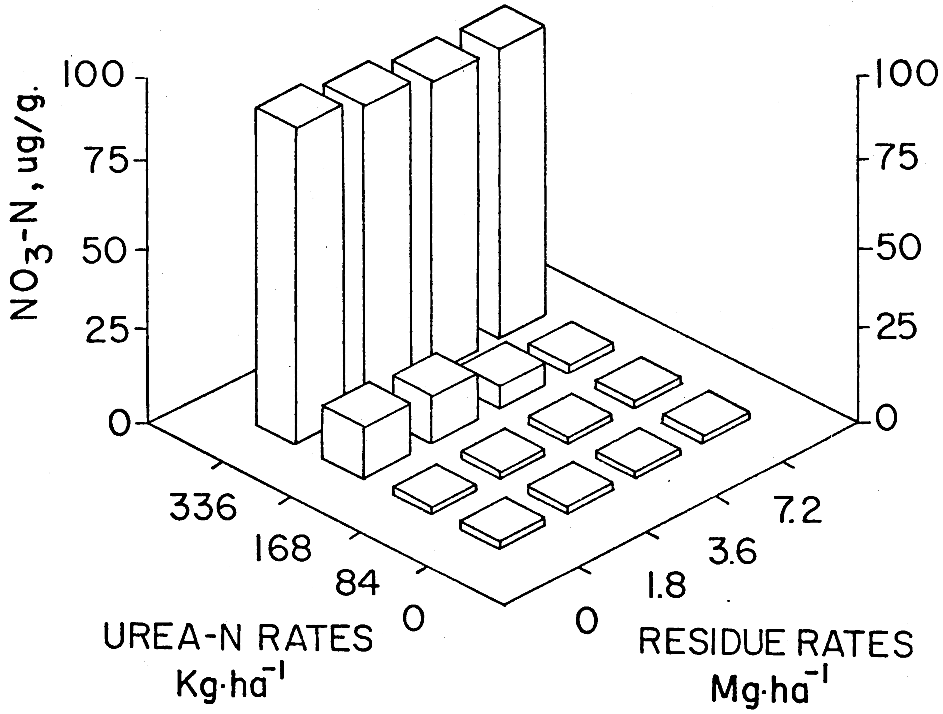


Figure 17. Effect of N and Residue Rates on NO_3-N For Twenty eight and Thirty six Days Incubation, Respectively

TABLE XIII

EFFECT OF N AND RESIDUE RATES ON pH FOR LAST DAY OF INCUBATION

N Rates kg.ha^{-1}	Residue Rates kg.ha^{-1}				Mean
	0	1800	3600	7200	
0	6.07	6.00	6.03	6.00	6.02
84	6.08	6.01	6.00	6.07	6.00
168	5.83	5.95	5.93	5.95	5.92
336	5.07	5.08	5.01	5.07	5.06

LSD (0.05)=0.06 for comparison between treatment means
LSD (0.05)=0.12 for comparison between any residue treatments

TABLE XIV

EFFECT OF N RATES ON pH OVER TIME

Incubation Days	N Rates kg.ha^{-1}			
	0	84	168	336
1	6.00	6.45	6.60	6.70
2	5.90	6.35	6.60	7.00
4	6.00	6.30	6.50	7.00
5	6.00	6.10	6.30	7.00
7	5.80	6.00	5.90	6.80
12	5.80	6.00	6.10	6.50
21	5.90	6.00	5.90	5.60
28	6.00	6.05	5.80	5.70
36	6.05	6.10	5.80	5.80
52	6.10	5.95	5.80	5.05
73	6.05	6.00	5.93	5.06

LSD (0.05)=0.16 for comparison between any two treatment means

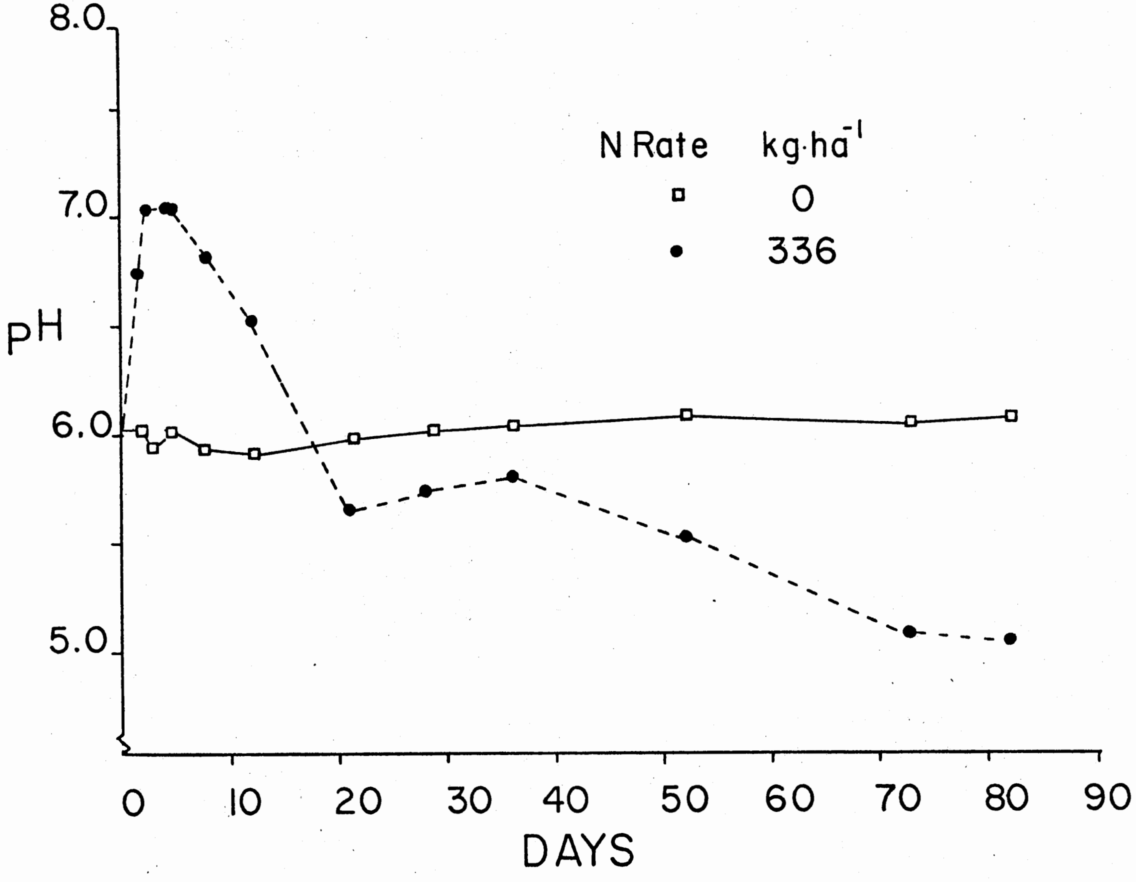


Figure 18. Effect of Two N Rates on Soil pH Over Time

CHAPTER VI

SUMMARY AND CONCLUSIONS

This laboratory study was aimed at evaluating changes in soil mineral N content (NH_4- and NO_3-N) resulting from surface urea fertilization with different levels of wheat straw residue over a twelve week imcubation period.

Urea hydrolysis occurred rapidly over the first two days of incubation regardless of N and/or residue rates. Ammonium-N decreased over the first three weeks while NO_3-N increased the first five weeks. Quadratic response models were derived for NH_4- and NO_3-N as affected by N rates and time for each residue level.

Extracted mineral N was highly dependent on N and residue rates. Decrease in mineral N due to residue application suggests that immobilization played an important role in N turnover during the first few weeks; however, gaseous losses by NH_3 volatilization and/or denitrification may have also occurred. The use of conventional techniques did not permit identification of mechanisms or extent of N loss. Therefore future laboratory research in this area should include ^{15}N to differentiate between N immobilized and N lost in gaseous forms.

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