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Yield and chemical composition of corn and nitrate movement in the soil as influenced by time of application and source of nitrogen

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# INTRODUCTION

The large quantity of N needed for the production of non-leguminous crops has resulted in a tremendous amount of research dealing with the effectiveness of N fertilizers. The source, rate, time, and method of applying N fertilizers are among the variables which have received the most extensive investigation. These studies have provided valuable information regarding the efficient use of N in the production of crops under a variety of soil and climatic conditions. Despite this fact, changes in crop production practices necessitate periodic reevaluation of certain fertilization techniques.

Several recent changes in corn production in the North Central region have created increased concern about the time of applying N fertilizers for this crop. The continued growth in the acreage of cultivated crops on individual farms has accentuated the importance of timing of field operations and the distribution of labor. The advantage of early planting of corn and the wide acceptance of this practice has reduced the time available for fertilizer application in the spring prior to planting. The trend toward narrower spacing between corn rows has made summer side-dressing of N more difficult. As a result of these changes, both farmers and fertilizer dealers have developed an increased interest in the possibilities of applying N in the fall for the following corn crop.

Research data indicate that under most conditions phosphorus and potassium fertilizers can be applied in the fall with little or no loss in nutritive value. Yield responses from fall applications of N have varied more with soil and seasonal weather conditions. Reduced efficiency of such applications has usually been associated with loss of N by leaching, denitrification and possibly other means.

Field experiments were therefore established in north central and northeast Iowa with the following objectives:

1. Evaluate fall, spring and summer application of N as they influence corn yields and chemical composition of corn leaves.
2. Use soil analysis to measure N movement in the profile and investigate possible relationships between time of N application, its position in the soil and the resulting corn yields.
3. Compare several N sources, including an experimental slow-release, sulfur-coated urea material, to determine their influence on corn yields when applied at different times.

# LITERATURE REVIEW

A study of the influence that time of N fertilizer application has on the final crop yield requires evaluation of many factors. Application of fertilizer N just prior to or during periods of rapid plant growth results in maximum uptake and utilization by the crop. Under these conditions N recovery by corn has been reported as approaching 80% of the applied N; however, recovery is more commonly in the range of 50 to 60%. Nitrogen not used by the crop may be immobilized by microorganisms and subsequently become part of the organic matter, may remain in the inorganic form in the soil and be available for future crop use or it may be lost from the soil profile. The very mobile nitrate form may be leached from the root zone if precipitation or irrigation exceed the soil water holding capacity and evapo-transpiration demands. Excess soil moisture may also contribute to poor aeration and result in anaerobic conditions favorable for denitrification, a process whereby nitrates are biologically reduced to gaseous compounds and become subject to loss from the soil.

The extent of N loss when present in the ammonium form is generally small. Volatilization losses of ammonia can be significant if an ammonium or ammonia-forming fertilizer is placed on or near the soil surface. Ammonium fixation and retention by clay minerals also occurs in some soils.

The possibility for losses by erosion exists where shallow incorporation of N fertilizers is practiced on sloping soils. Gaseous losses which occur during the nitrification process may also account for some of the N deficits.

The extent to which loss may occur by these various processes is clearly related to climatic conditions and the chemical and physical properties of the soil. The source of N fertilizer, and the time, rate and method of application are also factors affecting possible loss of fertilizer N. Reliable information regarding N losses is scanty because of the many interacting factors involved and because of the difficulty in directly measuring losses.

Application of N fertilizer to the corn crop has usually been associated with some of the cultural practices involved in preparing the soil or growing the crop. In areas where fall plowing is a common practice, N is often applied at that time. Such application occurs 6 to 8 months before maximum uptake by the crop, subjecting applied N to chemical and biological change and possible loss before needed by plants. Nitrogen is more commonly applied in the spring prior to planting. This practice reduces the period between application and uptake but still allows 2 to 3 months for potential loss. Sidedressing between the rows after crop emergence most nearly corresponds to the time of greatest uptake and minimizes losses but time and placement must be such that soil moisture is adequate for utilization of N by the crop. Timely rainfall or irrigation following sidedress application has usually resulted in the highest recovery of applied N by corn.

The literature relating to the influence of the time N is applied to corn will be discussed from a geographical standpoint; considering first, various regions of the United States where the extremes in climate and soil exist; secondly, the North Central region; and finally, the state of Iowa. In as much as possible the predominant mechanisms responsible for N loss will be considered under the differing environmental conditions.

United States

Dealing strictly with the theoretical approach, Nelson and Uhland (1955) have assembled climatic data for the eastern half of the United States to predict the areas where leaching of nutrients would be most serious. Average annual water surplus, defined as rainfall in excess of that held by the surface four feet of soil and the amount needed to meet evapo-transpiration demands, increases from zero in the Plains states to slightly over 20 inches in the eastern and southern states. Of particular interest is the fact that the eastern two thirds of Iowa is in the area where an average 3 to 8 inches of percolation occurs annually. Once established that percolation occurs and to what extent, the form of N in the soil becomes important in assessing losses from the root zone. Temperature and more specifically soil temperature in the region of N placement dictate the extent and rapidity of conversion of non-nitrate forms to nitrate. The authors point out that conflicting data regarding the use of a particular soil temperature to predict the rate of ammonium conversion to nitrate makes the practice of delaying fall applications of non-nitrate sources to reduce nitrate loss by percolation of questionable value. However from a theoretical standpoint later applications would seemingly decrease the leaching hazard but not eliminate it. An average daily minimum temperature, such as $40^{o}$F, progressively moves southward in the fall and early winter and northward in late winter and spring. Hence the higher amounts of percolation coupled with warmer temperatures increase the potential leaching of nitrates in the eastern and southern part of the United States.

The second avenue for N loss mentioned by Nelson and Uhland was erosion. They pointed out that considerable quantities of N and other nutrients could be lost since eroded materials generally contain higher nutrient levels than the soils from which they are derived. Highest erosion losses of N may take place concurrently with high intensity rains of late spring or when rainfall and thawing of snow occur at the same time on partially frozen soil. Deeper placement of fall applied N fertilizers would reduce the chances of loss by erosion or at least make it no more susceptible to this form of loss than later applications.

The authors also discuss loss by N volatilization as ammonia or nitric or nitrous oxides and by immobilization but conclude that there is little evidence to suggest that fall application would result in greater loss of applied N by these processes.

Southeastern States

Experimental data collected during 1955-59 in Alabama, Georgia and Mississippi by Pearson et al. (1961) indicate that yield response of corn at seven locations to fall applied N averaged only 59% that of spring applied N.

The relative effectiveness based on N recovery by whole plants was 62%. The marked variations, 7 to 89%, in effectiveness of fall applied N at different locations and years could not be explained on the basis of rainfall, estimated percolation, or soil texture; thus, leaching seemingly could not account for the low relative effectiveness. Appreciable amounts of N were lost in runoff from a fine-textured soil between the time of application in the fall and planting of corn the next spring, whereas negligible quantities were lost from a sandy loam. No consistent differences in corn yields were measured among the five N carriers applied in the fall; however, N recovery tended to be lower from urea than the other sources.

Boswell (1971) compared yields between fall, winter or spring plowdown and summer sidedress applications of ammonium nitrate for corn on a Piedmont soil (Cecil sandy loam) and on a Coastal Plains acid soil (Norfolk loamy sand) in Georgia. Yield differences were insignificant on the Piedmont soil and for the three individual years on the Coastal Plains soil; however, the combined three year data showed sidedress N treatments were significantly more effective than plowdown treatments. Plausible explanations for the corn yield differences due to time of application being so small as compared to results of earlier workers are: (a) higher plant population than earlier studies, (b) deeper placement (plowdown) of fertilizer, (c) higher yield levels and (d) higher N rate (166 kg/ha). It was also pointed out that the use of a single rate which generally gives maximum corn yields may not result in large differences due to time of application since some loss could occur and still leave sufficient N for the crop.

Kentucky data by Thomas and Miller (1971) from two locations indicated that approximately 80 lb/A of fall applied N was lost from the soil each winter. This conclusion was based on the fact that the check yields were equal to those produced by the 80 lb/A rate applied in the fall and that the 80 lb/A spring applied and 160 lb/A fall applied rates produced equivalent yields. No explanation was given for the large yield differences associated with the time of N application other than one of the silt loam soils was poorly drained.

These data indicate that under the climatic and soil conditions encountered in the southeastern United States, application of N very far in advance of planting is likely to result in reduced effectiveness. However, specific processes responsible for N losses were not easily identified.

Northeastern region

Stevenson and Baldwin (1969) observed a 30 to 87% range in relative efficiencies of fall versus spring preplant or spring sidedress application of N in the Ontario Province of Canada. Spring preplant application of N was as effective in increasing corn yields as was spring sidedressing. The authors attributed the low efficiency of fall applied N to loss of N by denitrification. Earlier research dealing with nitrification suggested that a large part of the N applied in the fall, even if entirely in the ammonium form, would be converted to the nitrate form and could then be denitrified. Yield were lower on clay soils than loam soils when N was applied in the fall.

Stevenson and Baldwin also found that three N sources differed only slightly in effectiveness, regardless of time applied. A trend did exist for higher yields with anhydrous ammonia and a significant difference was measured over urea in one experiment. Both of these sources gave a significant yield increase over ammonium nitrate in another experiment.

Reid et al. (1968) reported results of yield measurements and soil analysis which show average relative efficiencies of 30, 70 and 100% for fall, spring and summer N applications, respectively. These values represented data collected from several field experiments over a 12 year period in New York. Data from a 3 year study in New York led Bouldin and Lathwell (1968) to suspect that the primary routes of N loss were denitrification and leaching to below the rooting zone.

The data presented thus far would fit into the scheme presented by Nelson and Uhland (1955) however the losses of fall applied N seem to be associated more with average annual moisture surplus as it influences denitrification rather than leaching of nitrates from the root zone.

North Central States

Studies reported by Olson et al. (1964) in Nebraska where relatively high losses were observed with fall application can also be reconciled with the scheme since the greater losses generally occurred on irrigated experiments, where excess water could bring about leaching and denitrification. In one study of 14 experiments involving corn, 40 lb N/A sidedressed and 80 lb N/A fall or spring applied gave nearly equivalent yields and 80 lb N/A sidedressed gave approximately equal yields to 160 lb N/A applied in the fall or spring. When the yield response to applied N is expressed in terms of a percentage of the response for summer sidedressed N, the relative efficiencies become approximately 50, 70 and 85% respectively for the 40, 80 and 160 lb/A rates of N and approximately 70% across all rates. In another group of 8 irrigated corn experiments located on medium textured soils; ammonium nitrate, anhydrous ammonia and urea differed little in effectiveness but the 80 lb N/A rate applied in the fall produced especially poor results. At one site which included calcium nitrate, the $NO_3^-$-N content in the 4-6 foot soil depth at harvest time following a 160 lb N/A fall application was 31 lb/A whereas it was only 5 lb/A with the ammonium sulfate carrier. In another experiment on an irrigated Belfore silty clay loam it was found that a sizable quantity of $NO_3^-$-N had moved through the surface 6 foot of soil after one year. These data substantiated leaching as a mechanism for N loss when application of calcium nitrate and ammonium sulfate was made to irrigated soils. From these and other experiments circumstantial evidence would also predict that denitrification occurred particularly in the third foot of soil, the zone of maximum clay accumulation and compaction. Ammonia volatilization from surface application of fertilizer N was also cited as a possible loss mechanism, especially on neutral to alkaline soils where urea or an ammonia-forming N source was used.

In recent comparisons using anhydrous ammonia, urea and sulfur-coated urea in southeast Kansas, Whitney et al. (1971) showed no significant differences in corn yields between fall and spring applications. If a trend did exist it seemed to be that yield differences favoring spring application of N were more apparent at the 75 lb/A rate than at the 150 or 225 lb/A rates. Another experiment with irrigated corn, also located in southeast Kansas, gave similar but quite variable yields for fall and spring applied anhydrous ammonia, urea and sulfur-coated urea as reported by Murphy et al. (1971).

An early Indiana study by Larsen and Kohnke (1946) using ammonium sulfate as the N carrier resulted in no significant differences in corn yields between fall and spring applications on a Miami sandy loam or on a Crosby silt loam. But, fall application on a very poorly drained Vigo silt loam resulted in significantly lower yields than the spring application. Transformation studies involving ammonium sulfate and sodium nitrate revealed that approximately 80% of the ammonium N applied in November was nitrified by the first week in May in the Miami sandy loam whereas only about 50% was nitrified on the poorly drained Vigo silt loam. Most of the $NO_3^-$-N applied as sodium nitrate in November was leached from the surface 23 inches of the Miami silt loam by May, but nearly all the applied N was retained in the upper 23 inches of the Crosby silt loam during the winter and throughout the summer. The markedly lower corn yield associated with the fall applied N to the Crosby silt loam were explained by the excessive weed growth prior to and after planting the corn.

More recent work in Indiana by Stivers (1971) tends to confirm the earlier results. In experiments using ammonium nitrate, fall and spring applications did not produce significant differences in corn yields. Experimentation with urea surface broadcast and not incorporated in February or in April as compared to a June sidedress application 3 inches deep resulted in highly significant ($P < .01$) grain yield differences. The February and April applications produced 73 and 88% as much grain as the June sidedressing in 1968 and 85 and 95% as much in 1969. It was impossible to distinquish between placement and time effects, but the author suspected leaching and surface volatilization losses of N during both years when above average precipitation was received from February to August.

Welch et al. (1971) report on studies conducted at 4 locations in central and northern Illinois in which 5 rates of N were applied in the fall and as spring preplant. When the yield increase resulting from fall application is expressed as a percentage of the yield increase obtained with spring applied N, the resulting three-year average relative efficiencies were about 80 and 90% for the 67 and 134 kg/ha N rates at the Carthage and Hartsburg locations. Additional yield response at the 201 kg/ha or higher N rates was small at these two locations which resulted in nearly equal effectiveness of the fall and spring applications. At the Urbana location corn yields were similar for fall and spring applications at all rates of N. A summer sidedress application of N was also included in the four-year averages at the DeKalb location. The relative efficiencies, fall versus sidedress and spring versus sidedress were only 69 and 80% at the 56 kg/ha rate, but increased to 84 and 101% at the 224 kg/ha rate. It is interesting to note that the relative efficiencies were influenced by the quantity and distribution of precipitation. During wet years the fall and spring applications were generally much less effective than sidedress applications with relative efficiencies being in the order of 50%. When precipitation was more uniformly distributed, the relative efficiencies seldom dropped below 85% except at the 56 kg/ha rate. No attempt was made to measure losses of N responsible for the lower yields obtained with the earlier applications, but conditions were observed to be favorable for denitrification and leaching.

Certainly one of the longer term studies has been conducted in Minnesota by MacGregor et al. (1971). Nitrogen as ammonium nitrate and urea was broadcast in the fall and plowed down, broadcast in the fall and left over winter on the plowed surface, broadcast and incorporated in the spring or broadcast in late June on a Webster clay loam soil. Eleven year average results indicate a trend for highest yields with the spring application. Summer applications resulted in 1 to 3 bu/A lower yields and fall plowdown yields were 5 to 11 bu/A below those of spring applied N for the 40 and 80 lb N/A rates, respectively. Fall plowdown, fall plow and broadcast, spring and summer applications of the 40 lb/A rate produced average yields of 82, 88, 93 and 92 bu/A, respectively, while the 80 lb/A rate gave 100, 104 and 101 bu/A respectively for the fall plowdown, spring and summer applications. Little additional yield increase resulted from application of more than 80 lb/A N, the only exception possibly being when the N is fall applied. As with most of the data relating to time of N application it should be mentioned that large year to year variability existed. However, average yields reflecting the effects of different weather conditions are the best guideline for managing the controllable time and rate of N variables. Corn yields were not significantly different for the two N carriers used in the study. Analysis of soil samples taken to a depth of 7 feet did not provide easily distinguishable trends that might be helpful in explaining yield differences associated with the time N was applied.

Iowa

Corn yield differences associated with the time of N application in the northern part of Iowa might be expected to follow the trend established in southern Minnesota. However, early investigations in northwest Iowa by Dumenil et al. (1954) showed that ammonium nitrate broadcast and plowed under in the fall gave equal or slightly superior results to spring applications disked into the soil. In the tests which indicated an advantage for fall plowdown application, the deeper placement of N alone or in combination with phosphorus, was suspected as providing a more favorable nutrient and moisture environment during a late summer drought.

Somewhat similar results have been observed in north central Iowa where a fall and spring applied N comparison was begun in 1965 by Shrader (1971a). Ammonium nitrate broadcast and plowed down at a single 120 lb N/A rate in the fall has given slightly higher yields than N incorporated by disking in the spring. Since a placement difference as well as a time variable is reflected by the corn yields being measured, it is difficult to evaluate the influence of time of N application. A similarly designed experiment in northeast Iowa by Shrader (1971b) has favored the application of N in the spring over the fall. At this location the frequency of excessively wet soils is suspected of contributing to conditions for denitrification and leaching.

In summary, the yield response and relative efficiency of fall applied N as compared to spring or summer applied has been quite variable. Many studies have had a placement variable as well as time; thus, the effect of each was hard to identify. Where yield differences have been observed, fall application has generally resulted in the lower response and quite often this trend has been associated with soil and weather conditions which favored N loss by leaching, denitrification or other avenues. However, the actual loss of N by these processes has not been measured directly in most of the field studies.

# EXPERIMENTAL METHODS AND PROCEDURES

## Field Procedures

### Experimental sites

Three experimental sites were selected to study the time and rate of anhydrous ammonia application as it influenced corn yields. Two experiments were initiated in the fall of 1967, with the third added in the fall of 1968. Two additional sites were selected in the fall of 1969 for comparing sources of N as well as time and rate of application. Ammonium nitrate, urea and sulfur-coated urea were the N materials used in these studies.

The sites were all located on glacial till soils in the Clarion-Nicollet-Webster and Kenyon-Floyd-Clyde soil association areas. The Clarion-Webster sites were chosen because they represented a large corn producing area, because application of P and K fertilizers and plowing in the fall are common practices and because of their location convenient to Ames. Sites were selected in the Kenyon-Clyde area because the amount of precipitation and relatively poor drainage of many soils in the area was thought to favor N losses and accentuate the importance of proper application practices. In all cases an attempt was made to choose sites which would be responsive to N fertilization and were uniform in slope, fertility, drainage and other characteristics influencing productivity. One site (ISU Experimental Farm near Independence) known to be somewhat poorly drained was included because it possessed a soil moisture regime representative of many soils in northeast Iowa. This site was dropped after two years because of the extreme variability in drainage within the site. The location, soil type and other information regarding the sites are given in Table 1.

Table 1. Location and characteristics of the experimental sites used in the N studies

| Site | County | Cooperator | Soil Type[a] | Initial Soil Test pH | P | K |
|---|---|---|---|---|---|---|
| 1 | Hancock | ISU Expt. Farm | Webster clay loam | 7.0 | 31 | 90 |
| 2 | Buchanan | ISU Expt. Farm | Kenyon silt loam | 6.4 | 15 | 107 |
| 3 | Story | ISU Agronomy Farm | Webster clay loam | 6.2 | 38 | 130 |
| 4 | Butler | George Seehausen | Readlyn silty clay loam | 6.1 | 22 | 146 |
| 5 | Buchanan | Richard Thedens | Kenyon loam | 6.6 | 54 | 312 |

[a]Soil series descriptions have been given by Oschwald et al. (1965).

## Design of experiments

A randomized complete block design was used at all sites. At sites 1, 2 and 3 each of four blocks contained twelve treatments in a factorial arrangement of four rates by three times of anhydrous ammonia application. The three times of application were fall, spring and summer sidedress with rates of 0, 40, 80 and 160 lb/A at sites 1 and 2, and 0, 80, 160 and 240 lb/A at site 3. Each treatment was applied each year to the same 20 x 60 foot plot which provided for six 40-inch corn rows.

Each of three blocks at sites 4 and 5 consisted of ten treatments arranged as a 3 x 3 factorial and a control. Three sources, ammonium nitrate, urea and sulfur-coated urea, were compared at the applied rates of 30, 90 and 270 lb/A. The ten treatments were randomly assigned to the 38 x 40 foot whole plots and the times of application randomly assigned to the three 12 2/3 x 40 foot split plots.

Field experimental techniques

The fall applications were not made until after the soil temperature at the 6-inch depth was below 50°F. This practice is commonly recommended because nitrification is thought to practically cease below this temperature. Spring applications were made as early as soil conditions permitted field operations and proper sealing of the soil following ammonia injection. Nitrogen was applied as summer sidedress when corn reached a height of 8 to 12 inches except at site 4 where plants attained a 12 to 24 inch height. Actual application dates at each site are given in Table 2.

Anhydrous ammonia was selected as the N carrier on sites 1, 2 and 3 so as to provide all of the N in the ammonia form and to insure uniform placement (6-8 inch depth) irrespective of time of application. The apparatus used for ammonia application was a Squibb-Pitzer "Flo-trol" attached to a 50-pound tank which was then mounted on a toolbar having three injection knives. The rate of delivery was dependent on the pressure in the tank, the regulator setting and the ground speed of the tractor. It was impossible to apply the exact quantity desired but the rate actually applied to each plot was determined by weighing the tank prior to and after application.

Three solid N fertilizer sources were used on sites 4 and 5 to get

Table 2. General information about experimental operations at each of the sites

| Site[a] | Year | Source of Nitrogen[b] | Date of application Fall | Spring | Summer | Corn Hybrid | Date Planted | Population 1000 plants/A |
|---|---|---|---|---|---|---|---|---|
| 1 | 68 | AA | 11/9/67 | 3/30/68 | 6/3/68 | Dekalb XL45 | 5/2 | 22 |
| | 69 | AA | 11/9/68 | 4/30/69 | 6/11/69 | Dekalb XL45 | 5/7 | 24 |
| | 70 | AA | 11/8/69 | 4/23/70 | 6/4/70 | Dekalb XL45 | 4/30 | 26 |
| 2 | 68 | AA | 11/18/67 | 5/4/68 | 6/8/68 | Dekalb XL45 | 5/11 | 24 |
| | 69 | AA | 11/5/68 | 5/15/69 | 6/21/69 | Dekalb XL45 | 5/15 | 24 |
| 3 | 69 | AA | 11/25/68 | 5/9/69 | 6/18/69 | Dekalb XL45A | 5/14 | 26 |
| | 70 | AA | 11/13/69 | 4/27/70 | 6/5/70 | Dekalb XL45 | 4/29 | 26 |
| 4 | 70 | AN,U,SCU | 11/28/69 | 4/24/70 | 6/19/70 | Dekalb XL45 | 5/5 | 25 |
| 5 | 70 | AN,U,SCU | 12/2/69 | 4/25/70 | 6/10/70 | Northrup King 610 | 5/9 | 20 |

[a]Rates of 0, 40, 80, 160 lb N/A were used at sites 1 and 2, rates of 0, 80, 160, 240 lb N/A at site 3 and rates of 0, 30, 90, 270 lb N/A at sites 4 and 5.

[b]AA = anhydrous ammonia, AN = ammonium nitrate, U = urea and SCU = sulfur-coated urea.

some information regarding their performance, particularly as related to rate and time of application. The sulfur-coated urea was an experimental product of the Tennessee Valley Authority, containing 36% N and 17.5% S. It was thought that the slow N release characteristic of this material might reduce the chance of N loss when it was applied well in advance of crop use. Urea, from which N is very subject to loss under certain conditions, was included as a standard for comparison. Ammonium nitrate was also included for comparative purposes. All of these fertilizers were broadcast by hand on the experimental plots. Placement effects were minimized by applying the fall and spring treatments to the plowed surface and disking them into the soil, while the summer application was incorporated by cultivation.

Adequate P, K and other nutrients were provided so that maximum yields were attainable with the higher N application rates. The sources of N, corn hybrids, planting dates and final plant populations are given in Table 2.

Precipitation data normally recorded at existing Weather Bureau gauges was secured from the sites located on experimental farms. On the remaining sites farmers were asked to record rainfall with the use of Tru-Chek rain guages during the growing season and rainfall data for the balance of the year was obtained from the nearest reporting Weather Bureau station. A summary of precipitation data is given in Appendix Table 34.

Treatment evaluation criteria

Chemical analyses of corn leaf samples were used to assess the nutrient status of plants from the plots receiving the various treatments.

The leaf opposite and just below the ear was removed from 20 plants within the harvest area of each plot when the plants were approximately 75% silked. These samples were analyzed for total N, P and K after drying for 36 to 48 hours at 65°C and grinding to pass through a 50 mesh stainless steel screen.

Corn yield data were obtained by harvesting a small area located near the center of each plot. In 1968 the harvest area consisted of three rows each 30 feet in length with 40-inch spacing whereas in the following years the row length was reduced to 25 feet. The smaller plot size of sites 4 and 5 necessitated using two rows each 30 feet in length with 38-inch spacing. Soon after the corn reached a height of 8 inches the harvest area was selected and the stand thinned to the population indicated in Table 2. Corn harvested from this area was weighed and a subsample of shelled corn was weighed, dried at 65°C for at least 4 days and reweighed for determination of moisture content. After an adjustment for 2% moisture at the oven-dried weight, grain yields were calculated on the basis of 15.5% moisture.

Just prior to harvest the stalks broken below the ear were recorded as stalk-lodged plants. Observations were also taken on the number of barren and double-eared stalks in each harvest area. However, none of these measurements revealed any practical differences due to applied treatments.

Soil sampling procedures

Soil samples were taken to investigate the relationship between N movement in the profile and its influence on yields of corn. It was hoped that the position of N could be used to help explain any yield differences associated with the time of N application. Inorganic N, ammonium and nitrite plus nitrate, was measured on samples collected just prior to silking, the time when considerable uptake and utilization by the plant occurs (Hanway, 1962). In the summer of 1968 sites 1 and 2 were sampled to a depth of 4 feet but the soil analyses revealed that uneven distribution of N due to the band placement made it impossible to identify differences in N concentration due to time and rate of application.

Another phase of sampling involved taking soil cores six and twelve inches on either side of the center between two corn rows in an attempt to measure N movement from the ammonia bands applied at the three different times. These samples were taken in 6-inch increments to a depth of 4 feet.

The 270 lb N/A rate and the control plots from sites 4 and 5 were sampled just prior to the summer application and during the early part of silking. The first sampling involved taking 4 cores in 6-inch increments to a depth of 2 feet from each of the split plots of the aforementioned whole plots. Preliminary analysis suggested the need for taking 8 cores per plot at the second sampling along with the previously planned sampling of the third and fourth foot of soil in 12-inch increments. In as much as possible the samples were frozen within several hours by placing in a freezer where the temperatures were kept at 0 to -10$^{o}$F. Soil samples were maintained at this temperature until chemical analyses for various forms of N were performed.

## Laboratory Procedures

Leaf analysis

Prior to wet ashing the ground leaf samples were redried at 65°C for approximately 24 hours. A 0.5g subsample, 10 ml of concentrated $H_2SO_4$ and a glass bead were placed in a 100 ml volumetric flask and allowed to digest on a hot plate. The digested sample was then cooled and brought up to 100 ml volume with ammonia-free distilled water. Five ml aliquots were used for determining N, P and K.

The total N content of plant samples was measured using a slight modification of the steam distillation procedure described by Bremner (1965). A 5 ml aliquot of the digested sample was transferred to a 200 ml distillation flask which was then attached to the steam-distillation apparatus. After making the solution basic with approximately 5 ml of 5 N NaOH, ammonia was driven off as steam was allowed to pass through the solution until approximately 30 ml of distillate was collected in a 50 ml Erlenmeyer flask containing 5 ml of $H_3BO_3$-indicator solution. This solution was then titrated with standard 0.02 N $H_2SO_4$.

Total P was determined by a colorimetric procedure involving an acidified vanado-molybdate solution (Hanway, 1962). To 5 ml of the sample solution a 25 ml aliquot of the vanado-molybdate reagent was added and the mixture shaken vigorously before allowing approximately one hour for color development. The color intensity of the mixture was measured with a Klett-Summerson Photoelectric colorimeter along with those of standard solutions of $KH_2PO_4$ from which calibration curves were developed.

Total K was determined by diluting a 5 ml aliquot of sample solution with 100 ml of a 104 ppm lithium solution before reading on an Instrumentation Laboratory 143 Flame Photometer. Percent K was read directly as the photometer was calibrated with standard solutions.

Soil analysis

Soil profile samples were removed from storage at $0^{o}F$ or below, dried, passed through an 8 mesh screen and returned to storage at 35 to $40^{o}F$ for analysis the following day. A 15 g soil sample and 100 ml of 2 N KCl were placed in a 250 ml Erlenmeyer flask and shaken for one hour. Determination of $NH_4^+$-N and $NO_2^-$-N plus $NO_3^-$-N was achieved by the steam distillation procedure described by Bremner (1965). A 25 ml aliquot of the clear supernatant from the KCl-soil solution was pipetted into a 200 ml distillation flask which was then attached to the steam-distillation apparatus. After the addition of MgO, ammonia was driven off as steam was allowed to pass through the solution until approximately 25 ml of distillate was collected in a 50 ml Erlenmeyer flask containing 5 ml of $H_3BO_3$-indicator solution. After the addition of Devarda's alloy, another 25 ml of distillate was collected in a second 50 ml Erlenmeyer flask containing 5 ml of $H_3BO_3$-indicator solution to determine the $NO_2^-$-N plus $NO_3^-$-N. The distillate-indicator solutions were then titrated with standard 0.005 N $H_2SO_4$. Soil moisture content was determined and concentration of N was expressed as pounds per acre. Total N in the soil as it will be discussed in the remaining portion of the thesis is the sum of $NH_4^+$-N, $NO_2^-$-N and $NO_3^-$-N.

Soil samples were taken from each site prior to applying any fertilizer. These samples consisting of 16 cores per plot from the 0 to 6-inch depth were analyzed for available P, exchangeable K, soil pH and buffer pH. These tests were performed at the Iowa State University Soil Testing Laboratory according to the procedures described by Eik (1968). Mean values for each site are given in Table 1.

Soil samples used for total carbon and particle size analysis were a composite of the profile samples taken from the control plots for soil N determinations. Total carbon determination was carried out in a Leco Analyzer according to the procedure given by Tabatabai and Bremner (1970). Particle size analysis was run on the less than 2 mm material using a modification of the pipette method first proposed by Jennings et al. (1922) and later revised by Olmstead et al. (1930) and Kilmer and Alexander (1949). Further fractionations using the Wentworth (1922) scale were made at specific time intervals calculated from Stoke's law by Tanner and Jackson (1947).

## Statistical Procedures

Corn yields, leaf analysis data and soil N concentrations were evaluated using the analysis of variance (AOV) procedure given by Snedecor and Cochran (1967) and Cochran and Cox (1957). Estimates of single degree of freedom comparisons and appropriate significance tests were achieved by the use of the OMNITAB (Chamberlain and Jowett, 1968) regression program according to the procedure described by Cady and Fuller (1970).

# RESULTS AND DISCUSSION

Studies reviewed thus far indicate the difficulty in predicting the influence time of N application has on final grain yields of corn and show that information relating soil profile N to growth of the crop during the season is very limited. The main objective of this study was to measure the effect of time and rate of application and source of N fertilizer on the yield of corn. Chemical analyses of plant and soil samples were used as additional information to help explain treatment effects. Presentation and discussion of the results from leaf analysis, yield observations and soil profile N analysis will be dealt with in that order.

## Leaf Analysis

The concentration of nutrients in various plant parts has been used for many years to evaluate the nutrient status of the plant and as an index of fertility requirements. Research has shown that maximum yields can be attained with a wide range in nutrient concentrations and that a number of factors such as variety, plant population, and soil and weather conditions just prior to sampling alter the results and interpretative value. Studies by Dumenil (1961) illustrate the wide range of N and P composition which can occur in the production of 95 to 100% of maximum yield. Adequate levels in the ear leaf at silking time reported by Barber and Olson (1968) are: N, 2.75-3.25%; P, .25-.35%; and K, 1.75-2.25% which are in close agreement with the values given by Jones (1967).

### Nitrogen

The concentration of N in corn leaves generally increased with later application of fertilizer and markedly increased as higher rates of N were applied. This is illustrated in Tables 3-7, where the mean concentrations of leaf N, P and K are given by treatment for each experiment. The generally lower leaf N concentrations noted in Tables 3-6 are thought to partially be accounted for by the single-cross hybrid DeKalb XL45 used at these sites. It has been observed that this particular variety will normally tend to have somewhat lower leaf N levels than many hybrids. The data collected in this study show that maximum yields were associated with leaf N values of 2.50% or greater.

Statistical evaluation by the analysis of variance (AOV) technique revealed that time of N application had a significant effect on leaf N in two out of the three years at site 1 and one year at site 2 (Table 8 and 9. The linear increase in leaf N associated with the progressively later application of N was significant ($P < .05$) in 5 out of 9 site-years (Tables 8-12). The leaf N in 1968 at site 1 was generally high because of the residual N from the previous soybean crop. Near maximum yields were attained with the 80 lb/A rates and little additional yield occurred at the 160 lb/A rates. The leaf N levels of 2.50% or more associated with the 80 lb/A treatments were sufficient for maximum production. The positive linear effect with later N application was highly significant ($P < .005$), but it is interesting to observe that the highest leaf N level at the 40 lb/A rate was associated with the spring application and yield results also followed closely the trend of leaf N.

The 1969 leaf N data for site 1 showed a highly significant ($P < .005$) linear increase with the later application of N but the maximum leaf N concentration was only 2.56%. Generally low leaf N levels at this site and at site 2 in 1969 could not easily be explained. A positive linear

Table 3. Concentration of N, P and K in corn leaves for each treatment in each year at site 1 (Mean of 4 replications)

| lb N /A | 1968 Fall | 1968 Spring | 1968 Summer | 1969 Fall | 1969 Spring | 1969 Summer | 1970 Fall | 1970 Spring | 1970 Summer |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | % N | | | | |
| 0 | 1.91 | 1.95 | 2.01 | 1.22 | 1.18 | 1.26 | 1.08 | 1.14 | 1.16 |
| 40 | 2.24 | 2.47 | 2.32 | 1.40 | 1.44 | 1.52 | 1.56 | 1.58 | 1.66 |
| 80 | 2.50 | 2.53 | 2.73 | 1.72 | 1.90 | 2.11 | 1.99 | 2.04 | 2.21 |
| 160 | 2.68 | 2.76 | 2.83 | 2.13 | 2.52 | 2.56 | 2.48 | 2.66 | 2.51 |
| | | | | | % P | | | | |
| 0 | .247 | .251 | .250 | .312 | .309 | .295 | .197 | .210 | .193 |
| 40 | .261 | .266 | .256 | .267 | .250 | .230 | .177 | .179 | .192 |
| 80 | .269 | .266 | .281 | .257 | .266 | .272 | .204 | .204 | .216 |
| 160 | .271 | .278 | .285 | .268 | .302 | .300 | .245 | .246 | .236 |
| | | | | | % K | | | | |
| 0 | 1.65 | 1.64 | 1.69 | 2.15 | 2.15 | 2.19 | 1.83 | 1.86 | 1.88 |
| 40 | 1.63 | 1.58 | 1.70 | 2.16 | 2.15 | 2.19 | 1.93 | 1.84 | 1.90 |
| 80 | 1.48 | 1.45 | 1.53 | 2.09 | 2.14 | 2.10 | 1.80 | 1.69 | 1.80 |
| 160 | 1.35 | 1.43 | 1.51 | 2.04 | 2.06 | 2.09 | 1.65 | 1.63 | 1.79 |

Table 4. Concentration of N, P and K in corn leaves for each treatment in each year at site 2 (mean of 4 replications)

| lb N /A | 1968 Fall | 1968 Spring | 1968 Summer | 1969 Fall | 1969 Spring | 1969 Summer |
|---|---|---|---|---|---|---|
| | | | % N | | | |
| 0 | 1.71 | 1.65 | 1.94 | 1.39 | 1.21 | 1.33 |
| 40 | 2.09 | 1.97 | 2.50 | 1.42 | 1.51 | 1.58 |
| 80 | 2.24 | 2.33 | 2.37 | 1.36 | 1.69 | 1.96 |
| 160 | 2.79 | 2.70 | 2.96 | 2.04 | 2.06 | 2.56 |
| | | | % P | | | |
| 0 | .196 | .191 | .208 | .209 | .198 | .198 |
| 40 | .206 | .197 | .241 | .211 | .200 | .186 |
| 80 | .213 | .217 | .228 | .200 | .199 | .211 |
| 160 | .257 | .242 | .260 | .221 | .213 | .249 |
| | | | % K | | | |
| 0 | 2.29 | 2.35 | 2.31 | 2.50 | 2.38 | 2.54 |
| 40 | 2.30 | 2.25 | 2.29 | 2.51 | 2.60 | 2.68 |
| 80 | 2.26 | 2.18 | 2.34 | 2.51 | 2.54 | 2.58 |
| 160 | 2.20 | 2.23 | 2.33 | 2.58 | 2.46 | 2.53 |

trend was also observed in 1970 but the highest leaf N was associated with the spring applied 160 lb/A rate, which probably accounted for the lower significance level ($P < .05$) for the linear effect of time.

Unfavorable soil moisture conditions in some plots resulted in the extremely variable leaf N values given in Table 4 for site 2. The trend for a linear effect of time of N application on leaf N was present in both years and was significant for 1969 results. As previously mentioned, this site was dropped after the second year because of the extremely variable internal drainage among plots.

Leaf N values and yield were generally quite high in 1969 at site 3

Table 5. Concentration of N, P and K in corn leaves for each treatment in each year at site 3 (mean of 4 replications)

| lb N /A | 1969 Fall | 1969 Spring | 1969 Summer | 1970 Fall | 1970 Spring | 1970 Summer |
|---|---|---|---|---|---|---|
| | | | % N | | | |
| 0 | 2.40 | 2.48 | 2.41 | 1.36 | 1.40 | 1.31 |
| 80 | 2.94 | 2.82 | 2.91 | 2.01 | 2.23 | 2.22 |
| 160 | 3.12 | 3.12 | 3.03 | 2.39 | 2.47 | 2.31 |
| 240 | 3.08 | 3.06 | 3.01 | 2.47 | 2.57 | 2.59 |
| | | | % P | | | |
| 0 | .238 | .248 | .248 | .133 | .138 | .141 |
| 80 | .263 | .262 | .259 | .181 | .194 | .184 |
| 160 | .266 | .266 | .269 | .211 | .209 | .199 |
| 240 | .269 | .267 | .265 | .212 | .212 | .218 |
| | | | % K | | | |
| 0 | 2.16 | 2.13 | 2.18 | 1.81 | 1.79 | 1.91 |
| 80 | 2.15 | 1.94 | 1.99 | 1.84 | 1.53 | 1.60 |
| 160 | 1.94 | 1.86 | 2.08 | 1.64 | 1.44 | 1.71 |
| 240 | 1.94 | 2.04 | 1.85 | 1.60 | 1.64 | 1.54 |

because of favorable moisture conditions and residual N from the previous soybean crop. Leaf N concentrations increased with rates up to 160 lb N/A but differed little with time of application. In 1970, the highest leaf N resulted from the spring applied 80 and 160 lb/A rates which was likely responsible for the F-test for the quadratic time effect exceeding the .05 probability level. At the 240 lb/A rate however, if a trend did exist it was for leaf N to increase with later application of N. Corn yields, to be discussed in more detail later, also followed closely the trends indicated by leaf N.

Statistical analysis of leaf N data combined over years for sites 1,

Table 6. Concentration of N, P and K in corn leaves for each treatment in 1970 at site 4 (mean of 3 replications)

| lb N /A | AN Fall | AN Spring | AN Summer | SCU Fall | SCU Spring | SCU Summer | Urea Fall | Urea Spring | Urea Summer |
|---|---|---|---|---|---|---|---|---|---|
| | | | | % N | | | | | |
| 0[a] | | | | 1.67 | 1.81 | 1.67 | | | |
| 30 | 1.93 | 1.98 | 2.15 | 1.74 | 1.90 | 1.94 | 1.87 | 1.98 | 2.13 |
| 90 | 2.65 | 2.64 | 2.65 | 2.41 | 2.42 | 2.21 | 2.51 | 2.57 | 2.67 |
| 270 | 3.01 | 2.86 | 2.95 | 2.82 | 2.73 | 2.70 | 2.86 | 2.85 | 2.89 |
| | | | | % P | | | | | |
| 0 | | | | .180 | .193 | .184 | | | |
| 30 | .194 | .200 | .218 | .186 | .196 | .201 | .190 | .194 | .216 |
| 90 | .229 | .229 | .232 | .215 | .222 | .225 | .223 | .230 | .238 |
| 270 | .252 | .247 | .252 | .240 | .231 | .236 | .254 | .242 | .242 |
| | | | | % K | | | | | |
| 0 | | | | 1.95 | 1.97 | 1.98 | | | |
| 30 | 1.95 | 1.85 | 1.95 | 1.85 | 1.95 | 1.95 | 1.93 | 1.93 | 1.90 |
| 90 | 1.82 | 1.90 | 1.67 | 1.70 | 1.72 | 1.88 | 1.63 | 1.65 | 1.80 |
| 270 | 1.63 | 1.40 | 1.82 | 1.55 | 1.48 | 1.67 | 1.52 | 1.55 | 1.67 |

[a]Control plots have no source designation.

Table 7. Concentration of N, P and K in corn leaves for each treatment in 1970 at site 5 (mean of 3 replications)

| lb N /A | AN | | | SCU | | | Urea | | |
|---|---|---|---|---|---|---|---|---|---|
| | Fall | Spring | Summer | Fall | Spring | Summer | Fall | Spring | Summer |
| | | | | % N | | | | | |
| 0[a] | | | | 2.74 | 2.78 | 2.83 | | | |
| 30 | 2.86 | 2.88 | 2.82 | 2.76 | 2.77 | 2.78 | 2.85 | 2.88 | 2.89 |
| 90 | 3.06 | 2.94 | 3.02 | 2.94 | 2.95 | 2.85 | 2.95 | 2.97 | 2.95 |
| 270 | 2.98 | 3.14 | 3.16 | 3.10 | 3.05 | 2.95 | 3.04 | 3.13 | 3.10 |
| | | | | % P | | | | | |
| 0 | | | | .286 | .284 | .292 | | | |
| 30 | .294 | .297 | .294 | .289 | .288 | .289 | .299 | .303 | .305 |
| 90 | .309 | .297 | .302 | .291 | .298 | .291 | .299 | .303 | .299 |
| 270 | .305 | .311 | .311 | .300 | .305 | .292 | .300 | .305 | .301 |
| | | | | % K | | | | | |
| 0 | | | | 2.38 | 2.32 | 2.27 | | | |
| 30 | 2.27 | 2.33 | 2.42 | 2.32 | 2.37 | 2.33 | 2.33 | 2.35 | 2.33 |
| 90 | 2.32 | 2.42 | 2.43 | 2.32 | 2.30 | 2.38 | 2.32 | 2.40 | 2.35 |
| 270 | 2.45 | 2.47 | 2.53 | 2.45 | 2.42 | 2.37 | 2.32 | 2.42 | 2.47 |

[a]Control plots have no source of designation.

Table 8. Analysis of variance of leaf N as influenced by time and rate of applied N for each year at site 1

| Source | df | 1968 MS[a] | 1968 F[b] | 1969 MS | 1969 F | 1970 MS | 1970 F |
|---|---|---|---|---|---|---|---|
| Blocks | 3 | .24 | 2.40+ | 1.48 | 6.14*** | .33 | 2.01 |
| Treatments | 11 | 4.23 | 42.30*** | 9.72 | 40.50*** | 12.53 | 78.31*** |
| Times | 2 | .83 | 8.30*** | 2.38 | 9.92*** | .49 | 3.02+ |
| T | 1 | 1.59 | 15.90*** | 4.73 | 19.71*** | .91 | 5.69+ |
| $T^2$ | 1 | .07 | .70 | .04 | .17 | .06 | .38 |
| Rates | 3 | 14.51 | 142.23*** | 32.99 | 137.24*** | 45.21 | 279.70*** |
| R | 1 | 42.08 | 420.80*** | 96.68 | 402.83*** | 135.61 | 847.56*** |
| $R^2$ | 1 | 1.41 | 14.10*** | 2.10 | 8.75** | -- | -- |
| $R^3$ | 1 | .04 | .40 | .20 | .83 | .01 | .06 |
| Time x Rate | 6 | .23 | 2.23+ | .54 | 2.23+ | .21 | 1.29 |
| TR | 1 | .08 | .80 | 2.14 | 8.92** | -- | -- |
| $TR^2$ | 1 | .01 | .10 | .01 | .04 | .25 | 1.56 |
| $TR^3$ | 1 | .18 | 1.80 | .19 | .79 | .16 | 1.00 |
| $T^2R$ | 1 | .06 | .60 | .69 | 2.88+ | .23 | 1.44 |
| $T^2R^2$ | 1 | .08 | .80 | .14 | .58 | .53 | 3.31+ |
| $T^2R^3$ | 1 | .96 | 9.60*** | .05 | .21 | .08 | .50 |
| Error | 33 | .10 | | .24 | | .16 | |

[a]All mean square values are coded (multiplied by 10).

[b]The symbols indicating significance level will be used throughout this thesis as follows: *** = 0.005 prob. level; ** = 0.01 prob. level; * = 0.05 prob. level; + = 0.10 prob. level.

Table 9. Analysis of variance of leaf N as influenced by time and rate of applied N for each year at site 2

| Source | df | 1968 MS[a] | 1968 F | 1969 MS | 1969 F |
|---|---|---|---|---|---|
| Blocks | 3 | 3.03 | 2.53+ | 2.38 | 2.13 |
| Treatments | 11 | 7.03 | 5.88*** | 6.38 | 5.75*** |
| Times | 2 | 3.70 | 3.10+ | 4.17 | 3.76* |
| T | 1 | 4.54 | 3.80+ | 7.53 | 6.78* |
| $T^2$ | 1 | 2.87 | 2.40 | .80 | .72 |
| Rates | 3 | 22.48 | 18.82*** | 18.33 | 16.53*** |
| R | 1 | 64.48 | 53.96*** | 50.20 | 45.23*** |
| $R^2$ | 1 | .23 | .19 | 3.80 | 3.42+ |
| $R^3$ | 1 | 2.72 | 2.28 | .99 | .89 |
| Time x Rate | 6 | .42 | .35 | 1.14 | 1.03 |
| TR | 1 | .19 | .16 | 4.61 | 4.15* |
| $TR^2$ | 1 | .09 | .08 | .43 | .39 |
| $TR^3$ | 1 | .59 | .49 | .52 | .47 |
| $T^2R$ | 1 | .18 | .15 | .09 | .08 |
| $T^2R^2$ | 1 | .02 | .02 | 1.18 | 1.06 |
| $T^2R^3$ | 1 | 1.43 | 1.20 | .03 | .03 |
| Error | 33 | 1.19 | | 1.11 | |

[a]All mean square values are coded (multiplied by 10).

2 and 3 is given in Table 11. The linear effect of time on leaf N was highly significant with F-tests exceeding probability levels of .005 and .01 at sites 1 and 2, respectively. At site 3 the quadratic effect of time was significant at the .05 probability level indicating that the 2-year mean leaf N values were higher for the spring applied N treatments than either the fall or summer applications.

Leaf N data for site 4 given in Table 6 and the statistical analysis in Table 12 show that the increase with the later application of N was significant at the .05 probability level. This is very evident at the 30 lb/A

Table 10. Analysis of variance of leaf N as influenced by time and rate of applied N for each year at site 3

| Source | df | 1969 MS[a] | 1969 F | 1970 MS | 1970 F |
|---|---|---|---|---|---|
| Blocks | 3 | .12 | 1.42 | .42 | 2.86 |
| Treatments | 11 | 3.03 | 36.07*** | 9.37 | 63.74*** |
| Times | 2 | .08 | .96 | .50 | 3.39+ |
| T | 1 | .15 | 1.79 | .19 | 1.29 |
| $T^2$ | 1 | .01 | .12 | .81 | 5.51* |
| Rates | 3 | 10.86 | 129.65*** | 33.60 | 228.58*** |
| R | 1 | 25.15 | 299.40*** | 86.95 | 591.50*** |
| $R^2$ | 1 | 7.43 | 88.45*** | 12.48 | 84.90*** |
| $R^3$ | 1 | -- | -- | 1.38 | 9.39** |
| Time x Rate | 6 | .09 | 1.12 | .20 | 1.37 |
| TR | 1 | .09 | 1.12 | .04 | .27 |
| $TR^2$ | 1 | .02 | .24 | .02 | .14 |
| $TR^3$ | 1 | .01 | .12 | 1.02 | 6.94* |
| $T^2R$ | 1 | -- | -- | -- | -- |
| $T^2R^2$ | 1 | .15 | 1.79 | .13 | .88 |
| $T^2R^3$ | 1 | .29 | 3.45+ | -- | -- |
| Error | 33 | .08 | | .15 | |

[a]All mean square values are coded (multiplied by 10).

rate for all sources and at the 90 lb/A rate for urea but leaf N remained nearly the same for all times at the 270 lb/A rate or decreased at the higher rates of sulfur-coated urea (SCU). The somewhat different trends in leaf N exhibited by the SCU source, particularly the decrease with higher N rates, largely accounted for the $TS^2$ interaction being highly significant ($P <.01$). Leaf N means across sources increased, remained the same and decreased with time at the 30,90 and 270 lb/A rates respectively, which gave a highly significant ($P <.005$) TR interaction.

Table 11. Individual site analysis of variance of combined leaf N data as influenced by year, time and rate of applied N

| Source | Site 1 | | | Site 2 | | | Site 3 | |
|---|---|---|---|---|---|---|---|---|
| | df | MS[a] | F | df | MS | F | MS | F |
| Blocks | 3 | 1.11 | 7.93*** | 3 | 4.94 | 3.55* | .08 | .83 |
| Treatments | 11 | 24.57 | 175.50*** | 11 | 12.69 | 9.13*** | 11.31 | 117.81*** |
| Times | 2 | 3.30 | 23.57*** | 2 | 7.62 | 5.48** | .24 | 2.50 |
| $T$ | 1 | 6.44 | 46.00*** | 1 | 11.88 | 8.55** | -- | -- |
| $T^2$ | 1 | .16 | 1.14 | 1 | 3.35 | 2.41 | .49 | 5.10* |
| Rates | 3 | 86.91 | 620.79*** | 3 | 40.22 | 28.94*** | 41.04 | 427.50*** |
| $R$ | 1 | 260.68 | 1852.01*** | 1 | 114.24 | 82.19*** | 102.81 | 1070.94*** |
| $R^2$ | 1 | .02 | .14 | 1 | 2.94 | 2.12 | 19.58 | 203.96*** |
| $R^3$ | 1 | .03 | .21 | 1 | 3.49 | 2.51 | .74 | 7.71** |
| Time x Rate | 6 | .50 | 3.57** | 6 | .61 | .44 | .14 | 1.46 |
| $TR$ | 1 | .96 | 6.86* | 1 | 1.47 | 1.06 | -- | -- |
| $TR^2$ | 1 | .16 | 1.14 | 1 | .46 | .33 | -- | -- |
| $TR^3$ | 1 | .53 | 3.79+ | 1 | -- | -- | .63 | 6.56* |
| $T^2R$ | 1 | .38 | 2.71 | 1 | .01 | .01 | -- | -- |
| $T^2R^2$ | 1 | .22 | 1.57 | 1 | .75 | .54 | -- | -- |
| $T^2R^3$ | 1 | .73 | 5.21* | 1 | .95 | .68 | .18 | 1.88 |
| Error A | 33 | .14 | | 33 | 1.39 | | .10 | |
| Year | 2 | 61.96 | 303.85*** | 1 | 84.55 | 97.12*** | 136.88 | 848.16*** |
| $Y$ | 1 | 78.15 | 390.75*** | | | | | |
| $Y^2$ | 1 | 45.78 | 228.90*** | | | | | |
| Trt x Year | 22 | .96 | 4.80*** | 11 | .74 | .84 | 1.08 | 6.69*** |
| Time x Year | 4 | .20 | .99 | 2 | .25 | .29 | .34 | 2.08 |
| $TY$ | 1 | .05 | .25 | 1 | .19 | .22 | .34 | 2.08 |
| $T^2Y$ | 1 | -- | -- | 1 | .32 | .37 | .33 | 2.04 |
| $TY^2$ | 1 | .76 | 3.80+ | | | | | |
| $T^2Y^2$ | 1 | -- | -- | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Rate x Year | 6 | 2.90 | 14.21*** | 3 | .58 | .67 | 3.42 | 21.18*** |
| RY | 1 | 13.30 | 66.50*** | 1 | .45 | .52 | 9.28 | 57.45*** |
| $R^2Y$ | 1 | .69 | 3.45+ | 1 | 1.09 | 1.25 | .33 | 4.04+ |
| $R^3Y$ | 1 | .04 | .20 | 1 | .21 | .24 | .65 | 2.48 |
| $RY^2$ | 1 | .39 | 1.95 | | | | | |
| $R^2Y^2$ | 1 | 2.79 | 13.95*** | | | | | |
| $R^3Y^2$ | 1 | .18 | .90 | | | | | |
| TxRxY | 12 | .24 | 1.17 | 6 | .95 | 1.10 | .16 | .99 |
| TRY | | | | 1 | 3.33 | 3.83+ | | |
| $TRY^2$ | 1 | 1.21 | 6.05* | | | | | |
| $TR^2Y$ | | | | 1 | | | .40 | 2.48 |
| $T^2R^2Y$ | 1 | .51 | 2.55 | | | | | |
| Error B | 72 | .20 | | 36 | .87 | | .16 | |

[a]All mean square values are coded (multiplied by 10).

Table 12. Analysis of variance of leaf N as influenced by time, source and rate of applied N in 1970 at sites 4 and 5

| Source | df | Site 4 | | Site 5 | |
|---|---|---|---|---|---|
| | | MS[a] | F | MS | F |
| Blocks | 2 | .05 | .18 | .34 | 2.27 |
| Treatments | 9 | 17.93 | 64.04*** | 1.27 | 8.47*** |
| Control vs Trt | 1 | 43.01 | 153.61*** | 2.42 | 16.13*** |
| Sources | 2 | 3.47 | 12.39*** | .50 | 3.33+ |
| S | 1 | .42 | 1.50 | .03 | .20 |
| $S^2$ | 1 | 6.51 | 23.25*** | .96 | 6.40* |
| Rates | 2 | 55.41 | 197.89*** | 3.94 | 26.27*** |
| R | 1 | 108.18 | 386.36*** | 7.87 | 52.47*** |
| $R^2$ | 1 | 2.63 | 9.39** | .01 | .07 |
| Source x Rate | 4 | .15 | .54 | .04 | .27 |
| SR | 1 | .05 | .18 | .01 | .07 |
| $SR^2$ | 1 | -- | -- | .10 | .67 |
| $S^2R$ | 1 | -- | -- | .04 | .27 |
| $S^2R^2$ | 1 | .54 | 1.93 | -- | -- |
| Error A | 18 | .28 | | .15 | |
| Time | 2 | .17 | 2.07 | .04 | .52 |
| T | 1 | .34 | 4.25* | -- | -- |
| $T^2$ | 1 | -- | -- | .07 | 1.00 |
| Time x Treatment | 18 | .24 | 2.89*** | .09 | 1.30 |
| TimexCon-Trt | 2 | .23 | 2.87+ | .06 | .86 |
| TxCon-Trt | 1 | .04 | .50 | .10 | 1.43 |
| $T^2$xCon-Trt | 1 | .42 | 5.25** | .02 | .29 |
| Time x Source | 4 | .29 | 3.62* | .09 | 1.29 |
| TS | 1 | .20 | 2.50 | -- | -- |
| $TS^2$ | 1 | .60 | 7.50** | .34 | 4.86* |
| $T^2S$ | 1 | .04 | .50 | .02 | .29 |
| $T^2S^2$ | 1 | .30 | 3.75+ | .01 | .14 |
| Time x Rate | 4 | .56 | 7.00*** | .06 | .86 |
| TR | 1 | 1.71 | 21.38*** | .01 | .14 |
| $TR^2$ | 1 | .31 | 3.88+ | .11 | 1.57 |
| $T^2R$ | 1 | .08 | 1.00 | .04 | .57 |
| $T^2R^2$ | 1 | .14 | 1.75 | .07 | 1.00 |
| T x S x R | 8 | .06 | .75 | .11 | 1.57 |
| $TS^2R$ | 1 | | | .41 | 5.86*** |
| $TS^2R^2$ | 1 | .28 | 3.50+ | | |
| Error B | 40 | .08 | | .07 | |

[a]All mean square values are coded (multiplied by 10).

Because of the extremely high fertility level at site 5 only small leaf N differences were associated with the times of N application (Tables 7 and 12). The SCU source of N gave significantly ($P < .05$) lower leaf N values than the other sources and a general decrease in leaf N with time observed with SCU as opposed to an increase with AN and urea accounted for the $TS^2$ interaction being significant at the .05 probability level.

As mentioned earlier an increase in the rate of applied N had a marked positive influence on % N in the corn leaves at all sites. Leaf N was increased significantly ($P < .005$) in a linear relationship as the rate of applied N increased at all sites in all years (Tables 8-12). The effect of applied N on leaf N became greater where the inherent soil N was low (Table 6) or became depleted by successive cropping (Table 3). The quadratic effect of applied N was also significant at several sites (Tables 8, 9, 10 and 12), where the higher applied N rates or inherently high soil N levels resulted in the leveling off of leaf N values.

Briefly summarizing, leaf N levels were in general agreement with yield data and this relationship could either be due to treatment, moisture or unmeasured factors.

Phosphorus

Despite the fact that at least recommended rates of P fertilizer were used in all the experiments, leaf P concentrations were generally lower than is considered desirable. This trend was probably associated with the use of hybrids which tend to be low in P but in some cases may have been due to unfavorable weather conditions or other unknown factors.

In general, time of N application had little if any consistent effect upon leaf P whereas higher N rates markedly increased % P in the corn leaves (Tables 3-7). Site 4 was the only location showing a significant increase in leaf P with the later time of N application. This increase was very pronounced at the 30 lb/A rate and to a lesser extent at the 90 lb/A rate, but leaf P levels remained constant or decreased at the 270 lb/A rate. With increasing amounts of applied N, leaf P was significantly increased in 7 out of the 9 site-years, an effect which has been observed by many researchers. The positive linear effect on leaf P with increasing N rates was highly significant ($P < .01$) for 6 site-years and the quadratic effect on leaf P was highly significant at 4 site-years. Leaf P data for 1969 and 1970 at site 1 exhibited a somewhat different trend in that leaf P response to increasing N rates was sigmoid.

Potassium

Leaf K concentrations were generally in the range of sufficiency as would be expected following adequate application of fertilizer K.

Time of N application had little influence on leaf K but increasing the rate of N significantly decreased leaf K (Tables 3-7). At site 4, where the only significant effect of time of N application on K leaf content was observed, leaf K levels increased with the later time of N application at the 90 and 270 lb/A rates but remained nearly constant at the 30 lb/A rate. In 7 of the 9 site-years the rate of N significantly influenced leaf K and this effect was a significant linear decrease in % K with increasing N rates. Leaf K concentration is often reported to decrease with increasing N fertilizer rates, particularly when a growth response to N is evident.

## Corn Yield

The influence of time of N application was generally to give larger corn yield response with the later applied fertilizer N. Careful examination of the data given in Tables 13, 16, 18, 21 and 22 indicates that the summer sidedress application usually resulted in the highest yield except for the 1970 season, when the spring applied N gave the largest response at sites 1, 3 and 4. Large yield responses occurred as the rate of applied N was increased, even at locations where inherent soil N levels were high.

Statistical procedures used to evaluate corn yield data were the same as those employed for leaf analysis, however, additional AOV tables were calculated with the control plot data omitted. This was done to avoid the possibility of having the three control yields for the fall, spring and summer treatments contribute to the time effect or the time by rate interaction. Regression analysis was performed by fitting the model $Y = f(M, B_i, N_f, N_f^2, N_{sp}, N_{sp}^2, N_s, N_s^2)$ where M = mean yield, $B_i$ = 1 to i terms for blocks, and $N_f$, $N_{sp}$, $N_s$ or the corresponding quadratic terms identify the amount of fall, spring and summer applied N, respectively. In the experiments involving anhydrous ammonia as the N source, actual rates of N applied in the field rather than the intended rates were used in fitting the regression model to the yield data. Relative efficiencies were calculated by expressing the predicted yield responses for fall or spring applied N as a percentage of the predicted yield response for summer applied N and plotting these values against the rate of N applied.

Site 1

The time of N application exerted a significant influence on corn yields at the .05 level in 1969 and for the combined 3-year period (Tables 13, 14 and 20). Figures 1-3 illustrate the trend at the lower N rates for fall applications to give the lowest yield each of the three years at this site, but little if any difference between the time of N application was evident at the 160 lb/A rate.

Below normal rainfall from the time of fall N application until after the spring application in 1968 (Table 34), followed by very favorable moisture distribution throughout the growing season undoubtedly contributed to the small spread in response due to time of N application. In addition, residual N from the previous soybean crop limited response to applied N, which tended to restrict any influence from time of fertilizer N application. However, the fall application tended to give yields inferior to the later times at the 40 and 80 lb/A rates. This condition closely parallels the trend in leaf N levels discussed earlier. Response to applied N was 15.5 and 38 bu/A for the 40 and 80 lb/A rates, with little additional increase at the 160 lb/A rate.

During the 1969 cropping season higher amounts of rainfall in early fall and throughout the winter and spring possibly explains the significant linear increase in yield response with the later application of N (Tables 13 and 14). Figure 2 illustrates that yields following fall applications of N were less than those of spring and summer applications at all rates used in the experiment. Yields favored summer over spring application at the two lower rates but were about equal for the two treatments at the 160 lb/A rate. Leaf N levels tended to correspond very closely with the

Table 13. Yields of corn as affected by time and rate of anhydrous ammonia at site 1 (Mean of 4 replications)

| Rate of N application lb/A | Bu/A at 15.5% moisture | | | |
|---|---|---|---|---|
| | Time of ammonia application | | | Rate ave. |
| | Fall | Spring | Summer | |
| | | 1968 | | |
| 0 | 119.6 | 112.4 | 124.2 | 118.7 |
| 40 | 128.9 | 142.1 | 131.5 | 134.2 |
| 80 | 152.2 | 159.0 | 159.0 | 156.7 |
| 160 | 158.5 | 156.5 | 160.5 | 158.5 |
| Ave. | 146.5 | 152.5 | 150.3 | |
| | | 1969 | | |
| 0 | 63.9 | 62.1 | 66.8 | 64.2 |
| 40 | 76.9 | 83.9 | 90.7 | 83.8 |
| 80 | 107.4 | 113.5 | 123.7 | 114.9 |
| 160 | 128.8 | 144.5 | 141.0 | 138.1 |
| Ave. | 104.4 | 114.0 | 118.5 | |
| | | 1970 | | |
| 0 | 34.7 | 38.2 | 41.8 | 38.2 |
| 40 | 52.3 | 74.4 | 68.8 | 65.2 |
| 80 | 93.0 | 102.1 | 99.3 | 98.1 |
| 160 | 144.0 | 134.9 | 132.0 | 137.0 |
| Ave. | 96.4 | 103.8 | 100.0 | |
| | | 3-year average yields | | |
| 0 | 72.7 | 70.9 | 77.6 | 73.7 |
| 40 | 86.0 | 100.1 | 97.0 | 94.4 |
| 80 | 117.5 | 124.9 | 127.3 | 123.2 |
| 160 | 143.8 | 145.3 | 144.5 | 144.5 |
| Ave. | 115.8 | 123.4 | 122.9 | |

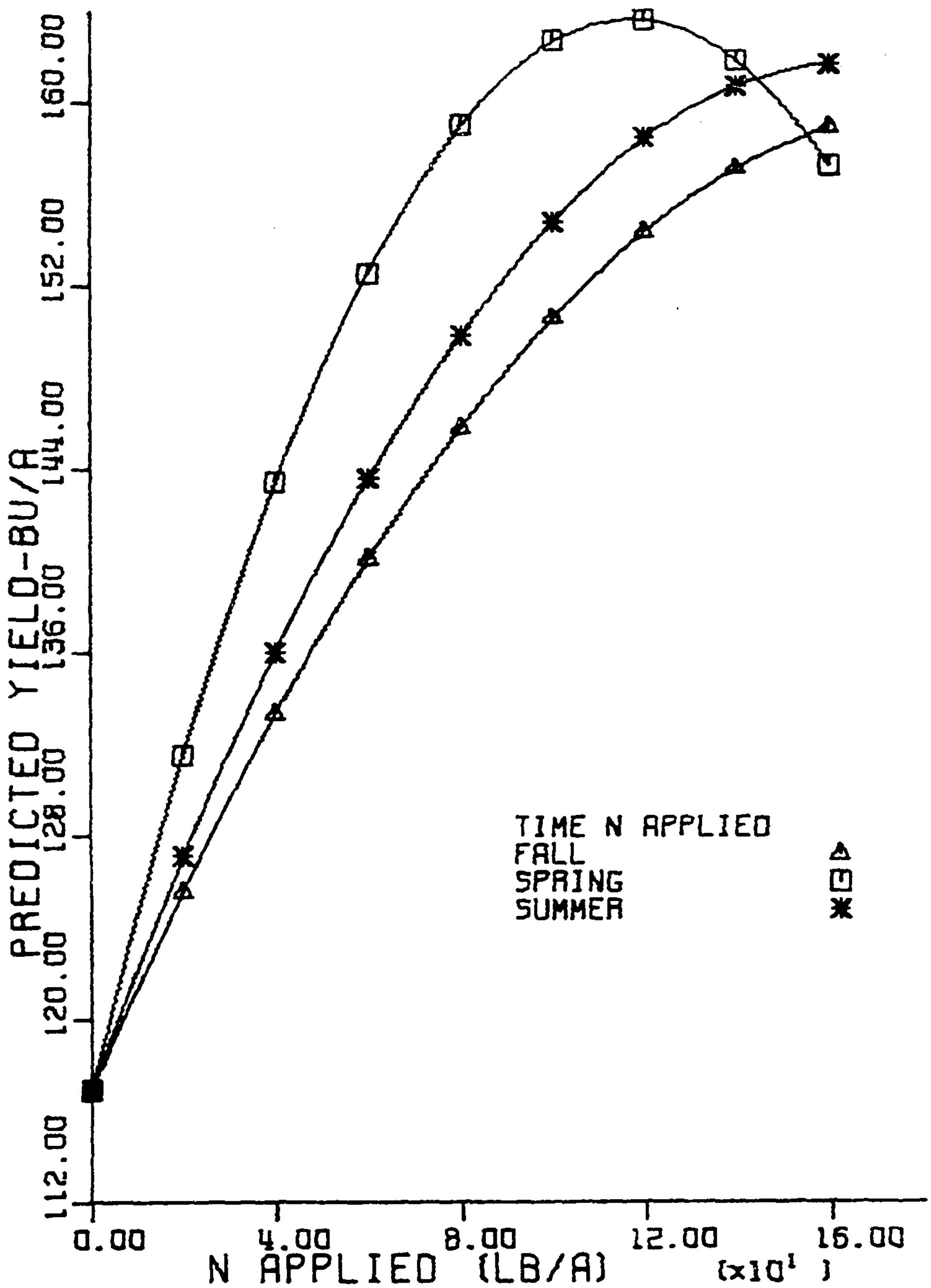
Table 14. Analysis of variance of corn yields as influenced by time and rate of applied N for each year at site 1

| Source | df | 1968 MS | 1968 F | 1969 MS | 1969 F | 1970 MS | 1970 F |
|---|---|---|---|---|---|---|---|
| Blocks | 3 | 453.42 | 6.50*** | 1076.37 | 6.80*** | 88.26 | 1.14 |
| Treatments | 11 | 1266.86 | 18.16*** | 3645.81 | 23.04*** | 6101.23 | 78.83*** |
| Times | 2 | 66.16 | .95 | 517.89 | 3.27+ | 172.21 | 2.23 |
| $T$ | 1 | 127.60 | 1.83 | 1022.65 | 6.46* | 161.55 | 2.09 |
| $T^2$ | 1 | 4.73 | .07 | 13.13 | .08 | 182.88 | 2.36 |
| Rates | 3 | 4370.29 | 62.63*** | 12863.50 | 81.29*** | 21821.43 | 281.94*** |
| $R$ | 1 | 12085.63 | 173.20*** | 38327.01 | 242.19*** | 65039.98 | 840.31*** |
| $R^2$ | 1 | 562.38 | 8.06** | 39.79 | .25 | 424.23 | 5.48* |
| $R^3$ | 1 | 462.87 | 6.63* | 223.68 | 1.41 | .01 | -- |
| Time x Rate | 6 | 115.38 | 1.65 | 79.61 | .50 | 217.48 | 2.81* |
| $TR$ | 1 | 1.31 | .02 | 93.18 | .59 | 457.31 | 5.91* |
| $TR^2$ | 1 | 3.85 | .06 | 112.12 | .71 | 384.34 | 4.97* |
| $TR^3$ | 1 | 22.88 | .33 | .28 | -- | 13.51 | .17 |
| $T^2R$ | 1 | 15.88 | .23 | 176.54 | 1.12 | 38.93 | .50 |
| $T^2R^2$ | 1 | 513.84 | 7.36* | 46.34 | .29 | 355.36 | 4.59* |
| $T^2R^3$ | 1 | 134.51 | 1.93 | 49.22 | .31 | 55.42 | .72 |
| Error | 33 | 69.78 | | 158.25 | | 77.40 | |

results indicated by the grain yields, both with respect to the influence of time and rate of N applied. Apparently the spring rainfall, in addition to the adequate subsoil moisture, resulted in some loss of N by denitrification to give the lower yields with the fall and spring applied N. Below normal rainfall in August and September probably encouraged plant uptake of moisture and N from the subsoil, which resulted in similar yields following spring and summer applications at the 160 lb/A rate. Response to applied N was large, 73.9 bu/A with 160 lb/A, as would be expected with second year corn, but the yields were limited some by the lack of rainfall and premature death of some plants. The latter was thought to have been caused by stalk rot.

Under the conditions which prevailed in 1970, the earlier applications of N tended to be more effective but the trends were somewhat erratic. The influence of time of N application was not statistically significant (Table 14) but the highest yield resulted from spring applied N at the 40 and 80 lb/A rates and from fall applied N at the 160 lb/A rate (Figure 3). Precipitation was below normal during June, July and August and possibly the summer application had not moved as deeply into the soil and was in a less favorable position with respect to soil moisture supplies. Results from leaf N analysis differed from yields in that % N increased with the later application of fertilizer N, the only exception being the spring applied 160 lb/A rate which produced the highest leaf N value. The highly significant ($P < .01$) response to applied N continued for the third consecutive year as the average yield with 160 lb/A was nearly 100 bu/A greater than the control. The trend for a linear increase in yield response with later N application at the 40 and 80 lb/A rates in contrast to the decreasing

Figure 1. Predicted corn yields for the three times of N application at site 1 in 1968



PREDICTED YIELD-BU/A
112.00
120.00
128.00
136.00
144.00
152.00
160.00
0.00
4.00
8.00
12.00
16.00
N APPLIED (LB/A)
(x10¹ )
TIME N APPLIED
FALL
SPRING
SUMMER

Figure 2. Predicted corn yields for the three times of N application at site 1 in 1969

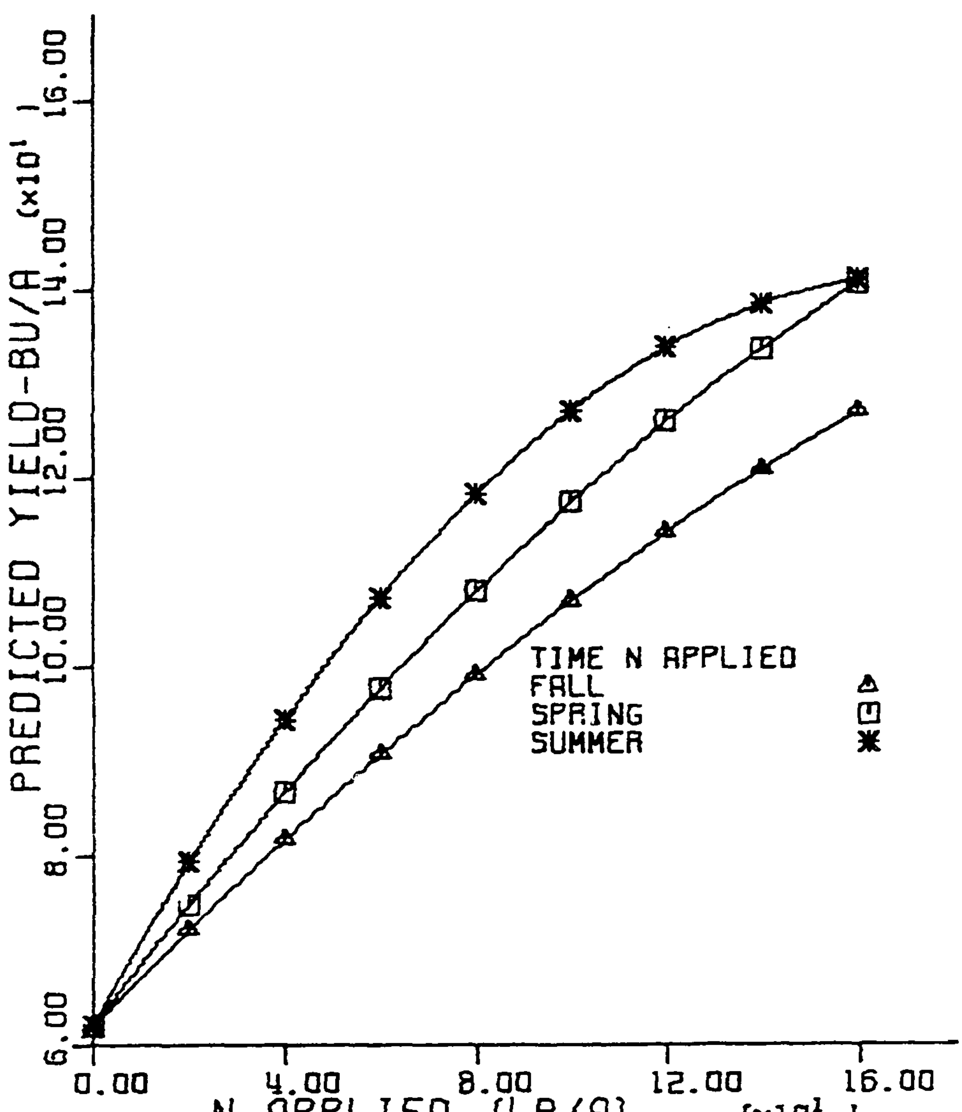
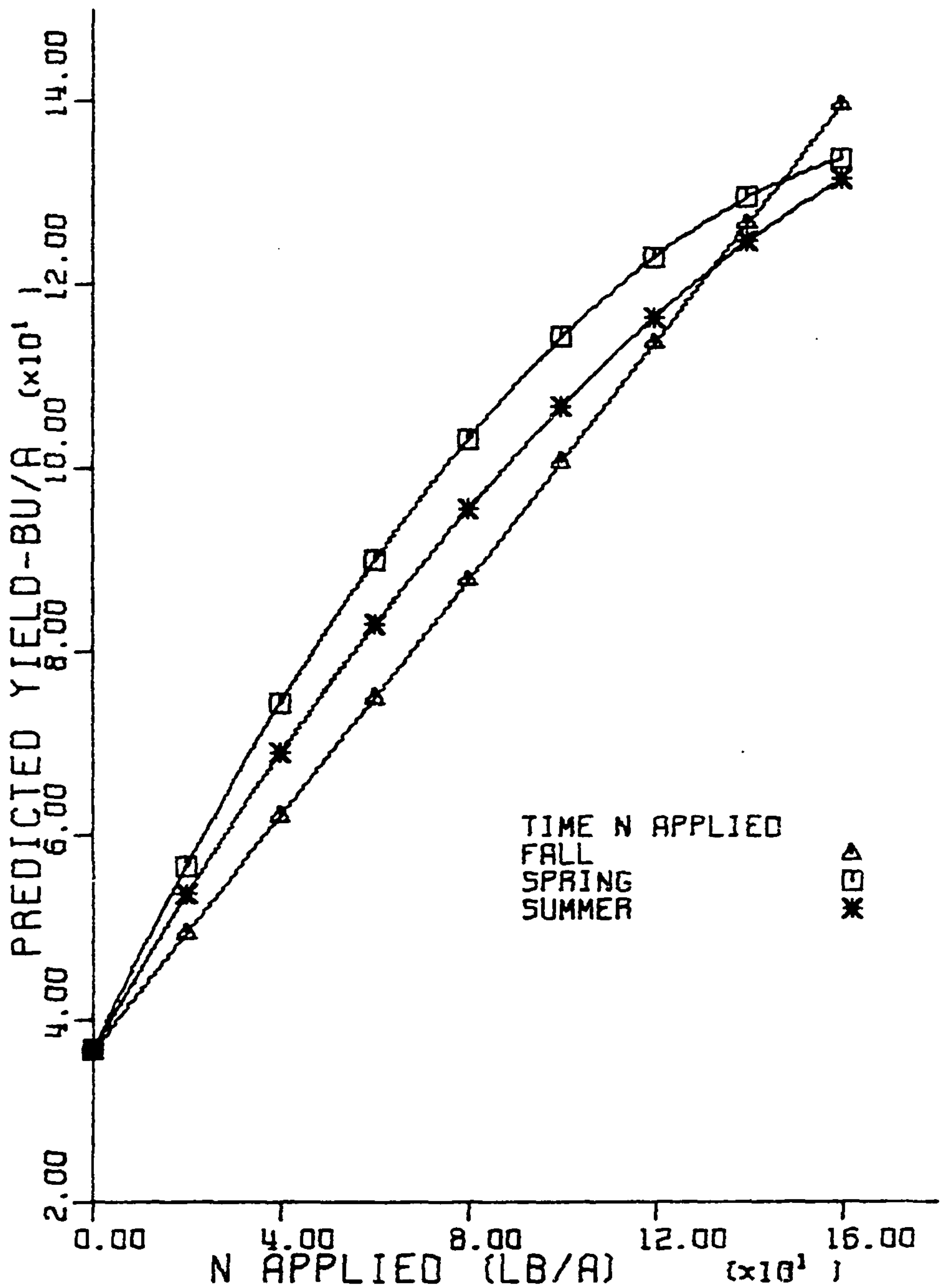

PREDICTED YIELD-BU/A (x10¹ )
6.00
8.00
10.00
12.00
14.00
16.00
N APPLIED (LB/A) (x10¹ )
0.00
4.00
8.00
12.00
16.00
TIME N APPLIED
FALL
SPRING
SUMMER

Figure 3. Predicted corn yields for the three times of N application at site 1 in 1970


PREDICTED YIELD-BU/A (x10[1])
2.00
4.00
6.00
8.00
10.00
12.00
14.00
N APPLIED (LB/A) (x10[1])
0.00
4.00
8.00
12.00
16.00
TIME N APPLIED
FALL
SPRING
SUMMER

yield response at the 160 lb/A rate largely accounted for the overall time by rate interaction being significant (P <.05), and more specifically for the TR interaction being highly significant (P <.005) when the control plot yields were omitted from the analysis (Tables 13, 14 and 40). The greater yield response of spring applied N over the fall and summer applications at the 40 and 80 lb/A rates as opposed to a decrease in yield response with later N applications at the 160 lb/A rate accounted for the $T^2R^2$ or $T^2R$ interaction being significant in Tables 14 and 40 respectively.

Three-year average yields and AOV are given in Tables 13 and 20. The influence of time of N application on corn yields was significant as was the linear increase in yield response with progressively later N application. Observation of the average yields for the three times of N application indicates that the yields resulting from fall applied N are different from those resulting from spring or summer applied N but the spring and summer treatments do not differ from each other. Comparison of the time treatments at the 40 and 80 lb/A rates shows the inferior results with fall applied N; however, as the rate was increased to 160 lb/A little or no difference in yield was observed.

Site 2

An examination of the yield data for site 2 given in Table 16 and the AOV in Tables 17 and 20 indicates inconsistent treatment effects and suggests that other factors markedly influenced corn yields. Response to an increasing rate of fertilizer N was positive and highly significant in both years and analysis of combined data also indicates this effect but little if any influence of time of N application can be detected.

Precipitation during the fall of 1967 and throughout the growing

Table 15. Regression coefficients, $R^2$ values and standard errors obtained by fitting the model to corn yields for each site and year plus selected combined data

| Site | Year | $b_0$ | Regression coefficients[a] | | | | | | $R^2$ | SE |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $b_1(N_f)$ | $b_{11}(N_f)^2$ | $b_2(N_{sp})$ | $b_{22}(N_{sp})^2$ | $b_3(N_s)$ | $b_{33}(N_s)^2$ | | |
| 1 | 68[b] | 116.856 | .4614*** | -.1240+ | .8013*** | -.3430*** | .5452*** | -.1655** | .815 | 9.253 |
| | 69[b] | 62.091 | .5227*** | -.0723 | .6589*** | -.1044 | .9128*** | -.2613** | .874 | 12.661 |
| | 70[b] | 36.609 | .6371*** | .0042 | 1.0592*** | -.2822*** | .8819*** | -.1802* | .935 | 10.898 |
| 2 | 68 | 47.253 | .2405* | -.0443 | .3254* | -.0758 | .5024*** | -.1890*** | .688 | 10.712 |
| | 69 | 27.636 | -.0180 | .2262 | .2085 | .0063 | .4234+ | -.0790 | .727 | 18.233 |
| 3 | 69[b] | 130.683 | .2093*** | -.0494** | .1721*** | -.0379* | .1926*** | -.0519** | .769 | 4.906 |
| | 70[b] | 73.959 | .4484*** | -.1073*** | .5606*** | -.1377*** | .5641*** | .1428*** | .856 | 9.800 |
| 4 | 70[bc] | 66.849 | .8495*** | -.2010*** | .9474*** | -.2421*** | .9595*** | -.2562*** | .878 | 10.720 |
| 5 | 70 | 138.571 | .0848** | -.0205+ | .0491 | -.0047*** | .0835** | -.0246* | .359 | 4.448 |
| Combined[d] | | 79.197 | .3504* | -.0414 | .4307* | -.0749 | .4757** | -.0998 | .282 | 71.897 |
| Combined[b] | | 81.016 | .5473*** | -.1211*** | .6693*** | -.1716*** | .6841*** | -.1856*** | .873 | 26.479 |
| Combined:[e] | | | | | | | | | | |
| | 68 | 116.857 | .4615* | -.1241 | .8013*** | -.3429* | .5453* | -.1655 | .932 | 13.787 |
| | 69 | 94.220 | .4406* | -1.1020 | .5348*** | -1.4864+ | .6324*** | -2.0272* | .852 | 28.504 |
| | 70 | 58.250 | .7449*** | -1.7611*** | .8703*** | -2.2600*** | .8754*** | -2.3663*** | .992 | 23.092 |

[a] Coefficients for the quadratic terms are coded (multiplied by 100).

[b] Combined analysis using treatment means for only the sites and years designated by [b].

[c] Only treatment means for the AN and urea N sources were included.

[d] Combined analysis using treatment means for all sites and years without block terms.

[e] Combined analysis using treatment means for each year of the sites designated by [b].

Table 16. Yields of corn as affected by time and rate of anhydrous ammonia at site 2 (Mean of 4 replications)

| Rate of N application lb/A | Bu/A at 15.5% moisture | | | |
|---|---|---|---|---|
| | Time of ammonia application | | | Rate ave. |
| | Fall | Spring | Summer | |
| | | 1968 | | |
| 0 | 47.9 | 39.1 | 50.0 | 45.7 |
| 40 | 62.8 | 60.3 | 73.7 | 65.6 |
| 80 | 61.3 | 66.5 | 68.8 | 65.5 |
| 160 | 76.5 | 82.1 | 74.8 | 77.8 |
| Ave. | 66.9 | 69.6 | 72.4 | |
| | | 1969 | | |
| 0 | 29.7 | 21.8 | 29.7 | 27.1 |
| 40 | 36.2 | 36.0 | 43.5 | 38.6 |
| 80 | 38.2 | 44.1 | 59.5 | 47.3 |
| 160 | 86.3 | 62.8 | 75.8 | 75.0 |
| Ave. | 53.6 | 47.6 | 59.6 | |
| | | 2 year average yields | | |
| 0 | 38.8 | 30.4 | 39.8 | 36.4 |
| 40 | 49.5 | 48.1 | 58.6 | 52.1 |
| 80 | 49.8 | 55.3 | 64.1 | 56.4 |
| 160 | 81.4 | 72.5 | 75.3 | 76.4 |
| Ave. | 60.2 | 58.6 | 66.0 | |

season of 1968 was above normal, resulting in accumulation of excess soil moisture in part of the experimental site. This non-uniformity in drainage gave considerable variation in yields from plots treated alike (Table 36). If the yields for the plots receiving N are considered (excluding controls), a trend for a slight increase in average yield response was observed with the later N application. The markedly different response to an increasing rate of N for the three times of application did result in a significant

Table 17. Analysis of variance of corn yields as influenced by time and rate of applied N for each year at site 2

| Source | df | 1968 MS | 1968 F | 1969 MS | 1969 F |
|---|---|---|---|---|---|
| Blocks | 3 | 1052.45 | 9.76*** | 5528.73 | 14.91*** |
| Treatments | 11 | 660.66 | 6.12*** | 1582.39 | 4.27*** |
| Time | 2 | 120.41 | 1.12 | 483.59 | 1.31 |
| T | 1 | 175.31 | 1.63 | 161.56 | .44 |
| $T^2$ | 1 | 65.51 | .61 | 805.61 | 2.17 |
| Rate | 3 | 2118.78 | 19.64*** | 5006.56 | 13.51*** |
| R | 1 | 5558.41 | 51.53*** | 13944.61 | 37.62*** |
| $R^2$ | 1 | 177.10 | 1.64 | 787.31 | 2.12 |
| $R^3$ | 1 | 620.80 | 5.76* | 287.76 | .78 |
| Time x Rate | 6 | 111.68 | 1.04 | 236.58 | .64 |
| TR | 1 | 21.83 | .20 | 30.89 | .08 |
| $TR^2$ | 1 | 161.55 | 1.50 | 765.38 | 2.06 |
| $TR^3$ | 1 | 4.32 | .04 | 275.88 | .74 |
| $T^2R$ | 1 | 456.88 | 4.24* | 135.15 | .36 |
| $T^2R^2$ | 1 | 6.36 | .06 | 204.46 | .55 |
| $T^2R^3$ | 1 | 19.16 | .18 | 7.73 | .02 |
| Error | 33 | 107.87 | | 370.71 | |

($P < .05$) $T^2R$ interaction in the analysis of all data (Table 17) but the significant level dropped considerably ($P < .10$) when the control plots were excluded from the analysis (Table 41). A highly significant linear increase in yield response was observed as higher rates of N were applied.

Much the same excess moisture situation prevailed during the 1969 season; however, the trends in yield response were somewhat different from those observed in 1968. Careful study of individual plot yields in Table 36 and field observations suggest that drainage differences within the area had a much greater influence on mean yields than the imposed time or rate treatments. This condition was believed to be partially responsible for the lowest yield occurring with spring applied N and with increasingly larger yields for the fall and summer applications respectively. The linear effect on yield was positive and highly significant as the rate of fertilizer N was increased, resulting in nearly a 50 bu/A response.

Combined data for the two years indicate a nonsignificant time of application effect and a highly significant rate effect (Table 20). The trend, if present, would seem to be that yields for fall and spring applied N are similar but somewhat lower than yields following summer application of N.

<u>Site 3</u>

Time of N application did not exert a significant influence on corn yields as indicated by Tables 18-20. However, when the control plot data were omitted (Table 42) a significant ($P < .05$) decrease in yield was detected in 1969 with the later application of fertilizer N (Table 18). A highly significant increase in yield response was observed both years with an increase in applied N.

Corn yields in 1969 were generally high because of the previous soybean crop, inherent fertility of the soil and fairly adequate rainfall throughout the growing season. The previously mentioned significant decrease in yield response with later N application, as illustrated by Figure 4 and Table 18, may have resulted from sufficient spring precipitation distributing the earlier applied N so as to maximize the use of subsoil moisture and nutrients. It must be kept in mind however, that mean yield differences were very small, a maximum of approximately 4 bu/A between the fall and summer applied treatments, and that the error mean square was extremely low (Table 42). Although the response to applied N was only 20

Table 18. Yields of corn as affected by time and rate of anhydrous ammonia at site 3 (Mean of 4 replications)

| Rate of N application lb/A | Bu/A at 15.5% moisture | | | |
|---|---|---|---|---|
| | Time of ammonia application | | | Rate ave. |
| | Fall | Spring | Summer | |
| | | 1969 | | |
| 0 | 129.1 | 131.7 | 130.5 | 130.4 |
| 80 | 147.4 | 144.3 | 140.9 | 144.2 |
| 160 | 149.5 | 146.8 | 150.7 | 149.0 |
| 240 | 153.2 | 150.8 | 146.0 | 150.0 |
| Ave. | 150.0 | 147.3 | 145.9 | |
| | | 1970 | | |
| 0 | 73.1 | 75.0 | 70.3 | 72.8 |
| 80 | 108.2 | 113.6 | 116.8 | 112.9 |
| 160 | 118.7 | 125.8 | 123.4 | 122.6 |
| 240 | 118.4 | 129.8 | 127.7 | 125.3 |
| Ave. | 115.1 | 123.1 | 122.6 | |
| | | 2 year average yields | | |
| 0 | 101.1 | 103.4 | 100.4 | 101.6 |
| 80 | 127.8 | 128.9 | 128.8 | 128.5 |
| 160 | 134.1 | 136.3 | 137.0 | 135.8 |
| 240 | 135.8 | 140.3 | 136.9 | 137.7 |
| Ave. | 132.6 | 135.2 | 134.2 | |

bu/A, both the positive linear and negative quadratic effects on corn yields were highly significant (Table 15 and 19).

Even though the time of application effect on 1970 yields was not significant, a trend was apparent for the later applications to give the higher yield (Tables 18, 19 and Figure 5). At the 80 lb/A rate, yields tended to increase with later N application whereas the spring applied N gave the greatest yield at the 160 and 240 lb/A rates followed by summer

Table 19. Analysis of variance of corn yields as influenced by time and rate of applied N for each year at site 3

| Source | df | 1969 MS | 1969 F | 1970 MS | 1970 F |
|---|---|---|---|---|---|
| Blocks | 3 | 19.35 | .83 | 69.79 | .72 |
| Treatments | 11 | 287.33 | 12.36*** | 1990.76 | 20.62*** |
| Times | 2 | 30.25 | 1.30 | 182.05 | 1.89 |
| T | 1 | 60.50 | 2.60 | 195.03 | 2.02 |
| $T^2$ | 1 | -- | -- | 169.07 | 1.75 |
| Rates | 3 | 974.38 | 41.91*** | 7101.50 | 73.54*** |
| R | 1 | 2423.16 | 104.22*** | 16778.52 | 173.76*** |
| $R^2$ | 1 | 483.87 | 20.81*** | 4201.89 | 43.52*** |
| $R^3$ | 1 | 16.12 | .69 | 324.10 | 3.36+ |
| Time x Rate | 6 | 29.49 | 1.27 | 38.29 | .40 |
| TR | 1 | 32.04 | 1.38 | 104.33 | 1.08 |
| $TR^2$ | 1 | .13 | .01 | 22.44 | .23 |
| $TR^3$ | 1 | 101.13 | 4.35* | 56.88 | .59 |
| $T^2R$ | 1 | 4.22 | .18 | 27.08 | .28 |
| $T^2R^2$ | 1 | 27.09 | 1.17 | 11.76 | .12 |
| $T^2R^3$ | 1 | 12.35 | .53 | 7.25 | .08 |
| Error | 33 | 23.25 | | 96.56 | |

and then fall applied N. Yields were generally lower in 1970 because of periods of insufficient moisture during early summer coupled with the infestation of southern corn leaf blight. Despite these adversities, the response to increasing rates of N was highly significant with a yield increase of nearly 53 bu/A.

Two-year average yields and AOV are given in Tables 18 and 20. Time of N application did not influence yield but a highly significant response to applied N was observed. Leaf N followed the same general trends as were indicated by the grain yields for both the 1969 and 1970 cropping seasons. The combined AOV of leaf N showed a significant ($P < .05$)

Figure 4. Predicted corn yields for the three times of N application at site 3 in 1969

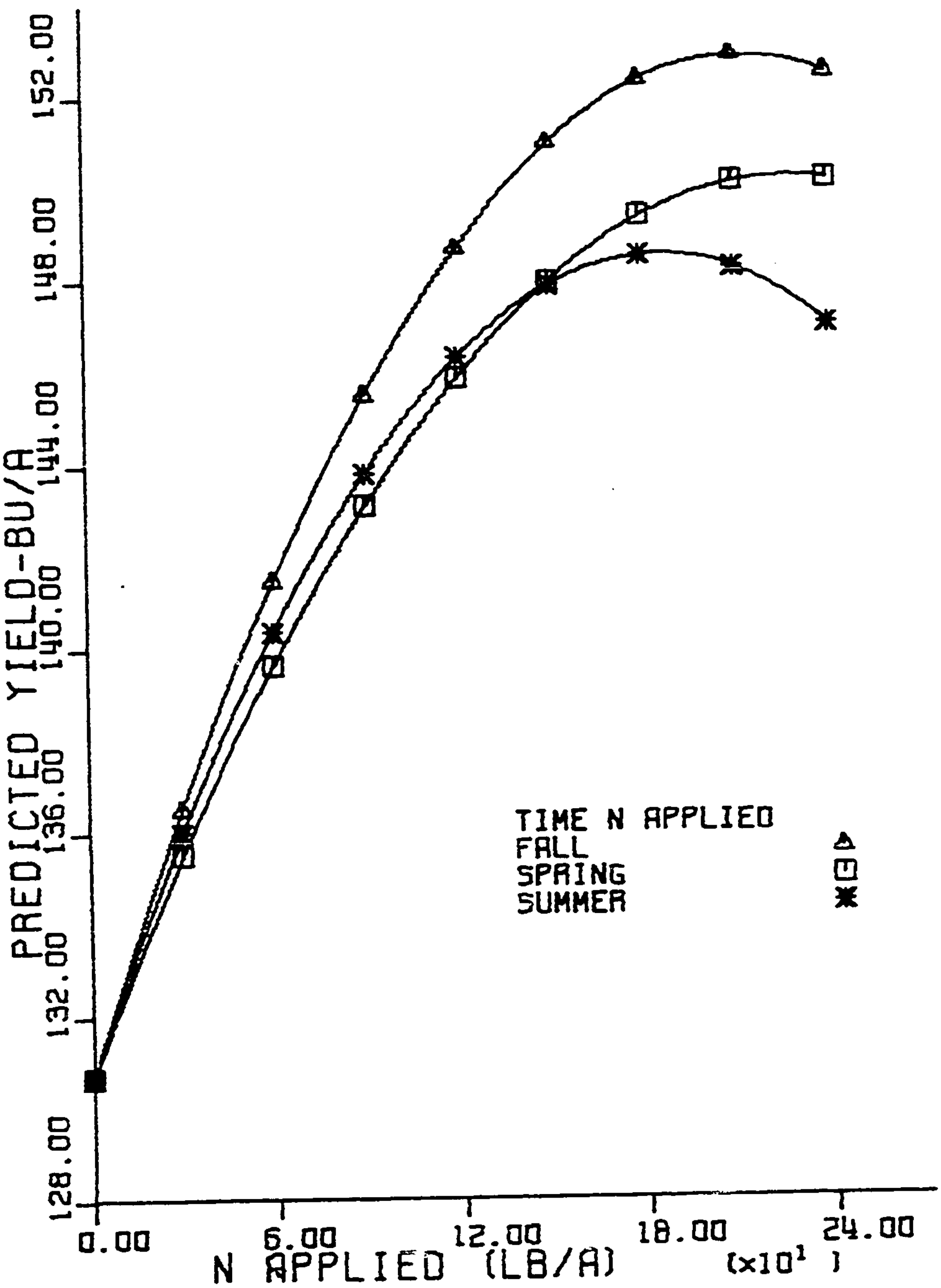

PREDICTED YIELD-BU/A
152.00
148.00
144.00
140.00
136.00
132.00
128.00
0.00
6.00
12.00
18.00
24.00
N APPLIED (LB/A)
(x10[1] )
TIME N APPLIED
FALL
SPRING
SUMMER

Figure 5. Predicted corn yields for the three times of N application at site 3 in 1970

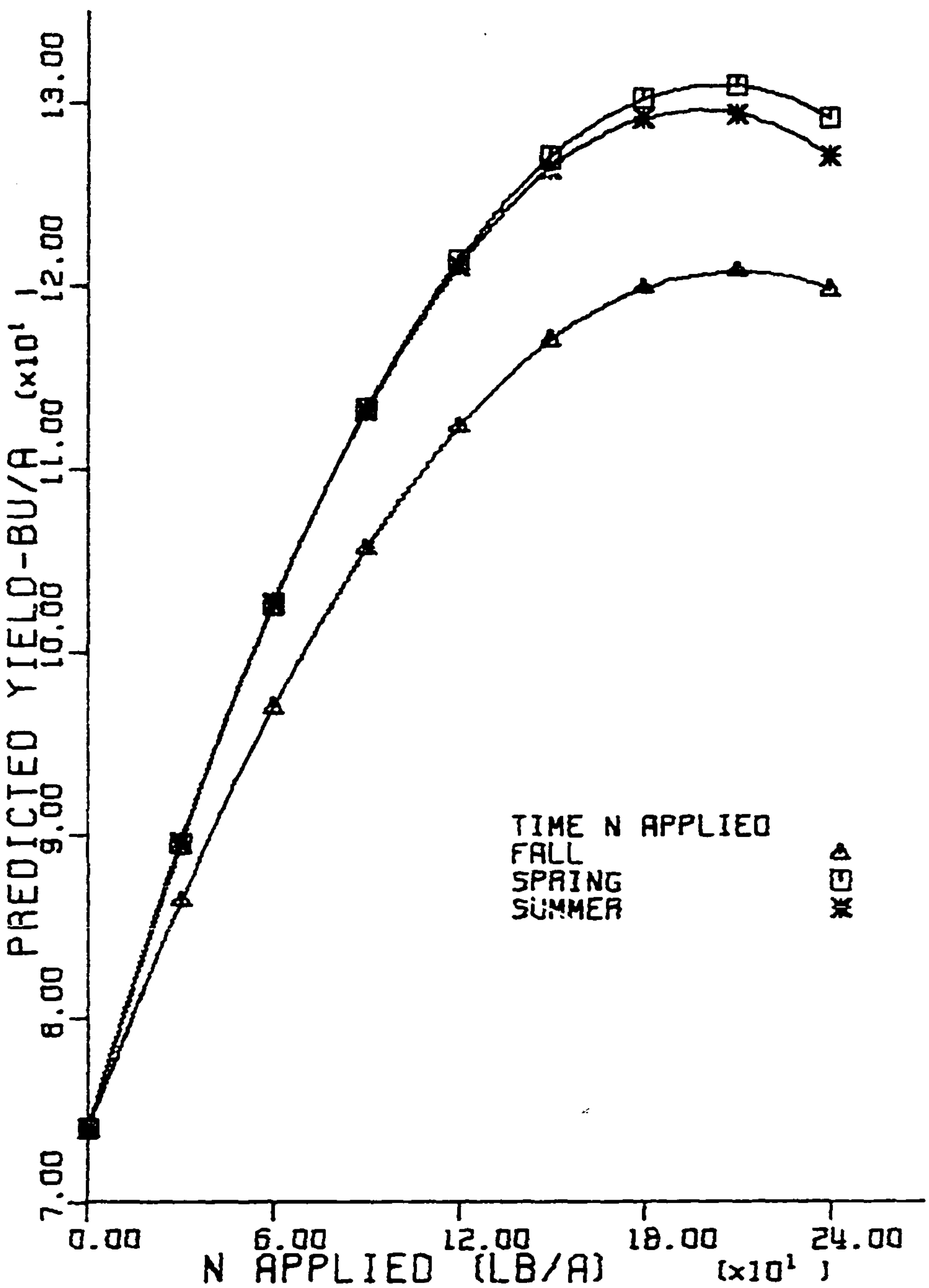

PREDICTED YIELD-BU/A (x10¹)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
TIME N APPLIED
FALL
SPRING
SUMMER
0.00
6.00
12.00
18.00
24.00
N APPLIED (LB/A)
(x10¹)

Table 20. Individual site analysis of variance of combined corn yield data as influenced by year, time and rate of applied N

| Source | Site 1 df | Site 1 MS | Site 1 F | df | Site 2 MS | Site 2 F | Site 3 MS | Site 3 F |
|---|---|---|---|---|---|---|---|---|
| Blocks | 3 | 884.14 | 5.04* | 3 | 5669.64 | 16.96*** | 46.28 | .69 |
| Treatments | 11 | 9772.34 | 55.72*** | 11 | 1968.98 | 5.89*** | 1832.80 | 27.23*** |
| Times | 2 | 584.60 | 3.33* | 2 | 501.00 | 1.50 | 51.71 | .77 |
| T | 1 | 1044.79 | 5.96* | 1 | 336.73 | 1.01 | 19.14 | .28 |
| $T^2$ | 1 | 124.41 | .71 | 1 | 665.27 | 1.99 | 84.27 | 1.25 |
| Rates | 3 | 35086.02 | 200.08*** | 3 | 6513.75 | 19.48*** | 6662.77 | 98.97*** |
| R | 1 | 104808.60 | 597.68*** | 1 | 18555.51 | 55.51*** | 15977.16 | 237.33*** |
| $R^2$ | 1 | 3.39 | .02 | 1 | 108.80 | .33 | 3768.75 | 55.98*** |
| $R^3$ | 1 | 446.01 | 2.54 | 1 | 876.94 | 2.62 | 242.39 | 3.60+ |
| Time x Rate | 6 | 178.10 | 1.02 | 6 | 185.92 | .56 | 11.51 | .17 |
| TR | 1 | 55.28 | .32 | 1 | 52.32 | .16 | 10.37 | .15 |
| $TR^2$ | 1 | 344.66 | 1.97 | 1 | 815.10 | 2.44 | 12.96 | .19 |
| $TR^3$ | 1 | .11 | -- | 1 | 105.57 | .32 | 3.16 | .05 |
| $T^2R$ | 1 | 40.57 | .23 | 1 | 47.53 | .14 | 4.96 | .07 |
| $T^2R^2$ | 1 | 401.63 | 2.29 | 1 | 69.36 | .21 | 37.27 | .55 |
| $T^2R^3$ | 1 | 226.34 | 1.29 | 1 | 25.62 | .08 | .34 | .01 |
| Error A | 33 | 175.36 | | 33 | 334.30 | | 67.32 | |
| Year | 2 | 42250.47 | 468.45*** | 1 | 6670.00 | 32.04*** | 29382.49 | 568.37*** |
| Y | 1 | 79051.44 | 876.50*** | | | | | |
| $Y^2$ | 1 | 5449.41 | 60.42*** | | | | | |
| Treatment x Year | 22 | 620.78 | 6.88*** | 11 | 274.08 | 1.32 | 445.29 | 8.61*** |
| Time x Year | 4 | 85.83 | .95 | 2 | 102.99 | .50 | 160.60 | 3.11* |
| TY | 1 | 1.00 | .01 | 1 | .14 | -- | 236.39 | 4.57* |
| $T^2Y$ | 1 | 266.02 | 2.95+ | 1 | 205.84 | .99 | 84.80 | 1.64 |
| $TY^2$ | 1 | 64.41 | .71 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $T^2Y^2$ | 1 | 11.90 | .13 | | | | | |
| Rate x Year | 6 | 1984.59 | 22.00*** | 3 | 611.94 | 2.94* | 1413.12 | 27.34*** |
| RY | 1 | 10526.27 | 116.71*** | 1 | 947.55 | 4.55* | 3224.56 | 62.38*** |
| $R^2Y$ | 1 | 117.77 | 1.31 | 1 | 855.60 | 4.11* | 916.98 | 17.74*** |
| $R^3Y$ | 1 | 981.73 | 10.89*** | 1 | 31.62 | .15 | 97.83 | 1.89 |
| $RY^2$ | 1 | 41.25 | .46 | | | | | |
| $R^2Y^2$ | 1 | 229.08 | 2.54 | | | | | |
| $R^3Y^2$ | 1 | 11.45 | .13 | | | | | |
| T x R x Y | 12 | 117.19 | 1.30 | 6 | 162.35 | .78 | 56.27 | 1.09 |
| $TRY^2$ | 1 | 291.72 | 3.23+ | | | | | |
| $T^2R^2Y^2$ | 1 | 506.62 | 5.62* | | | | | |
| $TR^3Y$ | | | | 1 | | | 154.85 | 3.00+ |
| Error B | 72 | 90.19 | | 36 | 208.21 | | 51.70 | |

quadratic effect of time of N application and corresponded with the trend of slightly higher 2-year average yields following the spring applied N.

Site 4

Time of N application did not have a significant influence on corn yields at this site, but trends existed for higher yields with later application at the lower N rates and with earlier application at the 270 lb/A rate (Tables 21, 23 and Figure 6). Response to applied N was large as indicated by the 77 bu/A increase in yield and a significantly lower yield level resulted from sulfur-coated urea than from ammonium nitrate or urea.

This site was located on soil relatively low in inherent fertility to which only starter N had been applied to the corn crop of the previous year. This accounts for the large response to the first increment of N applied, namely, over 20 bu/A increase from 30 lb/A of N. At this N rate all three sources of N exhibited a trend for a greater increase in yield with later N application. A similar trend was also evident for the 90 lb/A rate, but the advantage for summer over fall application was only 4 to 7 bu/A compared to a 3 to 20 bu/A advantage at the 30 lb/A rate. The 270 lb/A rate reacted differently, with the yield response tending to decrease with later N application. This decrease amounted to as much as 14 bu/A for the AN and urea sources. The trend for decreasing yield response with later N application contrasted with an increasing yield response at the 30 and 90 lb/A rates resulted in a highly significant ($P < .01$) TR interaction. Soil tests measuring $NO_3^-$-N concentration in the profile from the plots receiving 0 or 270 lb N/A (Figure 16a) showed higher N levels at greater soil depths following fall or spring application. The more favorable

Table 21. Yields of corn as affected by time, rate and source of N at site 4 in 1970 (Mean of 3 replications)

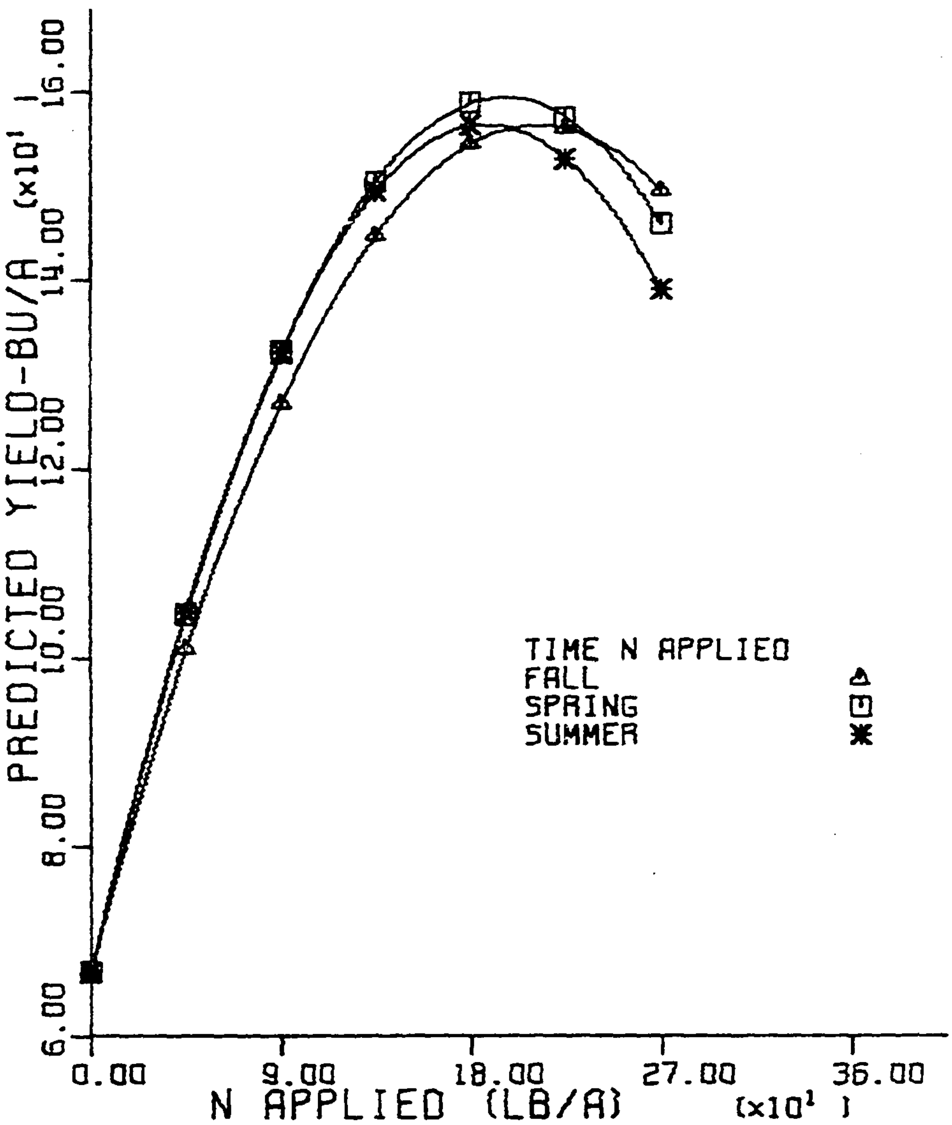
| Rate of N application lb/A | Source of N[a] | Bu/A at 15.5% moisture | | | |
|---|---|---|---|---|---|
| | | Time of N application | | | Rate ave. |
| | | Fall | Spring | Summer | |
| 0 | | 61.4 | 77.3 | 65.5 | 68.1 |
| 30 | AN | 92.1 | 95.7 | 94.7 | 91.6 |
| | SCU | 77.1 | 87.9 | 88.7 | |
| | Urea | 86.5 | 94.6 | 107.2 | |
| 90 | AN | 131.2 | 135.3 | 138.6 | 131.0 |
| | SCU | 122.7 | 123.9 | 116.5 | |
| | Urea | 134.2 | 138.8 | 137.6 | |
| 270 | AN | 152.4 | 143.7 | 141.3 | 145.0 |
| | SCU | 142.9 | 143.6 | 138.1 | |
| | Urea | 153.1 | 151.2 | 138.5 | |
| Average | | 115.4 | 119.2 | 116.7 | |
| Average for sources | AN | | | | 125.0 |
| | SCU | | | | 115.7 |
| | Urea | | | | 126.9 |

[a]AN = ammonium nitrate and SCU = sulfur-coated urea.

position of N with respect to moisture may have been responsible for the increased yields associated with the earlier applications of the 270 lb/A rate. However, the same line of reasoning does not explain the reverse trend for the lower rates.

Yields from the sulfur-coated urea (SCU) source were significantly (P <.01) lower than the AN and urea sources with an average difference of about 10 bu/A (Tables 21 and 23). At the 270 lb/A rate and later applications, the SCU yields did approach the same level as the other sources.

Figure 6. Predicted corn yields for the three times of N application at site 4 in 1970


PREDICTED YIELD-BU/A (x10¹)
16.00
14.00
12.00
10.00
8.00
6.00
0.00
9.00
18.00
27.00
36.00
N APPLIED (LB/A)
(x10¹)
TIME N APPLIED
FALL
SPRING
SUMMER

The slow release characteristic of SCU was apparent at all rates and times of application and was largest at the 90 lb/A summer application where the yield was approximately 22 bu/A less than AN or urea.

Site 5

Table 22 indicates yields were in general quite high from all plots at this location and that the average response to the 270 lb/A rate was only 6 bu/A. Neither time nor source of N application had a significant influence on corn yields.

A favorable moisture distribution throughout the growing season (Table 34) coupled with a high fertility level from past applications of manure could largely account for the small yield response from applied N. Uniformity among whole plots treated alike was quite high as indicated by the low error A mean square in Table 23 which allowed for the detection of a highly significant ($P < .005$) response to applied N. This high degree of uniformity also appeared among split plots which accounted for the detection of the overall time by rate interaction and caused the $T^2R$ to be highly significant ($P < .005$).

Relative efficiency of times of N application

Several methods have been used to compare times or sources of N applied to corn based on predicted or actual yield responses. Pesek (1964) described an approach which indicated the relative efficiency of two times of application by expressing the first derivatives of the yield function as a percentage, providing that the costs of application are the same. This approach was attempted but even with square root or grafted polynomials (Fuller, 1969) fitted to the yield data, calculated efficiencies became

Table 22. Yields of corn as affected by time, rate and source of N at site 5 in 1970 (Mean of 3 replications)

| Rate of N application lb/A | Source of N[a] | Bu/A at 15.5% moisture: Time of N application: Fall | Spring | Summer | Rate ave. |
|---|---|---|---|---|---|
| 0 | | 140.0 | 137.9 | 142.8 | 140.2 |
| 30 | AN | 144.2 | 141.1 | 143.2 | 139.7 |
| | SCU | 136.1 | 136.4 | 139.2 | |
| | Urea | 142.4 | 135.4 | 138.9 | |
| 90 | AN | 145.6 | 142.4 | 144.7 | 144.2 |
| | SCU | 145.8 | 143.6 | 142.3 | |
| | Urea | 142.3 | 144.9 | 145.8 | |
| 270 | AN | 147.3 | 146.1 | 142.3 | 146.0 |
| | SCU | 146.1 | 149.2 | 144.1 | |
| | Urea | 146.2 | 149.6 | 143.0 | |
| Average | | 143.6 | 142.7 | 142.6 | |
| Average for sources | AN | | | | 144.1 |
| | SCU | | | | 142.5 |
| | Urea | | | | 143.2 |

[a]AN = ammonium nitrate and SCU = sulfur-coated urea.

strictly hypothetical when the maximum yield was approached by the most responsive time of application. Because this method measures the comparative yield response per additional pound of N applied at a particular point on the X-axis and does not take into consideration the accumulative response of lower rates of N another method often used by researchers was decided upon.

The procedure used first involved fitting functions with linear and quadratic terms for each of the three times of N application to the yield

Table 23. Analysis of variance of corn yields as influenced by time, source and rate of applied N in 1970 at sites 4 and 5

| Source | df | Site 4 | | Site 5 | |
|---|---|---|---|---|---|
| | | MS | F | MS | F |
| Blocks | 2 | 445.37 | 3.31+ | 79.02 | 1.59 |
| Treatments | 9 | 7502.65 | 55.68*** | 89.53 | 1.80 |
| Control vs Trt | 1 | 23996.92 | 178.08*** | 74.28 | 1.50 |
| Sources | 2 | 963.03 | 7.15** | 16.75 | .34 |
| S | 1 | 47.23 | .35 | 11.57 | .23 |
| $S^2$ | 1 | 1878.83 | 13.94*** | 21.93 | .44 |
| Rates | 2 | 20657.11 | 153.30*** | 287.57 | 5.79* |
| R | 1 | 38421.14 | 285.13*** | 542.77 | 10.93*** |
| $R^2$ | 1 | 2893.08 | 21.47*** | 32.36 | .65 |
| Source x Rate | 4 | 71.06 | .53 | 30.72 | .62 |
| SR | 1 | .05 | -- | 55.51 | 1.12 |
| $SR^2$ | 1 | -- | -- | 7.10 | .14 |
| $S^2R$ | 1 | 87.30 | .65 | 55.61 | 1.12 |
| $S^2R^2$ | 1 | 199.28 | 1.48 | 4.67 | .09 |
| Error A | 18 | 134.75 | | 49.66 | |
| Time | 2 | 113.96 | 1.43 | 8.84 | 1.15 |
| T | 1 | 24.83 | .31 | 13.63 | 1.77 |
| $T^2$ | 1 | 203.10 | 2.54 | 4.05 | .52 |
| Time x Treatment | 18 | 108.92 | 1.37 | 17.83 | 2.31 |
| Time x Con-Trt | 2 | 133.55 | 1.67 | 22.27 | 2.88+ |
| T x Con-Trt | 1 | 13.52 | .17 | 24.32 | 3.15+ |
| $T^2$ x Con-Trt | 1 | 253.57 | 3.18+ | 20.22 | 2.62+ |
| Time x Source | 4 | 21.82 | .27 | 4.97 | .64 |
| TS | 1 | 28.45 | .36 | 3.18 | .41 |
| $TS^2$ | 1 | 4.48 | .06 | 2.17 | .28 |
| $T^2S$ | 1 | 13.79 | .17 | 7.10 | .92 |
| $T^2S$ | 1 | 40.56 | .51 | 7.44 | .96 |
| Time x Rate | 4 | 269.15 | 3.37* | 39.05 | 5.06*** |
| TR | 1 | 1071.92 | 13.43*** | 19.36 | 2.51 |
| $TR^2$ | 1 | 1.97 | .02 | 8.00 | 1.04 |
| $T^2R$ | 1 | .04 | -- | 125.02 | 16.19*** |
| $T^2R^2$ | 1 | 2.67 | .03 | 3.82 | .49 |
| T x S x R | 8 | 66.20 | .83 | 12.53 | 1.62 |
| TSR | 1 | 177.12 | 2.22 | | |
| $TS^2R^2$ | 1 | 163.63 | 2.05 | 48.17 | 6.24* |
| $T^2SR$ | 1 | | | 19.84 | 2.57 |
| Error B | 40 | 79.82 | | 7.72 | |

data. Relative efficiencies were then defined as the predicted yield responses for fall or spring applied N as a percentage of the predicted yield response for summer applied N. These values were plotted against the rate of N applied and appear in Figures 7 through 12 and 14.

The relative efficiencies for site 1 followed much the same pattern in 1968 and 1970 (Figures 7 and 9) with the fall applied N being considerably less efficient and the spring applied N somewhat more efficient than the summer applied N. At the higher rates of application, such as 120 lb/A or greater, yield responses were similar and efficiencies between times of application differed little. The relative efficiencies for fall and spring applied N were both markedly low in 1969 at the lower N rates with the fall applied N reaching only an 80% efficiency level at the 160 lb/A rate (Figure 8). Yield results given in Table 13 are in very close agreement with the above observations.

Due to the irregular yield response and small response at sites 2 and 5 respectively, the relative efficiencies were not calculated for these sites.

In 1969, the relative efficiencies at site 3 for fall and spring applied N were greater than 100% except for spring applied N at the lower rates of N application (Figure 10). The 1970 results given in Figure 11 indicated 100% or slightly greater efficiency for spring as compared to summer applied N but showed a very low efficiency for fall applied N, only about 80 to 85% of the summer applied N. Corn yield response for fall applied N remained below that of summer applied N throughout the range of N rates used but the AOV did not indicate a significant difference between the two times of N application (Tables 18 and 19).

Generally the same type of relative efficiency curve existed for the spring versus summer applied N at site 4 as was observed at site 3 in 1970 (Figure 12). The fall applied N was somewhat less efficient at the lower N rates and slightly more efficient at the very high N rates than the summer applied N. Predicted yields and relative efficiencies for site 4 were calculated on the basis of AN and urea N sources and did not include yields from plots receiving SCU. Observing yields from Table 21 for the fall and summer N application for the AN and urea sources confirms the change in efficiency from the low to higher N rates but again no significant difference between times of N application was indicated by AOV in Table 23.

An effort was made to arrive at an overall view of the influence that time of N application has on corn yields by the use of a combined regression analysis using treatment means. Yield data included in the combined analysis were the 3 years from site 1, 2 years from site 3 and one year from site 4 and gave $R^2$ values of .282 and .873 respectively in the absence or presence of block terms in the model (Table 15). Predicting yield functions for the three times of application were then plotted against rate of N applied and illustrated in Figure 13.

Although the combined data may be construed to be somewhat biased because of several years data which favor the spring application of N, it does indicate that response to fall application was usually less than spring or summer applied N. The low relative efficiency of fall applied N is clearly shown in Figure 14, particularly at the lower rates of applied N. Rates of 150 lb/A or greater would seem to result in 90% or more efficiency for fall applied N as compared to summer. Figure 14 also indicates that spring and summer N applications would generally result in nearly the

Figure 7. Efficiencies of fall and spring applied N relative to summer application, as measured by corn yield increases at site 1 in 1968

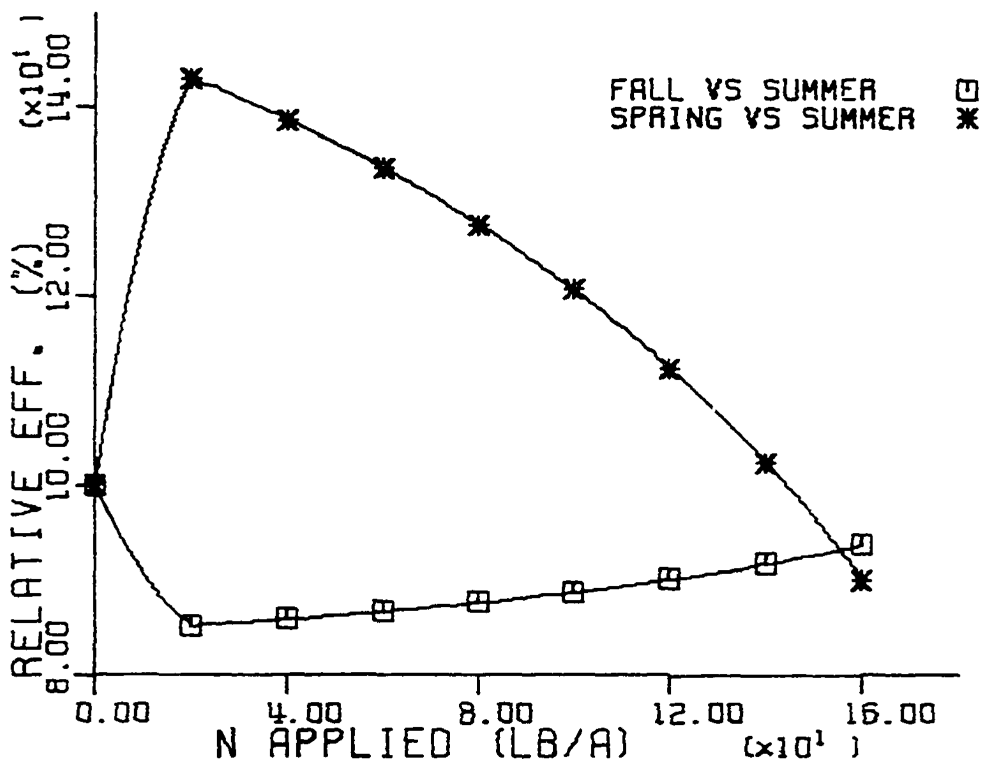

FALL VS SUMMER
SPRING VS SUMMER
RELATIVE EFF. (%)
(x10[1])
8.00
10.00
12.00
14.00
0.00
4.00
8.00
12.00
16.00
N APPLIED (LB/A)
(x10[1])

Figure 8. Efficiencies of fall and spring applied N relative to summer application, as measured by corn yield increases at site 1 in 1969

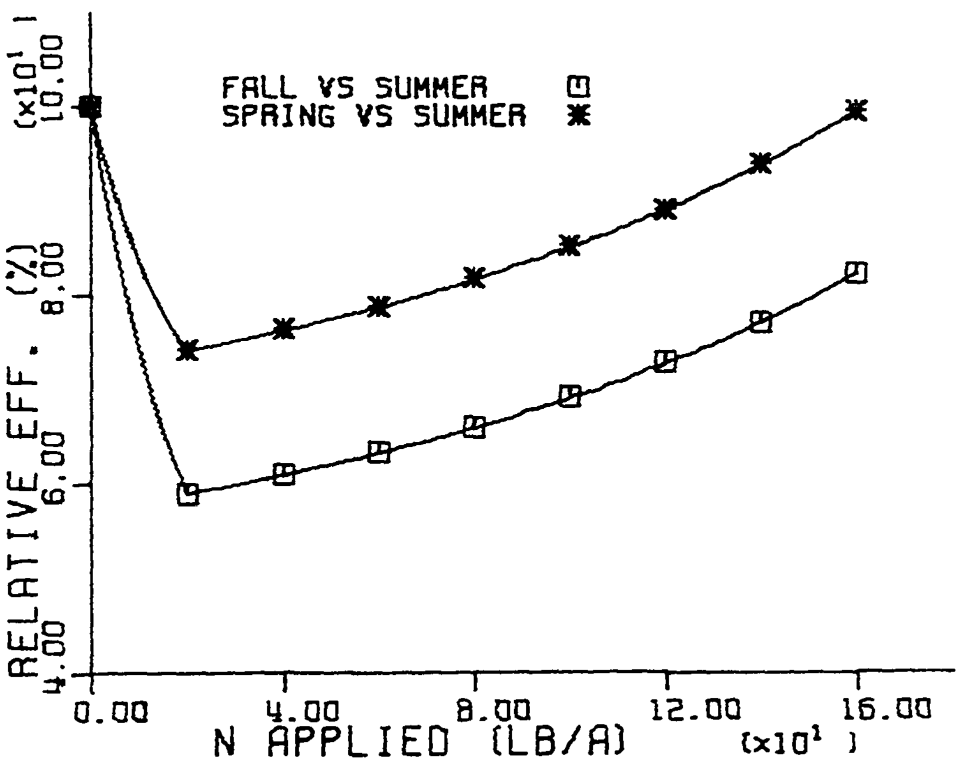

FALL VS SUMMER
SPRING VS SUMMER
RELATIVE EFF. (%)
(x10¹)
10.00
8.00
6.00
4.00
0.00
4.00
8.00
12.00
16.00
N APPLIED (LB/A)
(x10¹)

Figure 9. Efficiencies of fall and spring applied N relative to summer application, as measured by corn yield increases at site 1 in 1970

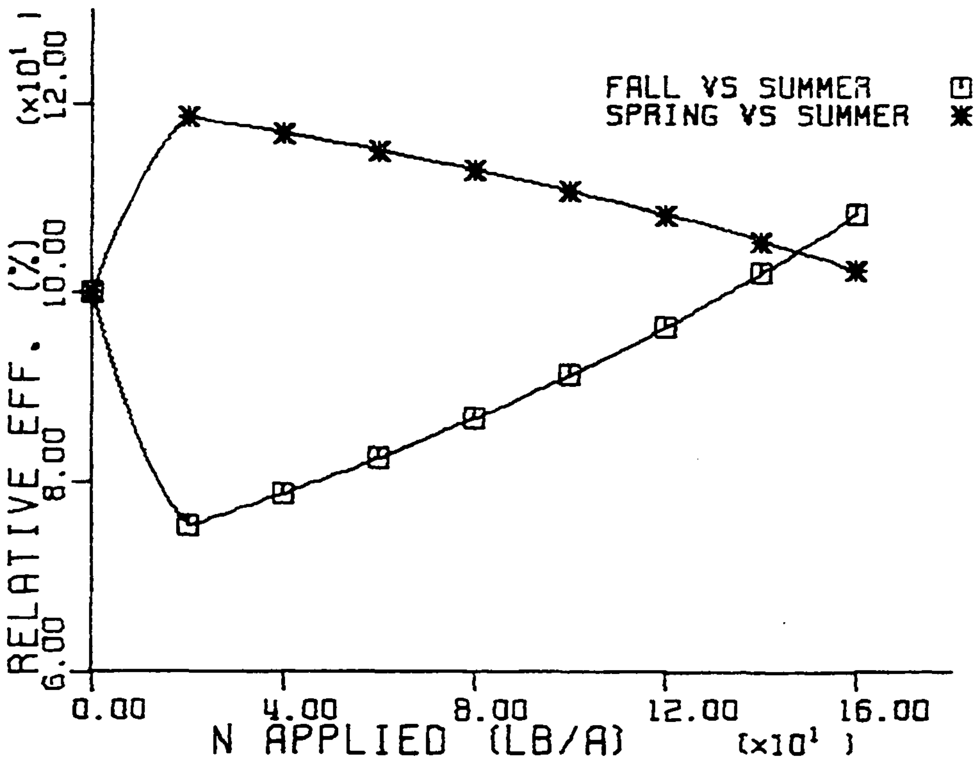

FALL VS SUMMER
SPRING VS SUMMER
RELATIVE EFF. (%)
(x10¹ )
6.00
8.00
10.00
12.00
0.00
4.00
8.00
12.00
16.00
N APPLIED (LB/A)
(x10¹ )

Figure 10. Efficiencies of fall and spring applied N relative to summer application, as measured by corn yields increases at site 3 in 1969

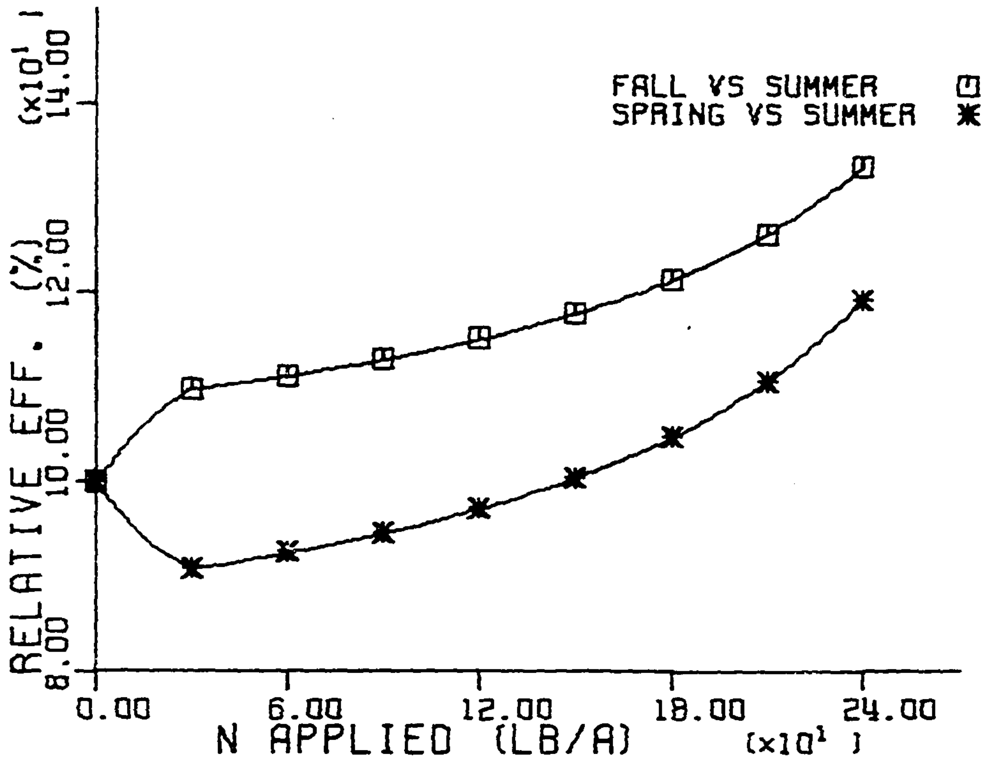
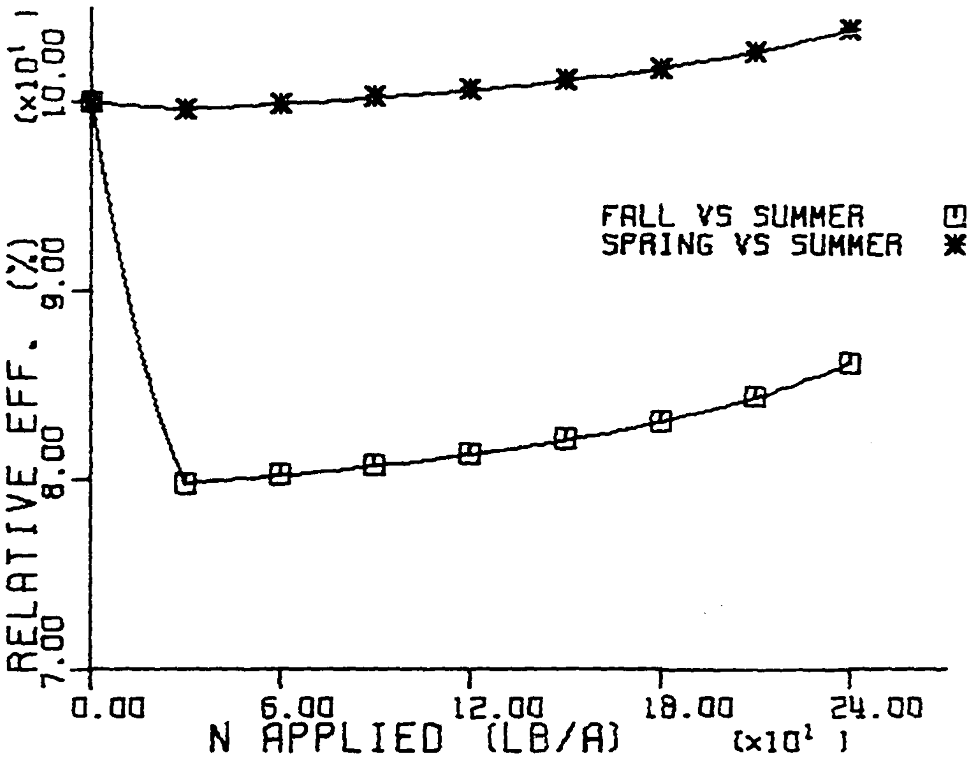
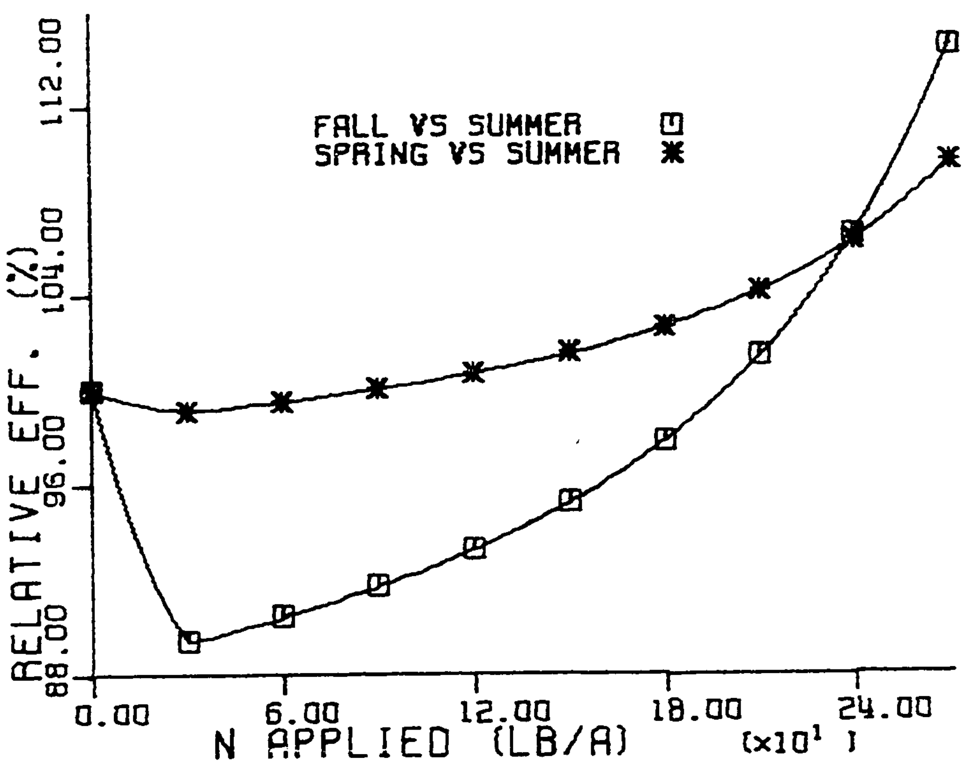

FALL VS SUMMER
SPRING VS SUMMER
RELATIVE EFF. (%)
(x10¹ )
8.00
10.00
12.00
14.00
0.00
6.00
12.00
18.00
24.00
N APPLIED (LB/A)
(x10¹ )

Figure 11. Efficiencies of fall and spring applied N relative to summer application, as measured by corn yield increases at site 3 in 1970



(x10¹ )
10.00
9.00
8.00
7.00
RELATIVE EFF. (%)
FALL VS SUMMER
SPRING VS SUMMER
0.00
6.00
12.00
18.00
24.00
N APPLIED (LB/A)
(x10¹ )

Figure 12. Efficiencies of fall and spring applied N relative to summer application, as measured by corn yield increases at site 4 in 1970



FALL VS SUMMER
SPRING VS SUMMER
RELATIVE EFF. (%)
88.00
96.00
104.00
112.00
0.00
6.00
12.00
18.00
24.00
N APPLIED (LB/A)
(x10¹ )

Figure 13. Combined six site-year predicted corn yields for the three times of N application

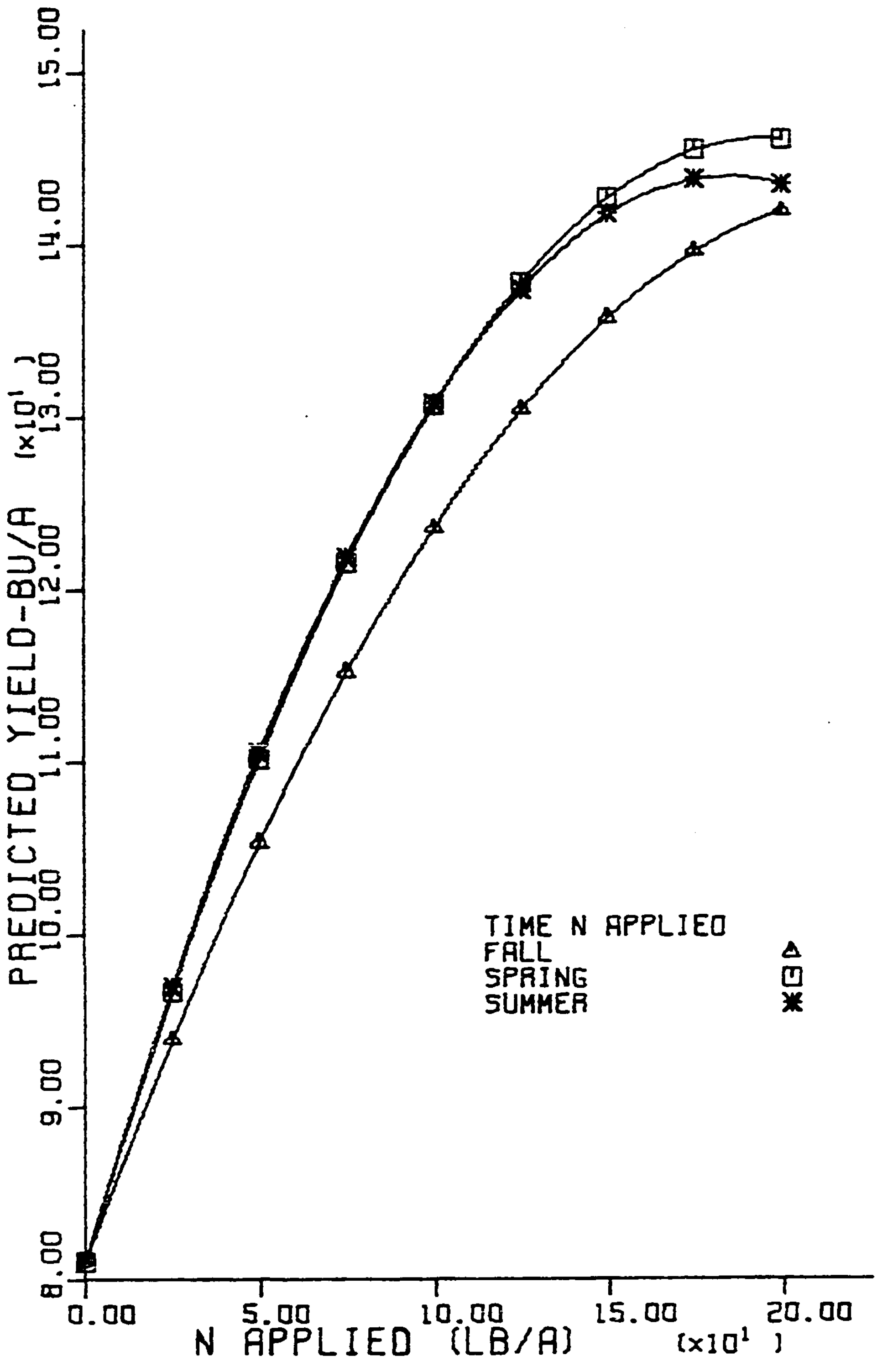
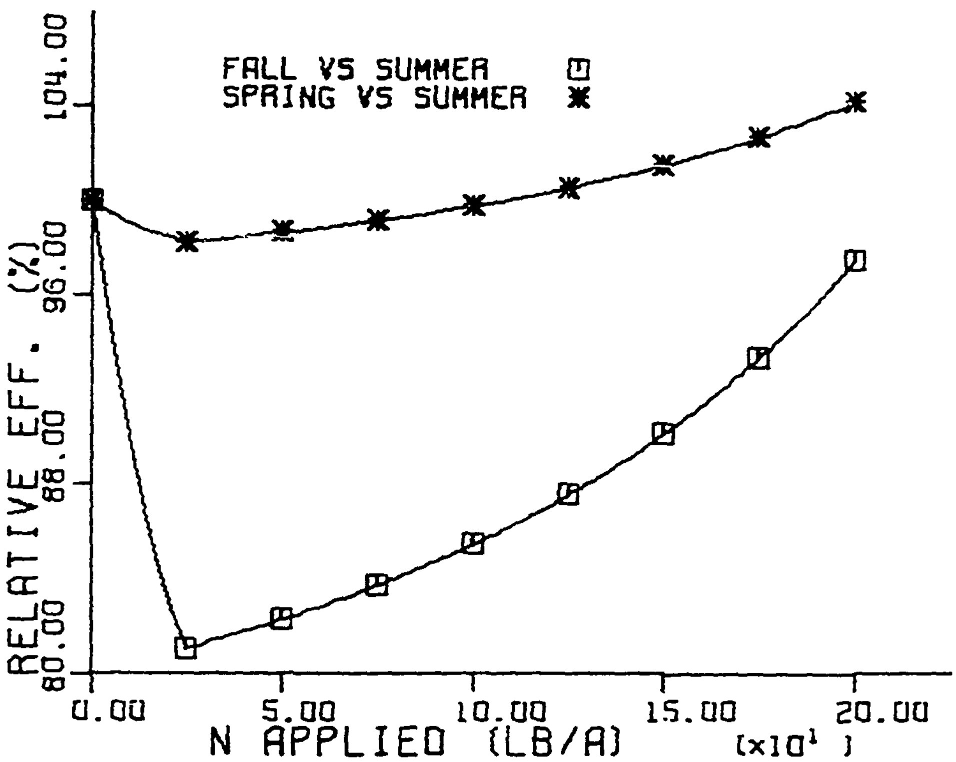

PREDICTED YIELD-BU/A (x10[1])
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
0.00
5.00
10.00
15.00
20.00
N APPLIED (LB/A) (x10[1])
TIME N APPLIED
FALL
SPRING
SUMMER

Figure 14. Efficiencies of fall and spring applied N relative to summer application, as measured by corn yield increases for the combined data from the six site-years



FALL VS SUMMER
SPRING VS SUMMER
RELATIVE EFF. (%)
80.00
88.00
96.00
104.00
0.00
5.00
10.00
15.00
20.00
N APPLIED (LB/A)
(x10$^1$ )

same yield response and relative efficiency.

## Soil Analysis

An attempt was made to assess the N concentration and distribution in the soil profile by taking soil samples at different times during the growing season. As previously mentioned, sampling of sites 1 and 2 revealed the difficulty in evaluating N status because of the zones of different N concentrations resulting from the placement of anhydrous ammonia 6 to 8 inches deep with a 40-inch spacing between bands. Part of the data from this survey will be presented later in this section to illustrate the difficulty in estimating overall N concentration. Earlier it was also mentioned that total N will be the total inorganic N or the sum of $NH_4^+$-N plus $NO_2^-$-N and $NO_3^-$-N and that the $NO_2^-$-N and $NO_3^-$-N fraction will be referred to simply as the $NO_3^-$-N concentration.

Soil samples taken from plots receiving 0 and 270 lb N/A in 1969-70 at sites 4 and 5 revealed significant differences in $NH_4^+$-N, $NO_3^-$-N and total N concentrations for the three times of application (Figures 15-23, Tables 24, 26, 28 and 30). In general, higher average N concentrations were associated with the later applied N, except of course, where the summer application had not been made prior to the first sampling. Control plots had significantly lower N concentrations than treated plots in most cases and the SCU source frequently produced higher $NH_4^+$-N but lower $NO_3^-$-N and total N levels than did the AN and urea sources (Tables 24-31). Concentrations of N decreased very significantly with depth and a number of significant time by depth interactions were observed.

First sampling

Data obtained from the June 18 sampling at site 4 indicated little if any difference in total N concentration from fall and spring applied N. However, a slightly larger proportion of the fertilizer N applied in the fall had been converted to the $NO_3^-$ form and had in turn been leached to a somewhat greater depth in the soil profile (Figures 15a, 16a and 17a). Statistically significant differences between soil N concentrations following the fall and spring fertilizer applications were somewhat obscured by the lower N levels from plots which had not received the summer application but were included in the AOV (Figures 15a, 16a, 17a and Table 24). This resulted in the highly significant linear and quadratic effects of time as well as contributing to many of the significant time by depth interactions. Figure 16a indicates the greater depth of $NO_3^-$-N movement associated with the earlier N application and would imply that some $NO_3^-$-N had moved below the 18 to 24 inch sampling depth, particularly with the fall applied N. Table 24 indicates that the control plots had significantly lower N concentrations than treated plots and that the SCU plots had significantly more $NH_4^+$-N, less $NO_3^-$-N and less total N than the AN and urea plots but indicated no difference between the AN and urea sources of N (Table 25).

Soil N concentrations at site 5 for the June 10 sampling followed many of the same trends observed at site 4. Notable differences included a somewhat higher degree of nitrification, a greater depth to which $NO_3^-$-N had been leached and a larger total N content in the surface 24 inches for the spring applied N than for the fall applied N (Figures 15-17 and Tables 24-27). These differences would seem to be related largely to soil textural differences rather than rainfall variations at the two sites

Table 24. Analysis of variance of pounds per acre of soil N in the first profile samples taken from the plots receiving 0 and 270-pound N treatments at site 4 (June 18, 1970)

| Source | df | $NH_4^+$-N MS | $NH_4^+$-N F | $NO_3^-$-N MS | $NO_3^-$-N F | Total N MS | Total N F |
|---|---|---|---|---|---|---|---|
| Blocks | 2 | 29.24 | 6.12* | 688 | 1.65 | 885 | 1.93 |
| Treatments | 3 | 214.47 | 44.96*** | 8115 | 19.50*** | 7371 | 16.10*** |
| Cont *vs* Trt | 1 | 136.53 | 28.62*** | 9589 | 23.05*** | 12013 | 26.24*** |
| SCU *vs* AN & U | 1 | 504.16 | 105.69*** | 13760 | 33.07*** | 8996 | 19.65*** |
| AN *vs* U | 1 | 2.72 | .57 | 998 | 2.40 | 1104 | 2.41 |
| Error A | 6 | 4.77 | | 416 | | 458 | |
| Time | 2 | 456.44 | 32.67*** | 24497 | 25.74*** | 30350 | 29.13*** |
| T | 1 | 186.89 | 13.38*** | 38735 | 40.71*** | 44303 | 42.52*** |
| $T^2$ | 1 | 725.98 | 51.97*** | 10223 | 10.74*** | 16398 | 15.74*** |
| Depth | 3 | 2466.91 | 176.59*** | 68439 | 71.92*** | 96874 | 92.98*** |
| D | 1 | 5765.96 | 412.74*** | 155586 | 163.51*** | 221256 | 212.37*** |
| $D^2$ | 1 | 1442.10 | 103.23*** | 45708 | 48.04*** | 63388 | 60.84*** |
| $D^3$ | 1 | 192.67 | 13.79*** | 4025 | 4.23* | 5979 | 5.74* |
| Time x Depth | 6 | 410.71 | 29.40*** | 11371 | 11.95*** | 15734 | 15.10*** |
| TD | 1 | 298.84 | 21.39*** | 29196 | 30.68*** | 35403 | 33.98*** |
| $TD^2$ | 1 | 162.00 | 11.60*** | 9660 | 10.15*** | 12325 | 11.83*** |
| $TD^3$ | 1 | 25.60 | 1.83 | 734 | .77 | 1034 | .99 |
| $T^2D$ | 1 | 1211.78 | 86.74*** | 19001 | 19.97*** | 29810 | 28.61*** |
| $T^2D^2$ | 1 | 640.65 | 45.86*** | 7896 | 8.30** | 13035 | 12.51*** |
| $T^2D^3$ | 1 | 125.39 | 8.98*** | 1738 | 1.83 | 2797 | 2.68 |
| Time x Trt | 4 | 85.89 | 6.15*** | 1907 | 2.00 | 1491 | 1.43 |
| T } x SCU *vs* | 1 | 40.11 | 2.87+ | 5208 | 5.47* | 4334 | 4.16* |
| $T^2$ } x AN & U | 1 | 280.33 | 20.07*** | 1358 | 1.43 | 404 | .39 |
| T } x AN | 1 | 12.00 | .86 | 91 | .10 | 37 | .04 |
| $T^2$ } x *vs* U | 1 | 11.11 | .80 | 971 | 1.02 | 1190 | 1.14 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth x Trt | 6 | 209.94 | 15.03*** | 2810 | 2.95* | 1533 | 1.47 |
| D SCU | 1 | 707.28 | 50.63*** | 12000 | 12.61*** | 6881 | 6.60* |
| $D^2$ x vs AN | 1 | 433.49 | 31.03*** | 4338 | 4.56* | 2029 | 1.95 |
| $D^3$ and U | 1 | 71.56 | 5.12* | 311 | .33 | 84 | .08 |
| D AN | 1 | 33.61 | 2.41 | 1 | -- | 44 | .04 |
| $D^2$ x vs | 1 | 6.72 | .48 | 8 | -- | 29 | .03 |
| $D^3$ U | 1 | 6.94 | .50 | 200 | .21 | 132 | .13 |
| T x D x Trt | 12 | 100.53 | 7.20*** | 1453 | 1.53 | 1123 | 1.08 |
| Error B | 75 | 13.97 | | 952 | | 1042 | |

Table 25. Pounds per acre of soil N in the first profile samples taken from the plots receiving 0 and 270-pound N treatments at site 4 (June 18, 1970). Average of fall and spring applications

| Depth (inches) | Control | Source of N applied | | |
|---|---|---|---|---|
| | | AN | Urea | SCU |
| | | $NH_4^+$-N | | |
| 0-6 | 12 | 20 | 18 | 36 |
| 6-12 | 8 | 8 | 8 | 8 |
| 12-18 | 4 | 4 | 4 | 4 |
| 18-24 | 2 | 2 | 4 | 4 |
| | | $NO_3^-$-N | | |
| 0-6 | 26 | 146 | 140 | 74 |
| 6-12 | 14 | 42 | 32 | 20 |
| 12-18 | 8 | 16 | 14 | 10 |
| 18-24 | 6 | 16 | 6 | 6 |
| | | Total N | | |
| 0-6 | 38 | 166 | 158 | 110 |
| 6-12 | 22 | 50 | 38 | 28 |
| 12-18 | 12 | 22 | 20 | 14 |
| 18-24 | 8 | 18 | 10 | 10 |

(Tables 33 and 34). Table 34 indicates similar rainfall for both sites from November 1969 to June 1970 and this situation continued prior to sampling as approximately one-half inch of rainfall occurred at each site. A much larger sand fraction along with the lower silt and clay content of the soil at site 5 undoubtedly provided a more favorable environment for nitrification which may have allowed a greater quantity of $NO_3^-$-N to be leached deeper into the soil profile.

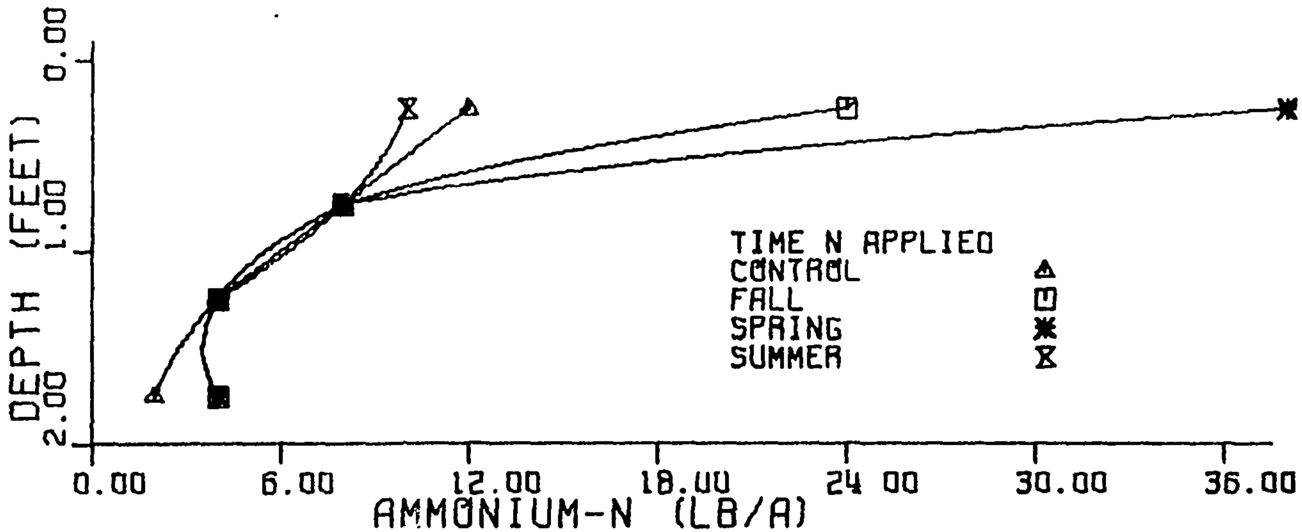
Table 26. Analysis of variance of pounds per acre of soil N in the first profile samples taken from the plots receiving 0 and 270-pound N treatments at site 5 (June 10, 1970)

| Source | df | $NH_4^+$-N | | $NO_3^-$-N | | Total N | |
|---|---|---|---|---|---|---|---|
| | | MS | F | MS | F | MS | F |
| Blocks | 2 | 1.20 | .08 | 2820 | 3.26 | 2849 | 2.84 |
| Treatments | 3 | 43.16 | 2.93 | 5296 | 6.12* | 5003 | 4.99* |
| Cont *vs* Trt | 1 | 7.17 | .49 | 10366 | 11.98* | 10919 | 10.88* |
| SCU *vs* AN & U | 1 | 115.58 | 7.86* | 3936 | 4.55+ | 2702 | 2.69 |
| AN *vs* U | 1 | 6.72 | .46 | 1587 | 1.83 | 1387 | 1.38 |
| Error A | 6 | 14.71 | | 865 | | 1003 | |
| Time | 2 | 72.49 | 3.40* | 27109 | 35.58*** | 29637 | 33.10*** |
| $T$ | 1 | 29.39 | 1.38 | 36902 | 48.43*** | 39014 | 43.58*** |
| $T^2$ | 1 | 115.58 | 5.42* | 17316 | 22.73*** | 20261 | 22.63*** |
| Depth | 3 | 472.35 | 22.16*** | 14534 | 19.07*** | 19670 | 21.97*** |
| $D$ | 1 | 1198.49 | 56.21*** | 42842 | 56.22*** | 58372 | 65.20*** |
| $D^2$ | 1 | 213.33 | 10.01*** | 56 | .07 | 51 | .06 |
| $D^3$ | 1 | 5.23 | .25 | 704 | .92 | 588 | .66 |
| Time x Depth | 6 | 88.58 | 4.15*** | 4526 | 5.94*** | 5608 | 6.26*** |
| $TD$ | 1 | 13.61 | .64 | 5585 | 7.33** | 6150 | 6.87* |
| $TD^2$ | 1 | 6.72 | .32 | 1104 | 1.45 | 939 | 1.05 |
| $TD^3$ | 1 | 6.94 | .33 | 734 | .96 | 598 | .67 |
| $T^2D$ | 1 | 272.00 | 12.76*** | 16599 | 21.78*** | 21121 | 23.59*** |
| $T^2D^2$ | 1 | 181.50 | 8.51*** | 3128 | 4.11* | 4817 | 5.38* |
| $T^2D^3$ | 1 | 50.70 | 2.38 | 6 | -- | 21 | .02 |
| Time x Trt | 4 | 37.59 | 1.76 | 1388 | 1.82 | 1105 | 1.23 |
| $T$ } x SCU *vs* | 1 | 44.45 | 2.08 | 54 | .07 | -- | -- |
| $T^2$ } x AN & U | 1 | 100.16 | 4.70* | 4460 | 5.85* | 3223 | 3.60+ |
| $T$ } x AN | 1 | .33 | -- | 176 | .23 | 192 | .21 |
| $T^2$ } x *vs* U | 1 | 5.44 | .26 | 860 | 1.13 | 1003 | 1.12 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth x Trt | 6 | 84.95 | 3.98*** | 428 | .56 | 206 | .23 |
| D SCU | 1 | 296.62 | 13.91*** | 1799 | 2.36 | 635 | .71 |
| $D^2$ xvs AN | 1 | 181.50 | 8.51*** | 122 | .16 | 6 | -- |
| $D^3$ and U | 1 | 24.30 | 1.14 | 13 | -- | 2 | -- |
| D AN | 1 | .28 | -- | 356 | .47 | 336 | .38 |
| $D^2$ x vs | 1 | 4.50 | -- | 192 | .25 | 139 | .16 |
| $D^3$ U | 1 | 2.50 | -- | 84 | .11 | 116 | .13 |
| T x D x Trt | 12 | 43.32 | 2.03* | 377 | .49 | 295 | .33 |
| Error B | 75 | 21.32 | | 762 | | 895 | |

Figure 15(a). Influence of time of N application on the distribution of $NH_4^+$-N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 4, as measured June 18, 1970

Figure 15(b). Influence of time of N application on the distribution of $NH_4^+$-N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 5, as measured June 10, 1970


DEPTH (FEET)
0.00
1.00
2.00
0.00
6.00
12.00
18.00
24 00
30.00
36.00
AMMONIUM-N (LB/A)
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

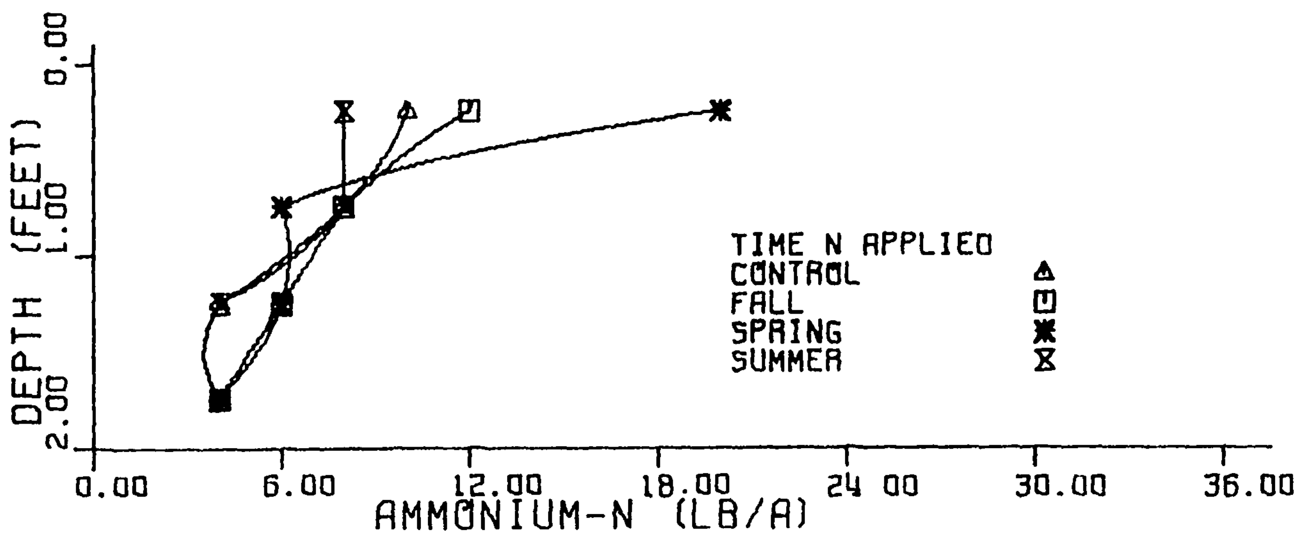
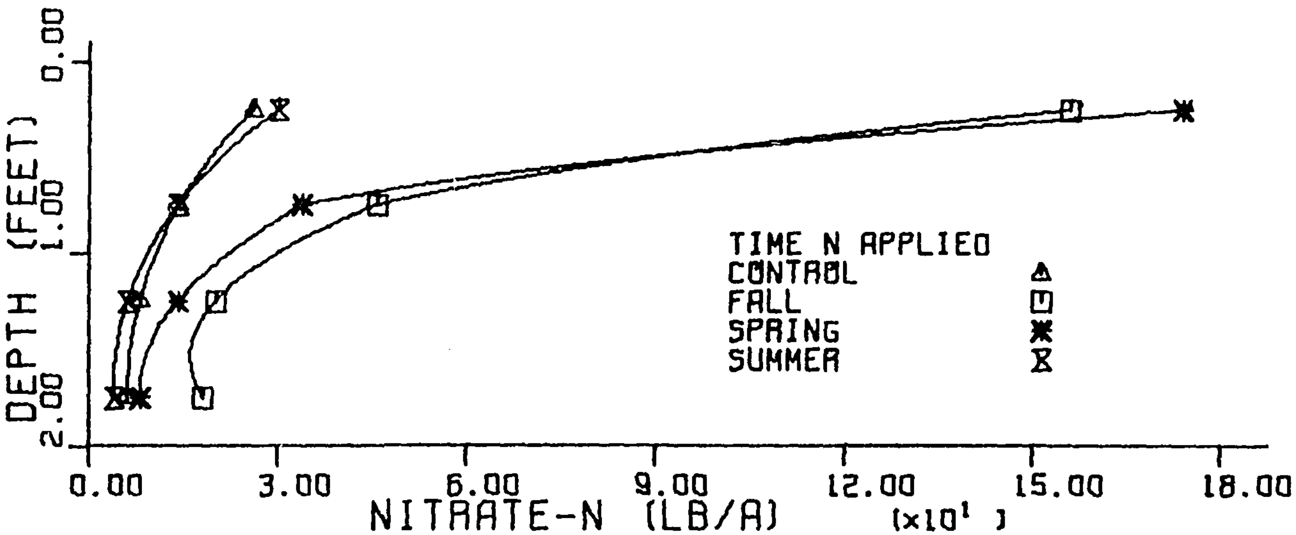

DEPTH (FEET)
0.00
1.00
2.00
0.00
6.00
12.00
18.00
24 00
30.00
36.00
AMMONIUM-N (LB/A)
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Figure 16(a). Influence of time of N application on the distribution of $NO_3^-$-N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 4, as measured June 18, 1970

Figure 16(b). Influence of time of N application on the distribution of $NO_3^-$-N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 5, as measured June 10, 1970


DEPTH (FEET)
0.00
1.00
2.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
NITRATE-N (LB/A)
(x10¹ )
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

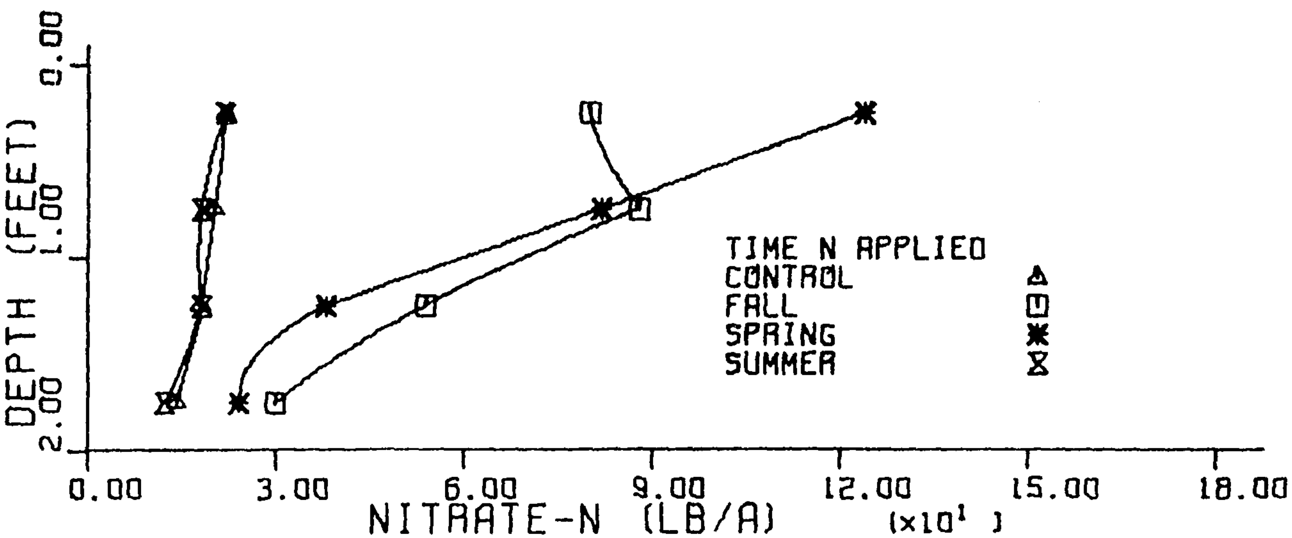
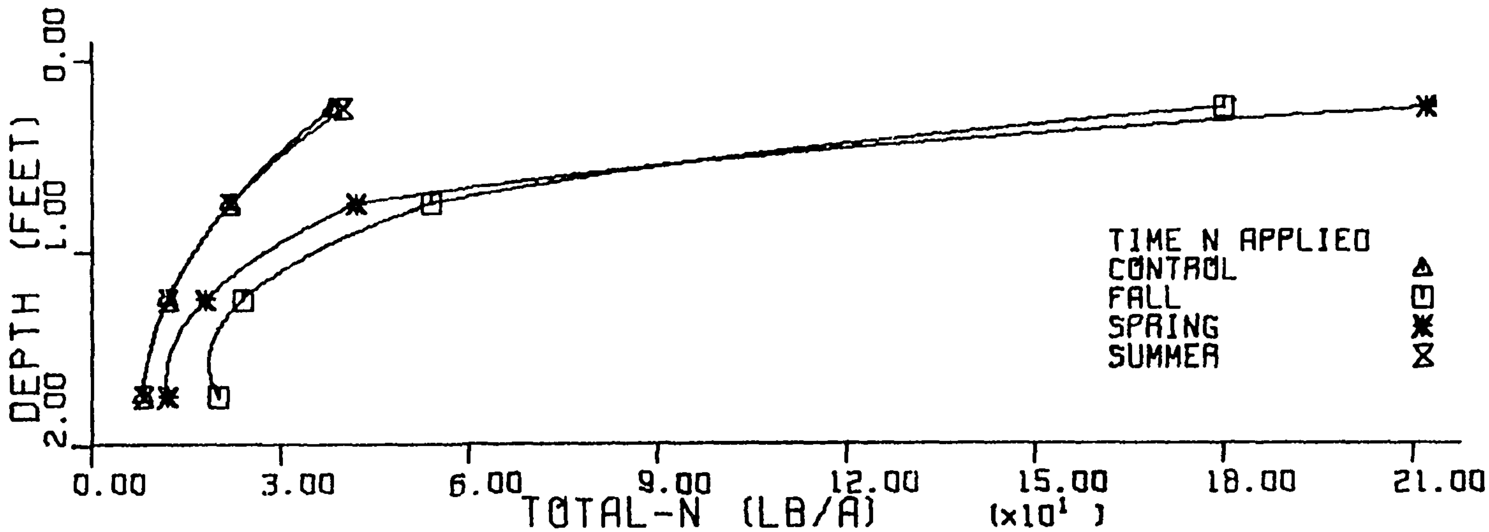

DEPTH (FEET)
0.00
1.00
2.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
NITRATE-N (LB/A)
(x10¹ )
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Figure 17(a). Influence of time of N application on the distribution of Total N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 4, as measured June 18, 1970

Figure 17(b). Influence of time of N application on the distribution of Total N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 5, as measured June 10, 1970


DEPTH (FEET)
0.00
1.00
2.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
TOTAL-N (LB/A)
(x10¹ )
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

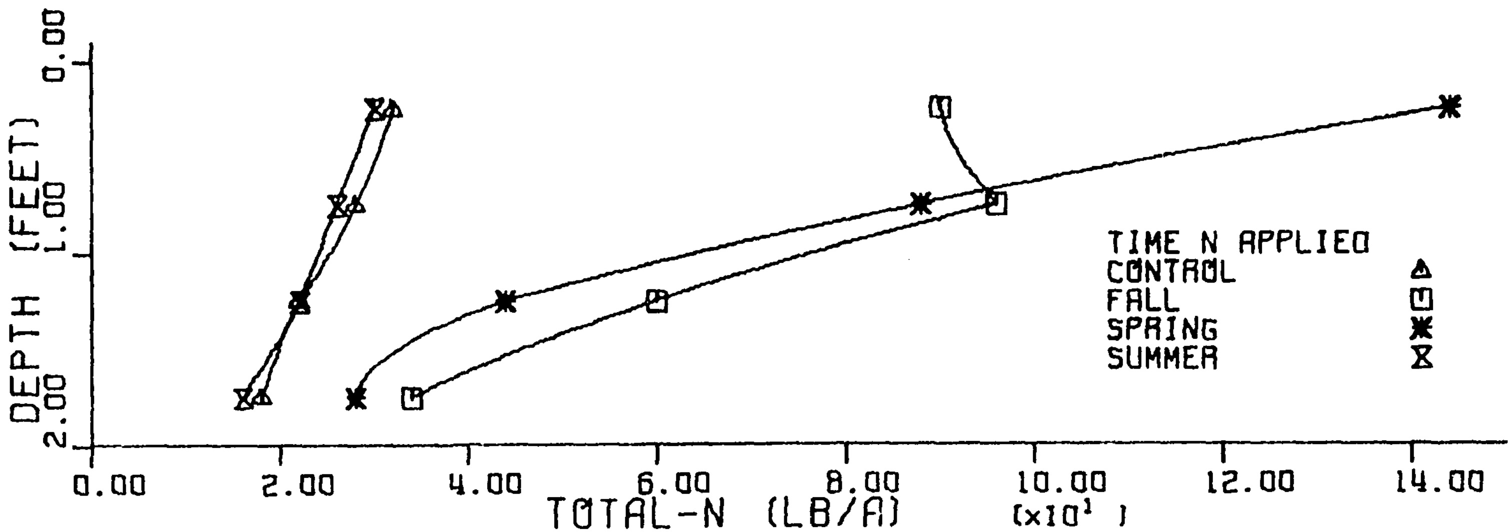

DEPTH (FEET)
0.00
1.00
2.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TOTAL-N (LB/A)
(x10¹ )
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Table 27. Pounds per acre of soil N in the first profile samples taken from the plots receiving 0 and 270-pound N treatments at site 5 (June 10, 1970). Average of fall and spring applications

| Depth (inches) | Control | Source of N applied: AN | Urea | SCU |
|---|---|---|---|---|
| | | $NH_4^+$-N | | |
| 0-6 | 10 | 10 | 10 | 20 |
| 6-12 | 8 | 6 | 8 | 6 |
| 12-18 | 4 | 6 | 6 | 4 |
| 18-24 | 4 | 4 | 4 | 4 |
| | | $NO_3^-$-N | | |
| 0-6 | 22 | 84 | 84 | 56 |
| 6-12 | 20 | 70 | 64 | 54 |
| 12-18 | 18 | 48 | 30 | 32 |
| 18-24 | 14 | 28 | 18 | 20 |
| | | Total N | | |
| 0-6 | 32 | 96 | 94 | 76 |
| 6-12 | 28 | 76 | 72 | 60 |
| 12-18 | 22 | 54 | 36 | 36 |
| 18-24 | 18 | 32 | 22 | 24 |

### Second sampling

Sampling later in the growing season (July 22-24) revealed that concentrations of $NH_4^+$-N and total N near the soil surface at site 4 were significantly greater following the summer application than either the fall or spring (Figures 18-20 and Table 28). Little difference was observed in N concentrations between the fall and spring applied N although the $NO_3^-$-N had moved to a slightly greater depth where the N was fall applied. Highly significant decreases in N concentrations were recorded with increasing depth, however, nearly equal $NH_4^+$-N, $NO_3^-$-N and total N levels were observed for the three times of N application at the 12-18, 18-24 and 18-24 inch depths, respectively. The large variations in $NH_4^+$-N and total N between times of application at the surface and nearly equal concentrations at the second or third sampling increment account for the highly significant time by depth interactions (Table 28, Figure 18 and 20). Plots receiving N had significantly higher $NO_3^-$-N and total N levels than the controls and plots receiving AN or urea had higher levels of these forms of N than did the SCU treated plots.

The August 20-21 sampling at site 5 indicated an increasingly greater quantity of $NO_3^-$-N and total N in the surface 4 feet with the later application of N. This is illustrated by Figures 21-23 and substantiated by the significant linear effect of time in Table 30. The leaching patterns associated with the time of N application in Figures 16b and 22 suggest close agreement with the theoretical sequence proposed by Gardner (1965). In this case, however, time of application has served as an index for the differing amounts of rainfall received at the two sites. The differences in N levels between sites at the time of the first sampling continued to exist (Figures 18-23). At site 5, the higher degree of nitrification of summer applied N was particularly evident. Large portions of the N concentrations were present in the surface 6 inches at site 4 whereas distribution was more uniform throughout the top 24 inches at site 5. Total N concentrations progressively increased with the later time of N application at site 5 in contrast to similar levels for fall and spring with a much greater N concentration following summer application at site 4. Although texture continued to play an important role in these site differences, more precipitation at site 5 undoubtedly had a greater influence during

Table 28. Analysis of variance of pounds per acre of soil N in the second profile samples taken from the plots receiving 0 and 270-pound N treatments at site 4 (July 22-24, 1970)

| Source | df | $NH_4^+$-N MS | $NH_4^+$-N F | $NO_3^-$-N MS | $NO_3^-$-N F | Total N MS | Total N F |
|---|---|---|---|---|---|---|---|
| Blocks | 2 | 635.75 | 1.41 | 77 | .19 | 398 | .86 |
| Treatments | 3 | 957.15 | 2.12 | 6195 | 15.12*** | 11827 | 25.70*** |
| Cont *vs* Trt | 1 | 1672.42 | 3.70 | 7027 | 17.15** | 15556 | 33.80*** |
| SCU *vs* AN & U | 1 | 967.88 | 2.14 | 11189 | 27.30*** | 18739 | 40.72*** |
| AN *vs* U | 1 | 231.14 | .51 | 370 | .90 | 1187 | 2.58 |
| Error A | 6 | 451.47 | | 410 | | 460 | |
| Time | 2 | 8942.00 | 13.59*** | 12 | .01 | 8903 | 4.71* |
| T | 1 | 13601.12 | 20.67*** | 4 | .01 | 14077 | 7.45** |
| $T^2$ | 1 | 4282.88 | 6.51* | 19 | .02 | 3728 | 1.97 |
| Depth | 5 | 14833.12 | 22.54*** | 60457 | 76.49*** | 135015 | 71.43*** |
| D | 1 | 41932.97 | 63.71*** | 157589 | 199.37*** | 362102 | 191.58*** |
| $D^2$ | 1 | 20320.61 | 30.87*** | 101279 | 128.13*** | 212329 | 112.34*** |
| $D^3$ | 1 | 9032.54 | 13.72*** | 35893 | 45.41*** | 80936 | 42.82*** |
| Lack of fit | 2 | 1439.75 | 2.19 | 3761 | 4.76* | 9854 | 5.21** |
| Time x Depth | 10 | 7981.83 | 12.13*** | 251 | .32 | 9479 | 5.01*** |
| TD | 1 | 27067.84 | 41.13*** | 215 | .27 | 32113 | 16.99*** |
| $TD^2$ | 1 | 20993.26 | 31.90*** | 811 | 1.03 | 30054 | 15.90*** |
| $TD^3$ | 1 | 9575.44 | 14.55*** | 686 | .87 | 15388 | 8.14** |
| T Lack of fit | 2 | 1404.43 | 2.13 | 73 | .09 | 2106 | 1.11 |
| $T^2D$ | 1 | 8278.32 | 12.58*** | 176 | .22 | 6042 | 3.20+ |
| $T^2D^2$ | 1 | 7022.58 | 10.67*** | 271 | .34 | 4534 | 2.40 |
| $T^2D^3$ | 1 | 3207.85 | 4.87* | 165 | .21 | 1919 | 1.02 |
| $T^2$ Lack of fit | 2 | 432.06 | .66 | 21 | .03 | 263 | .14 |
| Time x Trt | 4 | 1263.85 | 1.92 | 941 | 1.16 | 3469 | 1.84 |
| T } x SCU *vs* | 1 | 3800.18 | 5.77* | 1873 | 2.37 | 11008 | 5.82* |
| $T^2$ } x AN and U | 1 | 886.68 | 1.35 | 467 | .59 | 67 | .04 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $T$ } x AN | 1 | 234.73 | .36 | 1318 | 1.67 | 2665 | 1.41 |
| $T^2$ } vs U | 1 | 133.79 | .20 | -- | -- | 137 | .07 |
| Depth x Trt | 10 | 569.54 | .87 | 4339 | 5.49*** | 7997 | 4.23*** |
| $D$ } SCU | 1 | 1957.27 | 2.97+ | 20153 | 25.50*** | 34671 | 18.34*** |
| $D^2$ } x vs AN | 1 | 1520.26 | 2.31 | 12734 | 16.11*** | 23054 | 12.20*** |
| $D^3$ } & U | 1 | 690.13 | 1.05 | 4357 | 5.51* | 8516 | 4.51* |
| T x D x Trt | 20 | 1185.53 | 1.80 | 887 | 1.12 | 3416 | 1.81 |
| Error B | 117 | 658.16 | | 790 | | 1890 | |

Table 29. Pounds per acre of soil N in the second profile samples taken from the plots receiving 0 and 270 pound N treatments at site 4 (July 22-24, 1970). Average of three times of application

| Depth (inches) | Control | Source of N applied AN | Urea | SCU |
|---|---|---|---|---|
| | | $NH_4^+$-N | | |
| 0-6 | 8 | 66 | 84 | 46 |
| 6-12 | 6 | 12 | 10 | 10 |
| 12-18 | 8 | 8 | 8 | 8 |
| 18-24 | 8 | 6 | 6 | 6 |
| 24-36 | 4 | 4 | 2 | 4 |
| 36-48 | 2 | 2 | 2 | 2 |
| | | $NO_3^-$-N | | |
| 0-6 | 14 | 138 | 172 | 66 |
| 6-12 | 8 | 24 | 16 | 8 |
| 12-18 | 2 | 8 | 6 | 2 |
| 18-24 | 2 | 4 | 2 | 2 |
| 24-36 | 2 | 2 | 2 | 2 |
| 36-48 | 2 | 2 | 2 | 2 |
| | | Total N | | |
| 0-6 | 22 | 206 | 258 | 112 |
| 6-12 | 14 | 34 | 26 | 20 |
| 12-18 | 10 | 18 | 14 | 10 |
| 18-24 | 10 | 10 | 10 | 8 |
| 24-36 | 6 | 6 | 4 | 6 |
| 36-48 | 4 | 4 | 4 | 4 |

the period of time between samplings (Table 34). Significantly higher $NO_3^-$N and total N concentrations were found in the treated plots than the controls (Table 30). Significant differences among sources were also observed in the $NO_3^-$-N and total N levels, with AN showing the highest concentrations and SCU the lowest (Tables 30 and 31).

Figure 18. Influence of time of N application on the distribution of $NH_4^+$-N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 4, as measured July 22-24, 1970

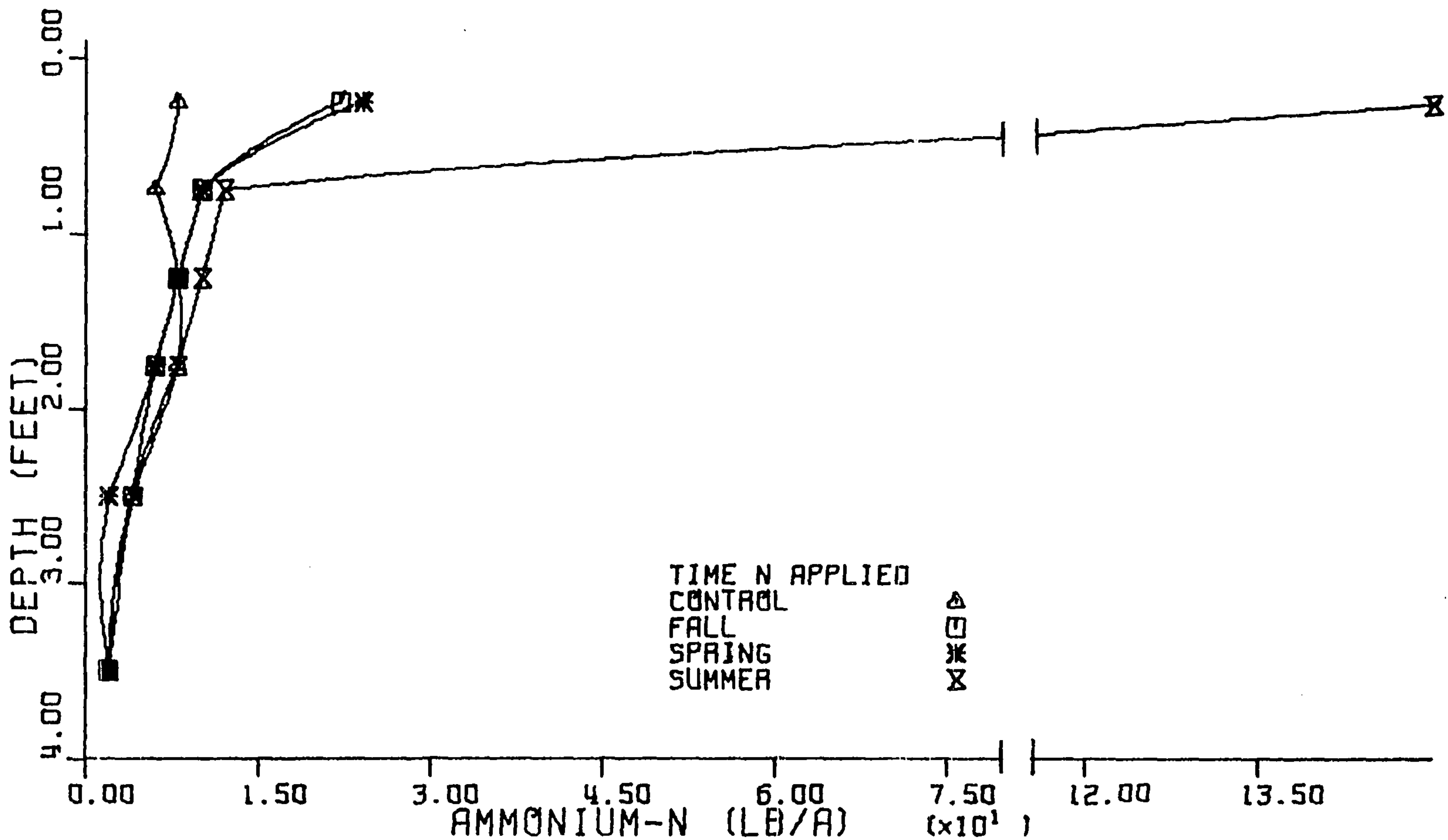

DEPTH (FEET)
0.00
1.00
2.00
3.00
4.00
AMMONIUM-N (LB/A) (x10[1])
0.00
1.50
3.00
4.50
6.00
7.50
12.00
13.50
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Figure 19. Influence of time of N application on the distribution of $NO_3^-$-N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 4, as measured July 22-24, 1970

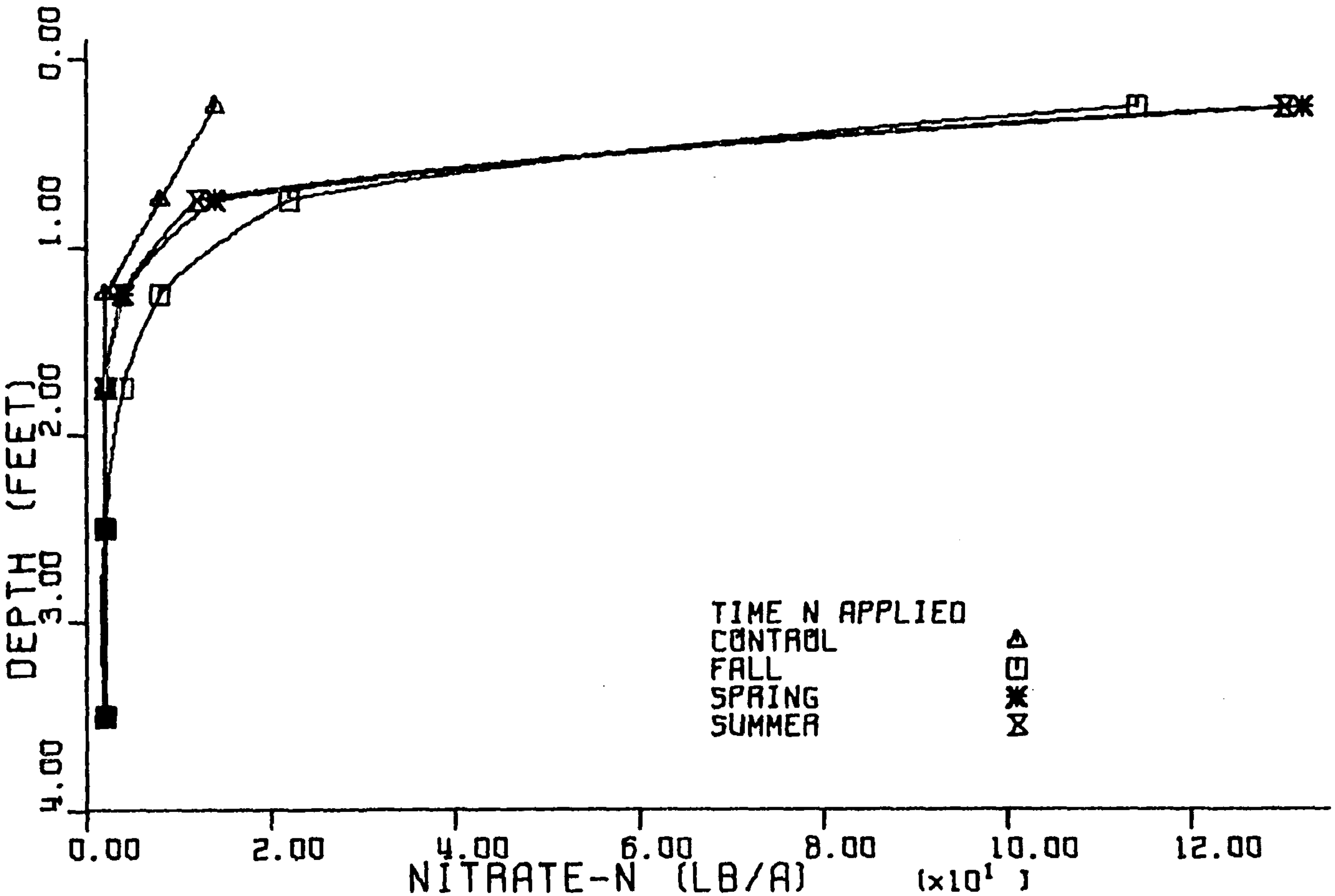

DEPTH (FEET)
0.00
1.00
2.00
3.00
4.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
NITRATE-N (LB/A)
(x10$^1$ )
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Figure 20. Influence of time of N application on the distribution of Total N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 4, as measured July 22-24, 1970

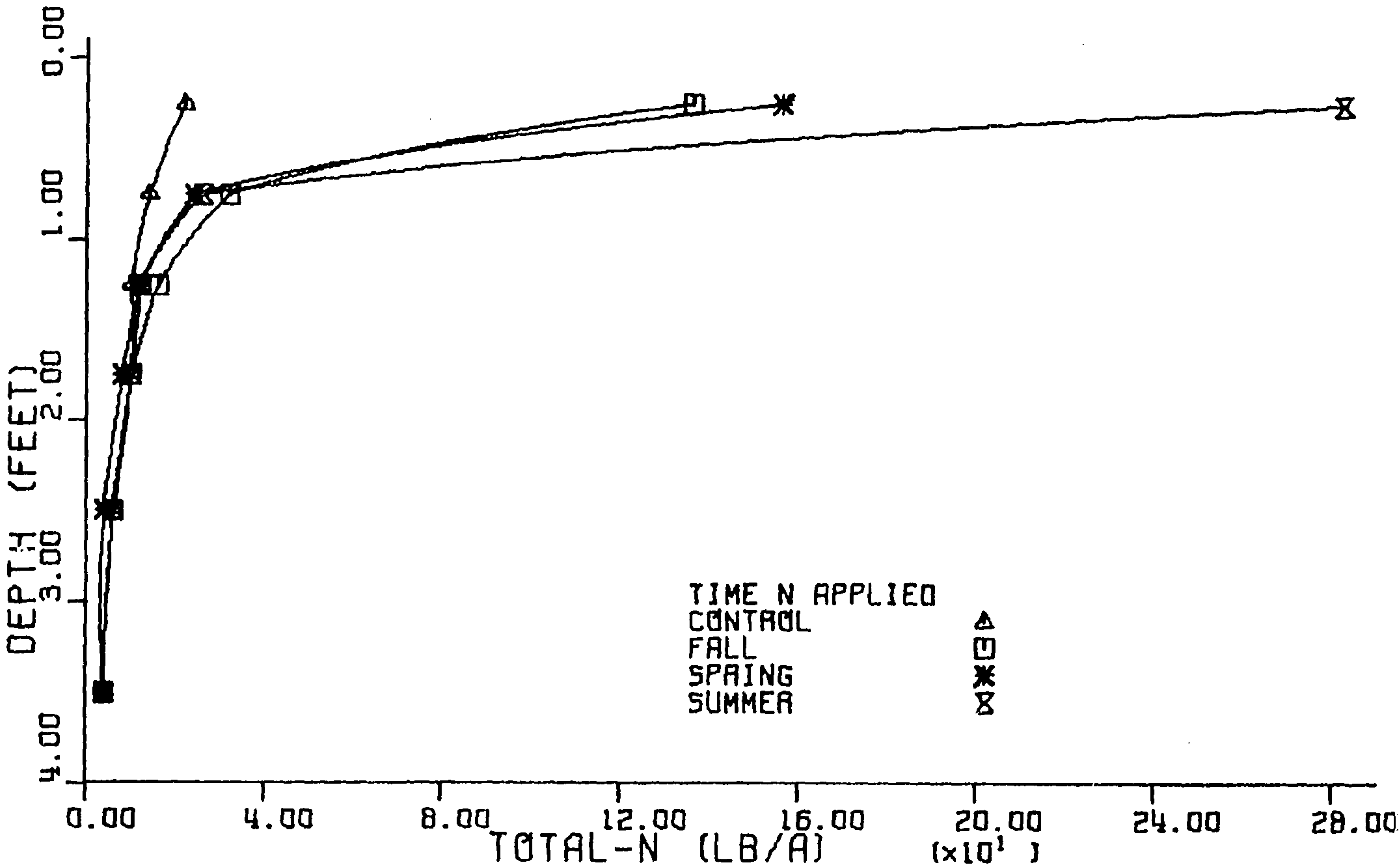

DEPTH (FEET)
0.00
1.00
2.00
3.00
4.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TOTAL-N (LB/A)
(x10¹ )
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Table 30. Analysis of variance of pounds per acre of soil N in the second profile samples taken from the plots receiving 0 and 270-pound N treatments at site 5 (August 20-21, 1970)

| Source | df | $NH_4^+$-N MS | $NH_4^+$-N F | $NO_3^-$-N MS | $NO_3^-$-N F | Total N MS | Total N F |
|---|---|---|---|---|---|---|---|
| Blocks | 2 | 394.82 | 4.62+ | 1809 | 32.03*** | 2962 | 61.45*** |
| Treatments | 3 | 352.82 | 4.13+ | 5111 | 90.50*** | 4603 | 95.51*** |
| Cont *vs* Trt | 1 | 51.20 | .60 | 10559 | 186.99*** | 12081 | 250.65*** |
| SCU *vs* AN & U | 1 | 1002.77 | 11.74* | 4283 | 75.84*** | 1141 | 23.67*** |
| AN *vs* U | 1 | 4.48 | .05 | 490 | 8.67* | 588 | 12.20* |
| Error A | 6 | 85.41 | | 56 | | 48 | |
| Time | 2 | 82.67 | 1.40 | 888 | 2.35+ | 1505 | 2.79+ |
| T | 1 | 161.33 | 2.73 | 1776 | 4.70* | 3008 | 5.58* |
| $T^2$ | 1 | 4.00 | .07 | 1 | -- | 1 | -- |
| Depth | 5 | 1379.15 | 23.34*** | 12575 | 33.24*** | 19879 | 36.85*** |
| D | 1 | 5414.32 | 91.64*** | 53222 | 140.70*** | 92587 | 171.62*** |
| $D^2$ | 1 | 1082.97 | 18.33*** | 50 | .13 | 667 | 1.24 |
| $D^3$ | 1 | 318.76 | 5.40* | 6684 | 17.67*** | 4084 | 7.57** |
| Lack of fit | 2 | 39.85 | .67 | 1459 | 3.86* | 1030 | 1.91 |
| Time x Depth | 10 | 58.85 | 1.00 | 2272 | 6.01*** | 2680 | 4.97*** |
| TD | 1 | 313.00 | 5.30* | 9622 | 25.44*** | 13406 | 24.85*** |
| $TD^2$ | 1 | 152.38 | 2.58+ | 4568 | 12.07*** | 6389 | 11.84*** |
| $TD^3$ | 1 | 46.47 | .79 | 1009 | 2.67 | 622 | 1.15 |
| T Lack of fit | 2 | 10.08 | .17 | 2935 | 7.76** | 2606 | 4.83** |
| $T^2D$ | 1 | 15.75 | .27 | 22[illegible] | .60 | 125 | .23 |
| $T^2D^2$ | 1 | 34.57 | .59 | 708 | 1.87 | 430 | .80 |
| $T^2D^3$ | 1 | 3.49 | .06 | 30 | .08 | 13 | -- |
| $T^2$ Lack of fit | 2 | 1.32 | .02 | 341 | .90 | 300 | .56 |
| Time x Trt | 4 | 21.08 | .36 | 1017 | 2.69* | 1110 | 2.06+ |
| T } x SCU *vs* AN & U | 1 | 1.50 | .03 | 3174 | 8.39*** | 3314 | 6.14* |
| $T^2$ } x SCU *vs* AN & U | 1 | 76.06 | 1.29 | -- | -- | 82 | .15 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T } x AN | 1 | 4.50 | .08 | 854 | 2.26 | 983 | 1.82 |
| $T^2$ } x vs U | 1 | 2.24 | .04 | 39 | .10 | 60 | .11 |
| Depth x Trt | 10 | 412.07 | 6.97*** | 524 | 1.38 | 1167 | 2.16* |
| D } x SCU | 1 | 1891.59 | 32.02*** | 829 | 2.19 | 216 | .40 |
| $D^2$ } x vs AN | 1 | 1426.78 | 24.15*** | 1191 | 3.15+ | 5224 | 9.68*** |
| $D^3$ } x & U | 1 | 536.69 | 9.08*** | 1613 | 4.26* | 4011 | 7.44** |
| T x D x Trt | 20 | 27.08 | .46 | 416 | 1.10 | 525 | .97 |
| Error B | 117 | 59.08 | | 378 | | 539 | |

Table 31. Pounds per acre of soil N in the second profile samples taken from the plots receiving 0 and 270-pound N treatments at site 5 (August 20-21, 1970). Average of three times of application

| Depth (inches) | Control | Source of N applied AN | Urea | SCU |
|---|---|---|---|---|
| | | $NH_4^+$-N | | |
| 0-6 | 12 | 16 | 10 | 42 |
| 6-12 | 10 | 8 | 10 | 12 |
| 12-18 | 8 | 6 | 6 | 8 |
| 18-24 | 6 | 4 | 6 | 8 |
| 24-36 | 4 | 4 | 4 | 4 |
| 36-48 | 2 | 2 | 2 | 4 |
| | | $NO_3^-$-N | | |
| 0-6 | 22 | 54 | 48 | 48 |
| 6-12 | 10 | 84 | 66 | 44 |
| 12-18 | 4 | 48 | 40 | 24 |
| 18-24 | 4 | 26 | 26 | 16 |
| 24-36 | 2 | 12 | 14 | 10 |
| 36-48 | 2 | 8 | 10 | 8 |
| | | Total N | | |
| 0-6 | 34 | 68 | 58 | 90 |
| 6-12 | 20 | 92 | 76 | 56 |
| 12-18 | 12 | 54 | 46 | 32 |
| 18-24 | 10 | 30 | 32 | 24 |
| 24-36 | 6 | 16 | 18 | 14 |
| 36-48 | 4 | 12 | 14 | 12 |

## Soil sampling after anhydrous ammonia application

Soil samples were taken just prior to silking at sites 1 and 2 in 1968 to investigate N concentration associated with the three times of application. The difficulty in estimating average N concentration at different depths following anhydrous ammonia application and subsequently

Figure 21. Influence of time of N application on the distribution of $NH_4^+$-N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 5, as measured August 20-21, 1970

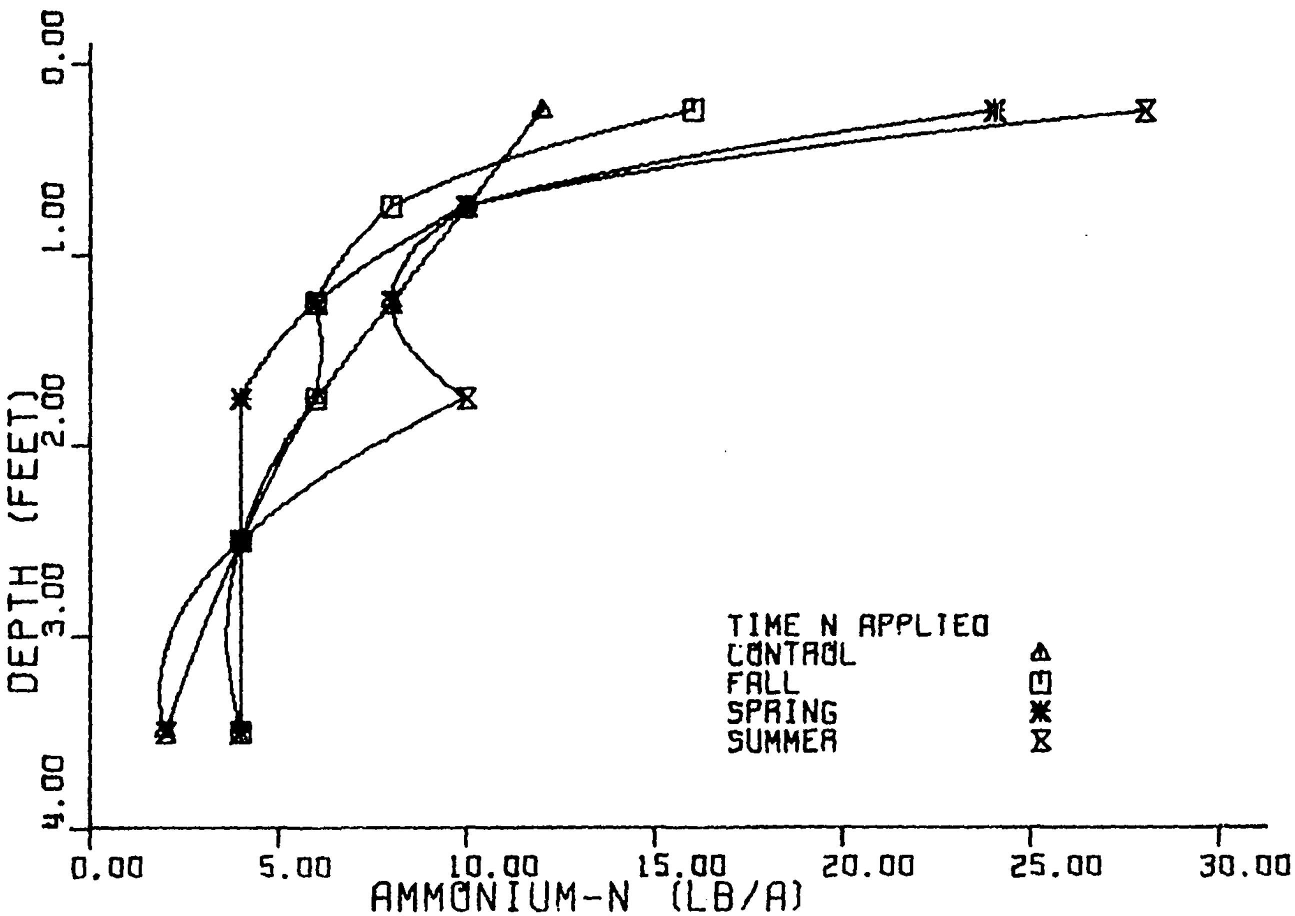

DEPTH (FEET)
0.00
1.00
2.00
3.00
4.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
AMMONIUM-N (LB/A)
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Figure 22. Influence of time of N application on the distribution of $NO_3^-$-N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 5, as measured August 20-21, 1970

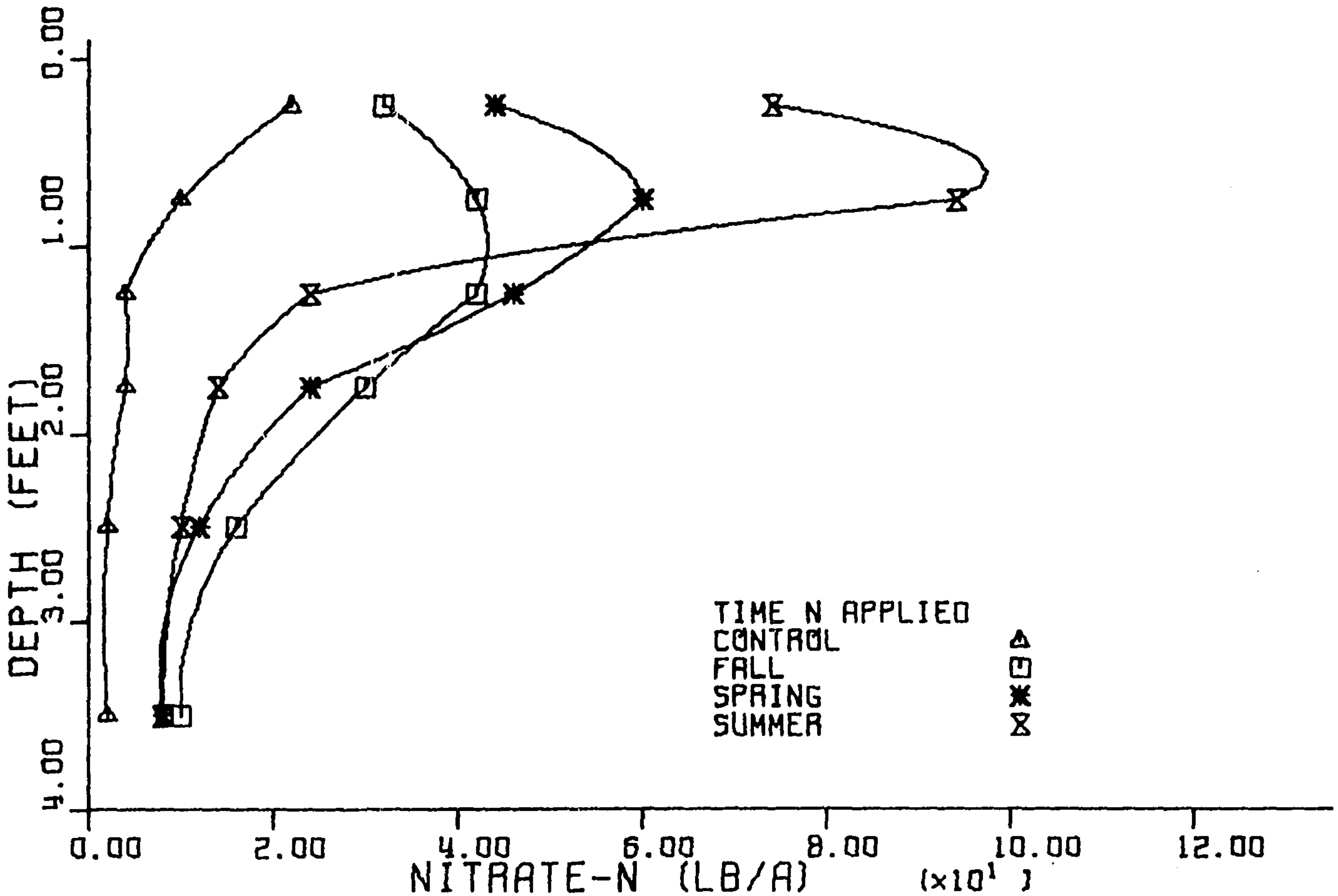

DEPTH (FEET)
0.00
1.00
2.00
3.00
4.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
NITRATE-N (LB/A)
(x10¹ )
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Figure 23. Influence of time of N application on the distribution of Total N (lb/A) in the soil profile of plots receiving 0 and 270 lb N/A at site 5, as measured August 20-21, 1970

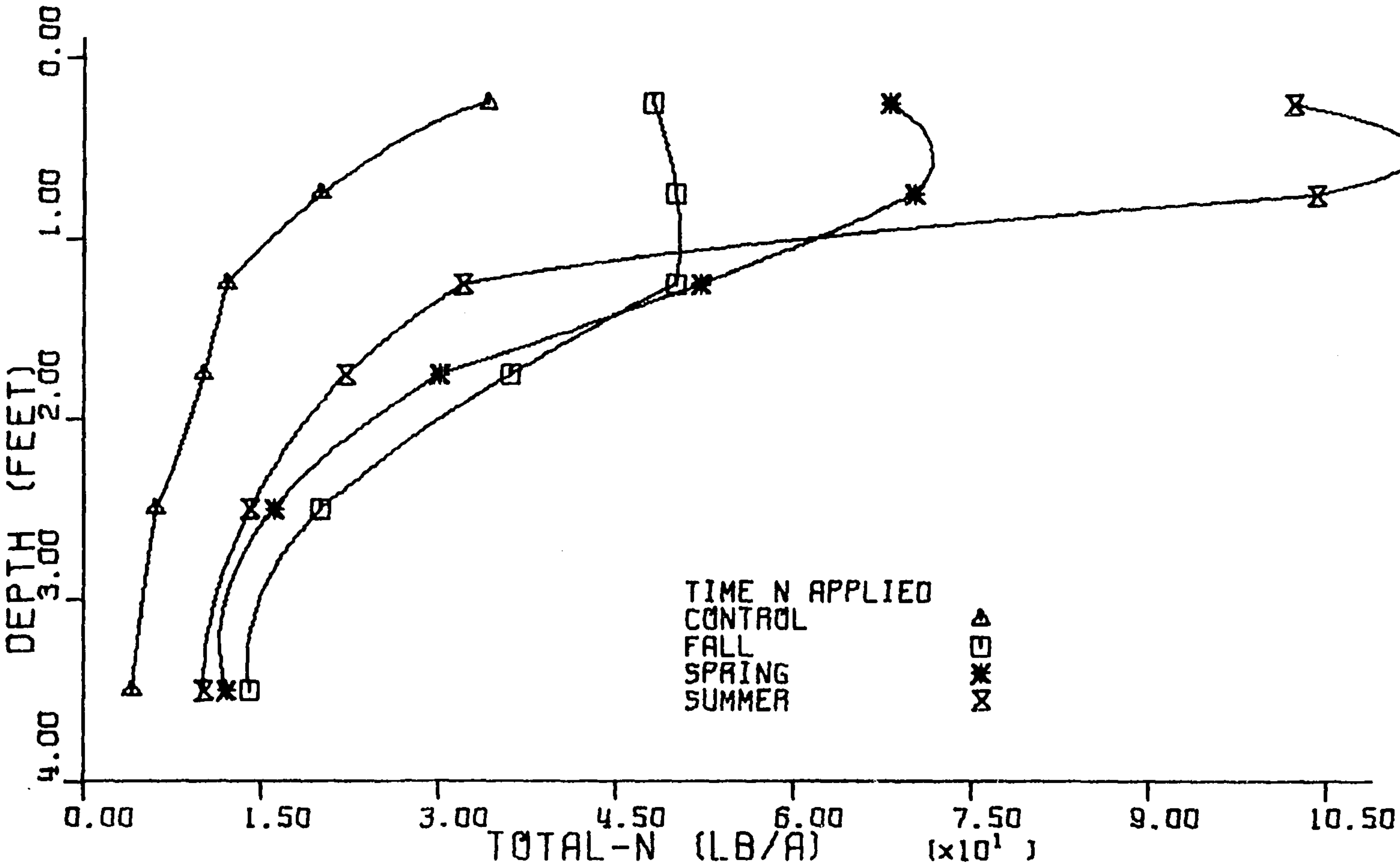

DEPTH (FEET)
0.00
1.00
2.00
3.00
4.00
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
TOTAL-N (LB/A)
[x10¹ ]
TIME N APPLIED
CONTROL
FALL
SPRING
SUMMER

Table 32. Total soil N concentration in lb/A of profile samples taken from plots receiving 160 lb N/A just prior to silking in 1968 at site 1

| Depth (inches) | Time of N application | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fall | | | | | Spring | | | | | Summer | | | | |
| | A[a] | B | C | D | E | A | B | C | D | E | A | B | C | D | E |
| 0-6 | 24 | 24 | 26 | 14 | 22 | 18 | 20 | 18 | 16 | 40 | 20 | 16 | 308 | 16 | 14 |
| 6-12 | 14 | 8 | 26 | 12 | 10 | 8 | 16 | 16 | 12 | 102 | 10 | 18 | 64 | 8 | 12 |
| 12-18 | 6 | 6 | 60 | 78 | 14 | 6 | 8 | 10 | 12 | 78 | 8 | 8 | 54 | 8 | 6 |
| 18-24 | 4 | 8 | 40 | 60 | 10 | 4 | 8 | 8 | 20 | 30 | 10 | 12 | 18 | 6 | 4 |
| 24-30 | 4 | 6 | 14 | 34 | 8 | 6 | 4 | 14 | 16 | 16 | 10 | 14 | 12 | 4 | 6 |
| 30-36 | 6 | 8 | 10 | 28 | 12 | 2 | 6 | 12 | 14 | 14 | 12 | 12 | 10 | 4 | 6 |
| 36-42 | 6 | 8 | 6 | 16 | 12 | 12 | 6 | 14 | 10 | 6 | 8 | 8 | 10 | 8 | 6 |
| 42-48 | 6 | 6 | 4 | 8 | 28 | 8 | 12 | 12 | 12 | 4 | 6 | 2 | 4 | 8 | 4 |

[a]Letters represent the location from which soil cores were removed; C = center between corn rows, B and D = 6 inches and A and E = 12 inches on either side of the center.

relating these values to corn yields is illustrated by Table 32. N concentrations in the profile samples from the plots of fall applied ammonia indicated that injection and the resulting zone of greatest N concentration was located approximately 6 inches to the side of the center of the interval between corn rows. Injecting the ammonia in the center between corn rows was obviously not achieved with the spring application because of the highest N concentrations 12 inches to the side of center.

Table 32 indicates that some leaching of N had occurred as the highest concentration of N appeared at the 12-18, 6-12 and 0-6 inch depths, respectively, for the fall, spring and summer times of application.

# SUMMARY

Data were collected at five experimental sites in north central and northeast Iowa to evaluate the influence of time of applying different rates and sources of N fertilizer for the corn crop. Leaf chemical composition, grain yields and movement of N in the soil profile were used as criteria for evaluation. Sites were located on soils of the Clarion-Webster and Kenyon-Clyde associations which represent areas of intensive row crop production in the state. In 1967 an experiment was initiated in each of these two soil associations, using anhydrous ammonia at rates of 0, 40, 80 and 160 lb N/A in late fall, early spring and early summer applications. Each experiment was laid out as a randomized complete block design using four blocks of the twelve treatments. Another experiment initiated in 1968 on a Webster soil involved similar techniques except that rates of N application were increased to 0, 80, 160 and 240 lb N/A. Two more studies started on soils of the Kenyon-Clyde association in 1970 included ammonium nitrate (AN), urea and sulfur-coated urea (SCU) as N sources, with each applied at rates of 30, 90 and 270 lb N/A. These nine treatments plus a control represented whole plots in each of three blocks of a completely randomized block design and were split for fall, spring and summer dates of application.

Chemical analyses of corn leaf samples taken at or near the 75% silking state were used to evaluate the influence of time and source at different rates of applied N. Increasing the rate of N application significantly increased leaf N content at all sites. Leaf N levels generally increased with later application of fertilizer N. In the experiments

involving N sources, leaf N contents were similar for comparable rates of AN and urea but were significantly lower for the SCU treatments.

Use of AOV statistical techniques indicated that a significant ($P < .05$) linear increase in leaf N was associated with progressively later application of N in 5 out of the 9 site-years of data collected. A linear trend was also evident in one site-year, while data from another site-year showed a significant quadratic effect due to time. In the latter case the highest leaf N levels were associated with the spring applied N but did not differ for fall and summer N applications. The slowly soluble SCU source produced significantly lower levels of leaf N than either AN or urea, while the latter two sources showed similar effects at both site 4 and 5. A decrease in leaf N with time was observed with the 270 lb N/A rate of SCU as opposed to an increase with the AN and urea sources and resulted in a significant $TS^2$ interaction. Results obtained in this study concur with previous work in that as N rates are increased leaf N content is markedly increased. Data from several site-years showed significant TR interactions arising from the increase in leaf N with later N applications at lower rates and similar or decreasing leaf N levels at the higher N rates.

Increasing the rate of N applied significantly increased leaf P levels in 7 of the 9 site-years. However, time of N application had little if any consistent effect on leaf P levels. Data from only one site-year indicated a significant increase in leaf P with the later time of N application.

Leaf K levels were rarely influenced by time of N application but data from one site-year showed a significant increase in leaf K with later applied N. This single observation was somewhat in conflict with the expected trend for leaf K to decrease as leaf N and applied N rates increased. The evidence that leaf K is significantly decreased with increasing applied N rates was exemplified by the data from 7 of 9 site-years in this study.

The influence of time of application on corn yields varied with individual sites and seasons but response generally increased with the later applications of fertilizer N. The average yields for several years show that the advantage for the later applications was most evident at the lower N rates and diminished as optimum rates were approached. Statistical analysis by AOV technique indicated that later application of N significantly increased corn yields during 1969 and for the combined 3-year period at site 1. The significant TR interaction at site 4 illustrates the trend of increased response with later applied N at lower rates and a decrease with time at the highest N rate. Excessive rainfall throughout the fall, winter or spring could result in periods during which the soil is saturated and provide opportunity for N loss by denitrification and leaching to account for the lower yields with earlier N application. Other results showing higher yields from earlier applied N, as in the 1970 season at sites 1, 3 and 4, support the concept that N in the soil profile which is in a more favorable position with respect to moisture during droughty periods may produce higher yields.

Because of the large corn yield response to rate of applied N the linear effect at all sites and years was highly significant. Even with the extremely variable soil moisture situation at site 2 and the previous soybean crops and inherently high fertility at sites 1, 3 and 5 significant linear yield increases were recorded.

Yield response from the SCU source was significantly less than the AN and urea sources. Largest differences between sources occurred at the 90 lb/A rate which clearly illustrated that this particular SCU material released N too slowly for optimum corn production.

Relative efficiency curves were developed to show the effectiveness of fall and spring applied N as compared to summer application. These figures illustrated the wide variation, usually the inferiority of earlier application, at lower N rates and similar efficiencies as the optimum or highest N rates were approached. The relative efficiency curves which resulted from the combined yield data for the 6 site-years from sites 1, 3 and 4 point out a range of 82 to 98 percent effectiveness for fall versus summer and a near 100 percent efficiency for spring versus summer applied N.

Soil samples were taken in 6 inch increments to a depth of 24 inches during mid-June before the summer N application was made at sites 4 and 5. Chemical analysis indicated considerable conversion of $NH_4^+$-N to $NO_3^-$-N with subsequent leaching of $NO_3^-$-N, some of which moved beyond the 24 inch depth. Average N concentrations were higher where application was made in the spring as compared to fall, however some of the earlier applied N had no doubt been leached from the portion of the profile sampled. The coarser textured soil of site 5 apparently was responsible for more nitrification and greater depth of $NO_3^-$-N movement which resulted in less total N in the surface 24 inches for the plots receiving fall applied N. SCU plots had significantly more $NH_4^+$-N, less $NO_3^-$-N and total N than the AN and urea plots but no different was noted between AN and urea sources of N.

Samples were taken to a depth of 48 inches at the same sites soon after the corn began silking. Concentrations of $NH_4^+$-N and total N in the surface 6 inches at site 4 were significantly greater following the summer application than either the fall or spring. Applied N which had been nitrified remained largely in the surface 6 inches of soil but the fall applied N in particular, had moved to the 12-18 inch depth. At site 5 however, the earlier the application of N, the greater the nitrification, depth of $NO_3^-$-N movement, and subsequent loss from the surface 4 feet of soil. The effect of the coarser textured soil in addition to more rainfall at this site resulted in substantial $NO_3^-$-N movement to the 12-18 and 18-24 inch depth with smaller amounts leaching to the 36 to 48 inch depth. Nitrogen applied at both sites as SCU continued to remain largely in the $NH_4^+$-N form in the surface 6 inches and lower concentrations of all forms of N were found in the profile taken with AN and urea sources.

Analysis of soil samples taken at sites 1 and 2 revealed the extreme difficulty in measuring N concentrations following the fall, spring and summer application of anhydrous ammonia. In most cases the $NH_3$ injection zone was at different distances from the corn row. This situation along with the greater depths of $NO_3^-$-N movement usually associated with earlier N application make it impossible to establish any clearly defined relationship between position of N in the profile and corn yield.

# CONCLUSIONS

The data collected from all sites during 1968-70 hopefully provide certain guidelines regarding the time for most effective application of N to corn. Leaf analyses and yields of corn agreed closely as a means of evaluating the influence of time of N application. Soil analysis to measure N content and distribution in the profile also helped to explain the yields recorded for the three times of N application. Relative efficiencies simply provided another means of expressing the effect of applying N at different lengths of time before crop use.

Yield results in this study varied from year to year at different locations but in general indicated a greater response to later applications of N. This was particularly true at the lower N rates used (30 to 40 lb N/A). As N rates approached levels which more nearly produced optimum yields little influence due to time of N application was observed. Distribution and quantity of annual rainfall undoubtedly has the greatest influence on crop response to time of N application. Rainfall and other climatic characteristics appear to place Iowa on the borderline with respect to the advisability of applying N in the fall for the following corn crop. It seems likely that fall application of N would have the greatest potential for use in the northwest one-third of Iowa. Early results reported by Dumenil et al. (1954) as well as Shrader (1971a) support the statement. As a result of the greater rainfall in eastern and southeastern Iowa it would be expected that response to fall applied N might be somewhat less than to later applications.

Circumstantial evidence would suggest several factors that contribute to yield differences due to N availability; (1) leaching, (2) denitrification, and (3) immobilization by microorganisms. Site 5 illustrates what happens in many soils where substantial losses of N could occur due to leaching beyond the rooting zone of crops. This is not to say that other avenues of loss would not also be operating but that movement of $NO_3^-$-N below the 4-foot depth could account for a sizeable portion of the amount applied. The effect of differential loss of N upon yields was not significant at this location however, primarily because large amounts of manure had been added in previous years. Favorable distribution of precipitation throughout the 1970 growing season undoubtedly contributed to mineralization of sufficient quantities of N so that little response was observed from applied N.

It was unfortunate that the lack of uniformity in soil drainage at site 2 overshadowed any possible measurement of time of N effect on yields. This site was typical of many soils of eastern Iowa which often are subject to periods where excessive moisture causes waterlogged conditions in the fall, spring or both times of the year. This condition along with the presence of relatively large amounts of organic matter in the surface horizons could account for N losses by denitrification.

Immobilization of a greater portion of the earlier applied N would be possible and as such could account for the lower responses. Measurement of this loss to plants would be difficult to distinguish from denitrification losses, particularly since the small changes in total soil nitrogen would be almost impossible to detect where only small amounts of applied N are used. Yet it is at the lower N rates where the difference in response is the greatest.

It should be pointed out that the methods of fertilizer placement used in these studies tended to avoid certain types of N loss. Surface applications with immediate incorporation or careful injection of anhydrous ammonia at about 8 inches depth practically eliminate losses due to erosion and volatilization of ammonia. Urea or other ammonium forming sources applied on the soil surface are subject to volatilization unless incorporated.

Time of N application has to this point been discussed only from the agronomic standpoint. Certainly the economic and other management decisions play an important role in deciding when N should be applied. Availability and cost of fertilizer materials, availability of labor and use of various cultural practices may favor application at certain times of the year. The final choice as to time of N application becomes a management decision in which all of these factors must be considered. The availability of adequate agronomic information regarding the possible odds and magnitude of yield loss due to early application greatly facilitates such decision making.

Soils and weather are such that fall N application in the northwest one-third of Iowa would normally result in little if any reduction in corn yields. In dry years, earlier applications might be more effective, particularly if this results in a more favorable placement of N with respect to moisture during droughty periods. Earlier applications in central Iowa would be less desirable primarily because of greater precipitation and the inadequate drainage characteristics of certain soils. Still larger quantities of precipitation in eastern and southeastern Iowa would make fall application somewhat more questionable.

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# APPENDIX

Table 33. Several soil characteristics for each of the five experimental sites

| Site | Soil depth (inches) | Soil particle analysis | | | % Carbon | pH |
|---|---|---|---|---|---|---|
| | | % Sand | % Silt | % Clay | | |
| 1 | 0-6 | 27.6 | 40.5 | 31.9 | 3.06 | 6.91 |
| | 6-12 | 28.9 | 38.0 | 33.1 | 2.16 | 7.35 |
| | 12-18 | 31.6 | 37.6 | 30.8 | 1.60 | 7.52 |
| | 18-24 | 35.3 | 35.3 | 29.4 | 1.45 | 7.61 |
| | 24-30 | 38.2 | 35.9 | 25.9 | 1.64 | 7.73 |
| | 30-36 | 40.4 | 35.9 | 23.7 | 1.86 | 7.80 |
| | 36-42 | 40.1 | 38.6 | 21.3 | 2.57 | 7.95 |
| | 42-48 | 40.8 | 41.3 | 17.9 | 2.29 | 7.97 |
| 2 | 0-6 | 19.5 | 54.8 | 25.7 | 2.17 | |
| | 6-12 | 17.9 | 56.0 | 26.1 | 1.79 | |
| | 12-18 | 20.7 | 51.6 | 27.7 | .76 | |
| | 18-24 | 33.9 | 40.0 | 26.1 | .40 | |
| | 24-30 | 46.4 | 28.6 | 25.0 | .15 | |
| | 30-36 | 43.9 | 30.2 | 25.9 | .09 | |
| | 36-42 | 42.7 | 30.5 | 26.8 | .11 | |
| | 42-48 | 42.4 | 31.1 | 26.5 | .06 | |
| 3 | 0-6 | 32.6 | 38.9 | 28.5 | 2.72 | |
| 4 | 0-6 | 13.6 | 56.3 | 30.1 | 2.66 | 5.48 |
| | 6-12 | 13.1 | 57.8 | 29.1 | 1.91 | 5.07 |
| | 12-18 | 12.6 | 56.0 | 31.4 | 1.04 | 4.83 |
| | 18-24 | 23.7 | 47.7 | 28.6 | .26 | 5.05 |
| | 24-36 | 39.8 | 32.8 | 27.4 | .19 | 5.79 |
| | 36-48 | 40.1 | 32.0 | 27.9 | .59 | 7.49 |
| 5 | 0-6 | 44.8 | 34.3 | 20.9 | 2.04 | |
| | 6-12 | 38.1 | 35.9 | 26.0 | 2.03 | |
| | 12-18 | 35.6 | 36.8 | 27.6 | 1.04 | |
| | 18-24 | 41.7 | 31.4 | 26.9 | .59 | |
| | 24-36 | 46.3 | 27.0 | 26.7 | .22 | |
| | 36-48 | 40.2 | 32.3 | 27.5 | .12 | |

Table 34. Monthly precipitation for each year at the five experimental sites

| Site | Year | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 67 | .88 | .23 | .77 | 2.63 | 3.00 | 9.04 | .68 | 2.97 | 1.63 | 1.56 | .26 | .71 |
| | 68 | .37 | .04 | .32 | 4.88 | 2.33 | 5.98 | 8.13 | 2.06 | 5.15 | 4.82 | .48 | 1.75 |
| | 69 | 1.70 | 1.11 | 1.12 | 2.27 | 4.39 | 8.23 | 6.93 | 1.45 | 1.40 | 3.09 | .34 | 1.33 |
| | 70 | .11 | T | 1.35 | .96 | 7.93 | 3.20 | 2.29 | 1.50 | 3.74 | 4.17 | 2.06 | .96 |
| 2[a] | 67 | 1.82 | .80 | 2.88 | 2.60 | 2.33 | 9.41 | 2.57 | 4.19 | 2.31 | 3.47 | 1.81 | 1.51 |
| | 68 | .80 | .18 | 1.23 | 4.87 | 2.86 | 6.33 | 15.91 | 5.25 | 4.26 | 2.13 | .88 | 2.51 |
| | 69 | 2.31 | .07 | .80 | 4.20 | 4.40 | 6.27 | 8.22 | .45 | 2.10 | 2.72 | .40 | 1.26 |
| 3 | 68 | .48 | .07 | 1.37 | 6.23 | 2.41 | 9.09 | 2.25 | 3.33 | 4.28 | 2.93 | 1.31 | 1.86 |
| | 69 | .92 | .81 | .56 | 4.11 | 3.21 | 5.96 | 4.90 | 2.02 | 4.48 | 4.03 | .05 | .82 |
| | 70 | .12 | T | 2.39 | 1.67 | 7.48 | 3.15 | 3.79 | 5.76 | 5.32 | 3.44 | 1.58 | .91 |
| 4 | 69 | 1.48 | .45 | .80 | 4.35 | 3.12 | 9.48 | 9.07 | 2.09 | 2.32 | 3.91 | .20 | 2.75 |
| | 70 | .10 | .60 | 2.15 | 1.55 | 7.00 | 1.84 | 4.13 | .93 | 5.60 | 5.79 | 2.25 | .53 |
| 5[b] | 69 | 2.31 | .07 | .80 | 4.53 | 3.50 | 5.59 | 7.02 | .44 | 2.44 | 2.80 | .40 | 1.26 |
| | 70 | .09 | .23 | 2.39 | 1.82 | 6.42 | 7.26 | 3.91 | 1.47 | 7.29 | 3.32 | 1.02 | 1.18 |

[a]Rainfall data recorded at ISU farm is given for April through October, otherwise data reported was taken from official station Independence 2 SW.

[b]Rainfall data given for sites 4 and 5 are from Allison and Independent Weather Bureau stations, respectively.

Table 35. Corn yields for individual plots and years at site 1

| Block | N/A | Bu/A at 15.5% moisture | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1968 | | | 1969 | | | 1970 | | |
| | | Time of N application | | | Time of N application | | | Time of N application | | |
| | | Fall | Spring | Summer | Fall | Spring | Summer | Fall | Spring | Summer |
| 1 | 0 | 119.5 | 97.1 | 106.9 | 58.0 | 61.3 | 59.6 | 38.7 | 47.1 | 49.9 |
| | 40 | 108.6 | 132.8 | 108.9 | 57.1 | 67.4 | 72.4 | 39.6 | 66.2 | 69.2 |
| | 80 | 146.3 | 164.9 | 150.2 | 107.1 | 107.2 | 111.1 | 88.3 | 103.1 | 88.7 |
| | 160 | 154.3 | 146.6 | 161.5 | 110.2 | 137.0 | 112.9 | 142.7 | 134.0 | 136.5 |
| 2 | 0 | 131.7 | 112.2 | 127.3 | 80.4 | 59.2 | 60.0 | 38.3 | 40.6 | 44.9 |
| | 40 | 144.9 | 143.3 | 139.8 | 84.7 | 77.7 | 88.0 | 59.6 | 77.3 | 77.7 |
| | 80 | 149.8 | 155.6 | 163.8 | 79.9 | 129.5 | 130.2 | 83.8 | 115.4 | 103.4 |
| | 160 | 163.1 | 157.4 | 160.0 | 120.7 | 129.0 | 140.2 | 133.0 | 138.1 | 121.3 |
| 3 | 0 | 126.4 | 123.9 | 136.3 | 66.1 | 64.8 | 86.3 | 25.9 | 27.8 | 37.3 |
| | 40 | 127.1 | 149.3 | 127.6 | 79.6 | 104.3 | 89.3 | 51.6 | 76.8 | 57.6 |
| | 80 | 159.2 | 162.2 | 161.7 | 118.9 | 126.5 | 138.6 | 96.5 | 104.8 | 91.3 |
| | 160 | 160.1 | 163.5 | 160.8 | 149.6 | 157.5 | 151.2 | 149.8 | 134.2 | 121.7 |
| 4 | 0 | 100.6 | 116.2 | 126.1 | 50.9 | 63.0 | 61.1 | 35.8 | 37.1 | 35.1 |
| | 40 | 135.1 | 142.8 | 149.8 | 86.2 | 86.1 | 113.0 | 58.3 | 77.2 | 70.8 |
| | 80 | 153.4 | 153.1 | 160.1 | 123.7 | 90.9 | 115.0 | 103.3 | 85.2 | 113.7 |
| | 160 | 156.5 | 158.3 | 159.7 | 134.7 | 154.6 | 159.8 | 150.6 | 133.1 | 148.6 |

Table 36. Corn yields for individual plots and years at site 2

| Block | N/A | Bu/A at 15.5% moisture | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1968 | | | 1969 | | |
| | | Time of N application | | | Time of N application | | |
| | | Fall | Spring | Summer | Fall | Spring | Summer |
| 1 | 0 | 42.0 | 40.3 | 55.6 | 35.1 | 13.9 | 37.9 |
| | 40 | 87.1 | 65.4 | 83.5 | 54.3 | 40.3 | 30.2 |
| | 80 | 79.7 | 77.2 | 76.9 | 73.6 | 44.5 | 73.6 |
| | 160 | 83.4 | 101.3 | 83.9 | 133.1 | 110.0 | 127.1 |
| 2 | 0 | 54.4 | 41.6 | 54.6 | 34.8 | 31.1 | 38.2 |
| | 40 | 63.6 | 79.5 | 78.9 | 40.3 | 60.3 | 63.1 |
| | 80 | 55.1 | 72.9 | 57.8 | 35.6 | 59.1 | 67.5 |
| | 160 | 87.7 | 85.7 | 74.6 | 117.4 | 61.2 | 77.5 |
| 3 | 0 | 61.7 | 39.1 | 29.4 | 37.0 | 38.3 | 26.5 |
| | 40 | 57.7 | 54.6 | 68.6 | 36.5 | 37.3 | 40.4 |
| | 80 | 54.6 | 72.2 | 83.6 | 27.2 | 63.9 | 76.2 |
| | 160 | 83.4 | 81.0 | 75.0 | 82.6 | 54.4 | 82.6 |
| 4 | 0 | 33.6 | 35.3 | 60.4 | 11.9 | 3.8 | 16.1 |
| | 40 | 42.7 | 41.5 | 63.7 | 13.8 | 6.1 | 40.3 |
| | 80 | 55.9 | 43.8 | 56.8 | 16.4 | 8.8 | 20.6 |
| | 160 | 51.3 | 60.3 | 65.5 | 12.2 | 25.7 | 15.9 |

Table 37. Corn yields for individual plots and years at site 3

| | | Bu/A at 15.5% moisture | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1969 | | | 1970 | | |
| | | Time of N application | | | Time of N application | | |
| Block | N/A | Fall | Spring | Summer | Fall | Spring | Summer |
| 1 | 0 | 133.3 | 124.5 | 122.9 | 77.6 | 70.8 | 66.5 |
| | 80 | 147.8 | 143.7 | 152.7 | 112.9 | 102.2 | 116.0 |
| | 160 | 151.0 | 148.7 | 151.8 | 110.8 | 117.7 | 111.2 |
| | 240 | 153.3 | 147.0 | 146.4 | 121.7 | 125.5 | 132.1 |
| 2 | 0 | 123.4 | 132.0 | 127.6 | 72.2 | 75.9 | 52.1 |
| | 80 | 146.8 | 145.9 | 135.8 | 115.9 | 131.4 | 113.8 |
| | 160 | 142.5 | 150.4 | 151.2 | 127.4 | 128.4 | 119.0 |
| | 240 | 149.7 | 152.9 | 140.4 | 133.5 | 121.8 | 118.4 |
| 3 | 0 | 127.7 | 135.0 | 134.2 | 63.6 | 73.2 | 78.9 |
| | 80 | 145.7 | 141.7 | 136.1 | 103.9 | 123.3 | 110.7 |
| | 160 | 156.8 | 141.3 | 152.2 | 124.1 | 124.1 | 125.9 |
| | 240 | 152.3 | 158.2 | 147.3 | 107.1 | 136.5 | 123.1 |
| 4 | 0 | 131.9 | 135.4 | 137.2 | 79.0 | 80.0 | 83.8 |
| | 80 | 149.2 | 145.7 | 138.9 | 100.2 | 97.6 | 126.7 |
| | 160 | 147.5 | 146.6 | 147.6 | 112.6 | 133.0 | 137.4 |
| | 240 | 157.4 | 145.2 | 150.0 | 111.2 | 135.5 | 137.1 |

Table 38. Corn yields for individual plots at site 4 in 1970

| | | Bu/A at 15.5% moisture | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | AN | | | SCU | | | Urea | | |
| | | Time of N application | | | Time of N application | | | Time of N application | | |
| Block | N/A | Fall | Spring | Summer | Fall | Spring | Summer | Fall | Spring | Summer |
| 1 | 0[a] | 78.2 | 84.8 | 90.0 | | | | | | |
| | 30 | 97.7 | 105.9 | 95.7 | 82.4 | 84.1 | 98.3 | 71.7 | 101.5 | 108.2 |
| | 90 | 142.0 | 133.8 | 143.3 | 125.1 | 121.4 | 101.9 | 122.8 | 139.9 | 139.8 |
| | 270 | 155.6 | 145.5 | 141.4 | 143.0 | 138.9 | 139.6 | 145.7 | 148.8 | 130.5 |
| 2 | 0[a] | 68.3 | 73.3 | 50.7 | | | | | | |
| | 30 | 106.9 | 105.2 | 99.7 | 81.8 | 100.7 | 77.6 | 108.1 | 93.9 | 104.3 |
| | 90 | 128.7 | 143.0 | 129.9 | 132.3 | 125.4 | 120.3 | 141.3 | 143.7 | 132.4 |
| | 270 | 151.0 | 146.8 | 142.8 | 147.8 | 152.7 | 139.4 | 155.3 | 146.9 | 148.2 |
| 3 | 0[a] | 37.7 | 73.9 | 55.9 | | | | | | |
| | 30 | 71.8 | 76.0 | 88.6 | 67.2 | 78.9 | 90.2 | 79.7 | 88.4 | 109.2 |
| | 90 | 122.8 | 129.1 | 142.5 | 110.8 | 124.8 | 127.2 | 138.5 | 132.9 | 140.6 |
| | 270 | 150.6 | 138.8 | 139.6 | 137.9 | 139.2 | 135.2 | 158.4 | 157.8 | 136.7 |

[a]No source designation was associated with control plots.

Table 39. Corn yields for individual plots at site 5 in 1970

| | | Bu/A at 15.5% moisture | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | AN | | | SCU | | | Urea | | |
| | | Time of N application | | | Time of N application | | | Time of N application | | |
| Block | N/A | Fall | Spring | Summer | Fall | Spring | Summer | Fall | Spring | Summer |
| 1 | 0[a] | 148.4 | 147.5 | 147.0 | | | | | | |
| | 30 | 146.6 | 141.2 | 147.3 | 143.8 | 145.2 | 143.9 | 141.2 | 136.2 | 139.5 |
| | 90 | 144.4 | 134.5 | 138.8 | 145.8 | 144.9 | 146.8 | 142.9 | 140.6 | 143.9 |
| | 270 | 146.2 | 147.1 | 142.6 | 145.9 | 147.6 | 144.1 | 144.8 | 145.8 | 141.4 |
| 2 | 0[a] | 138.1 | 139.1 | 142.8 | | | | | | |
| | 30 | 143.0 | 144.3 | 141.7 | 135.8 | 132.9 | 140.1 | 144.0 | 133.8 | 142.1 |
| | 90 | 140.4 | 147.7 | 145.4 | 147.4 | 141.5 | 138.1 | 145.6 | 147.1 | 148.2 |
| | 270 | 155.0 | 153.2 | 144.9 | 147.7 | 151.6 | 144.7 | 148.0 | 151.7 | 142.6 |
| 3 | 0[a] | 133.4 | 127.2 | 138.7 | | | | | | |
| | 30 | 142.9 | 137.8 | 140.6 | 128.8 | 131.1 | 133.6 | 141.9 | 136.3 | 135.1 |
| | 90 | 151.9 | 145.1 | 150.0 | 144.2 | 144.5 | 142.0 | 138.5 | 147.0 | 145.3 |
| | 270 | 140.7 | 138.0 | 139.5 | 144.7 | 148.3 | 143.5 | 145.9 | 151.3 | 145.1 |

[a]No source designation was associated with control plots.

Table 40. Analysis of variance of corn yields from the plots receiving N (3/4 of data) for each year at site 1

| Source | df | 1968 | | 1969 | | 1970 | |
|---|---|---|---|---|---|---|---|
| | | MS | F | MS | F | MS | F |
| Blocks | 3 | 271.42 | 4.56* | 1156.77 | 6.98*** | 111.33 | 1.31 |
| Treatments | 8 | 618.64 | 10.16*** | 2410.32 | 14.55*** | 4069.42 | 47.75*** |
| Times | 2 | 108.88 | 1.79 | 623.23 | 3.76* | 162.46 | 1.91 |
| T | 1 | 86.26 | 1.42 | 1194.27 | 7.21* | 78.48 | .92 |
| $T^2$ | 1 | 131.49 | 2.16 | 52.19 | .32 | 246.43 | 2.89 |
| Rates | 2 | 2203.77 | 36.19*** | 8906.82 | 53.78*** | 15503.80 | 181.92*** |
| R | 1 | 3547.80 | 58.26*** | 17690.92 | 106.82*** | 30938.56 | 363.03*** |
| $R^2$ | 1 | 859.74 | 14.12*** | 122.72 | .74 | 69.03 | .81 |
| Time x Rate | 4 | 80.97 | 1.33 | 55.61 | .34 | 305.71 | 3.59* |
| TR | 1 | .36 | .01 | 2.40 | .01 | 815.10 | 9.56*** |
| $TR^2$ | 1 | 26.70 | .44 | 14.74 | .09 | 21.60 | .25 |
| $T^2R$ | 1 | 295.02 | 4.84 | 120.97 | .73 | 385.33 | 4.52* |
| $T^2R^2$ | 1 | 1.78 | .03 | 84.34 | .51 | .81 | .01 |
| Error | 24 | 60.90 | | 165.62 | | 85.22 | |

Table 41. Analysis of variance of corn yields from the plots receiving N (3/4 of data) for each year at site 2

| Source | df | 1968 MS | 1968 F | 1969 MS | 1969 F |
|---|---|---|---|---|---|
| Blocks | 3 | 1274.92 | 16.86*** | 5780.71 | 13.91*** |
| Treatments | 8 | 229.14 | 3.03* | 1361.90 | 3.28* |
| Times | 2 | 92.41 | 1.22 | 428.41 | 1.03 |
| T | 1 | 184.91 | 2.45 | 216.00 | .52 |
| $T^2$ | 1 | --- | -- | 640.82 | 1.54 |
| Rates | 2 | 595.77 | 7.88*** | 4337.77 | 10.44*** |
| R | 1 | 891.81 | 11.79*** | 7949.73 | 19.13*** |
| $R^2$ | 1 | 299.72 | 3.96+ | 725.80 | 1.75 |
| Time x Rate | 4 | 114.20 | 1.51 | 340.72 | .82 |
| TR | 1 | 158.76 | 2.10 | 317.73 | .76 |
| $TR^2$ | 1 | 10.83 | .14 | 799.97 | 1.68 |
| $T^2R$ | 1 | 278.40 | 3.68+ | 275.04 | .66 |
| $T^2R^2$ | 1 | 8.80 | .12 | 70.14 | .17 |
| Error | 24 | 75.63 | | 415.53 | |

Table 42. Analysis of variance of corn yields from the plots receiving N (3/4 of data) for each year at site 3

| Source | df | 1969 MS | 1969 F | 1970 MS | 1970 F |
|---|---|---|---|---|---|
| Blocks | 3 | 13.56 | .62 | 69.48 | .70 |
| Treatments | 8 | 57.05 | 2.59* | 196.81 | 1.97+ |
| Times | 2 | 52.99 | 2.40 | 240.39 | 2.41+ |
| T | 1 | 102.51 | 4.65* | 338.25 | 3.39+ |
| $T^2$ | 1 | 3.46 | .16 | 142.52 | 1.43 |
| Rates | 2 | 116.51 | 5.29* | 512.19 | 5.13* |
| R | 1 | 204.76 | 9.29** | 923.80 | 9.25** |
| $R^2$ | 1 | 28.25 | 1.28 | 100.58 | 1.01 |
| Time x Rate | 4 | 29.36 | 1.33 | 17.32 | .17 |
| TR | 1 | .42 | .02 | .53 | .01 |
| $TR^2$ | 1 | 86.94 | 3.95+ | 24.51 | .25 |
| $T^2R$ | 1 | 1.62 | .07 | 43.13 | .42 |
| $T^2R^2$ | 1 | 28.44 | 1.29 | 1.12 | .01 |
| Error | 24 | 22.03 | | 99.87 | |

Table 43. Individual site analysis of variance of combined corn yield data from the plots receiving N (3/4 of data) as influenced by year, time and rate of applied N

| Source | Site 1 | | | Site 2 | | | Site 3 | |
|---|---|---|---|---|---|---|---|---|
| | df | MS | F | df | MS | F | MS | F |
| Blocks | 3 | 995.81 | 5.44** | 3 | 9326.99 | 29.27*** | 11.34 | .18 |
| Treatments | 8 | 5943.49 | 32.50*** | 8 | 1219.18 | 3.83** | 156.41 | 2.51* |
| Time | 2 | 660.06 | 3.61* | 2 | 360.61 | 1.13 | 42.47 | .68 |
| T | 1 | 925.93 | 5.06* | 1 | 400.21 | 1.26 | 34.17 | .55 |
| $T^2$ | 1 | 394.19 | 2.16 | 1 | 321.01 | 1.01 | 50.77 | .81 |
| Rates | 2 | 22799.25 | 124.66*** | 2 | 4031.29 | 12.65*** | 558.46 | 8.95*** |
| R | 1 | 45255.16 | 247.44*** | 1 | 7083.42 | 22.23*** | 999.19 | 16.01*** |
| $R^2$ | 1 | 343.26 | 1.88 | 1 | 979.15 | 3.07+ | 117.72 | 1.89 |
| Time x Rate | 4 | 157.33 | .86 | 4 | 242.41 | .76 | 12.36 | .20 |
| TR | 1 | 314.24 | 1.72 | 1 | 462.84 | 1.45 | --- | -- |
| $TR^2$ | 1 | 62.17 | .34 | 1 | 442.47 | 1.39 | 9.56 | .15 |
| $T^2R$ | 1 | 222.07 | 1.21 | 1 | .01 | -- | 30.72 | .49 |
| $T^2R^2$ | 1 | 30.83 | .17 | 1 | 64.32 | .20 | 9.14 | .15 |
| Error A | 24 | 182.89 | | 24 | 318.60 | | 62.40 | |
| Year | 2 | 24150.73 | 276.21*** | 1 | 4620.67 | 18.74*** | 13556.37 | 223.15*** |
| Y | 1 | 44455.15 | 508.43*** | | | | | |
| $Y^2$ | 1 | 3846.31 | 43.99*** | | | | | |
| Treatment x Year | 16 | 577.45 | 6.60*** | 8 | 371.87 | 1.51 | 97.45 | 1.60 |
| Time x Year | 4 | 117.25 | 1.34 | 2 | 160.21 | .65 | 250.91 | 4.13* |
| TY | 1 | .10 | -- | 1 | .61 | -- | 406.59 | 6.69* |
| $T^2Y$ | 1 | 8.95 | .10 | 1 | 319.81 | 1.30 | 95.22 | 1.57 |
| $TY^2$ | 1 | 432.98 | 4.95* | | | | | |
| $T^2Y^2$ | 1 | 26.95 | .31 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Rate x Year | 4 | 1907.55 | 21.82*** | 2 | 902.24 | 3.66* | 70.24 | 1.16 |
| RY | 1 | 6766.38 | 77.39*** | 1 | 1758.12 | 7.13* | 129.36 | 2.13 |
| $R^2Y$ | 1 | 707.97 | 8.10** | 1 | 46.36 | .19 | 11.11 | .18 |
| $RY^2$ | 1 | 155.63 | 1.78 | | | | | |
| $R^2Y^2$ | 1 | .22 | -- | | | | | |
| T x R x Y | 8 | 142.50 | 1.63 | 4 | 212.51 | .86 | 34.32 | .56 |
| TRY | 1 | 390.60 | 4.47* | | | | | |
| $T^2RY^2$ | 1 | 576.30 | 6.59* | | | | | |
| Error B | 54 | 87.44 | | 27 | 246.54 | | 60.75 | |

Table 44. Analysis of variance of corn yields from the plots receiving N (9/10 of data) in 1970 at sites 4 and 5

| | | Site 4 | | Site 5 | |
|---|---|---|---|---|---|
| Source | df | MS | F | MS | F |
| Blocks | 2 | 344.16 | 4.12* | 39.60 | .97 |
| Treatments | 8 | 5440.87 | 65.07*** | 91.44 | 2.23+ |
| Sources | 2 | 963.05 | 11.52*** | 16.75 | .41 |
| $S$ | 1 | 47.23 | .56 | 11.57 | .28 |
| $S^2$ | 1 | 1878.86 | 22.47*** | 21.93 | .54 |
| Rates | 2 | 20657.14 | 247.04*** | 287.55 | 7.02** |
| $R$ | 1 | 38421.18 | 459.48*** | 542.73 | 13.24*** |
| $R^2$ | 1 | 2893.09 | 34.60*** | 32.36 | .79 |
| Source x Rate | 4 | 71.66 | .86 | 30.72 | .75 |
| $SR$ | 1 | .05 | -- | 55.50 | 1.35 |
| $SR^2$ | 1 | --- | -- | 7.10 | .17 |
| $S^2R$ | 1 | 87.30 | 1.04 | 55.62 | 1.36 |
| $S^2R^2$ | 1 | 199.28 | 2.38 | 4.67 | .11 |
| Error A | 16 | 83.62 | | 40.98 | |
| Time | 2 | 42.36 | .58 | 12.94 | 1.70 |
| $T$ | 1 | 12.71 | .18 | 25.63 | 3.36+ |
| $T^2$ | 1 | 72.00 | .99 | .24 | .03 |
| Time x Treatment | 16 | 105.85 | 1.46 | 17.27 | 2.27* |
| Time x Source | 4 | 21.82 | .30 | 4.97 | .65 |
| $TS$ | 1 | 28.45 | .39 | 3.18 | .42 |
| $TS^2$ | 1 | 4.48 | .06 | 2.17 | .28 |
| $T^2S$ | 1 | 13.79 | .19 | 7.10 | .93 |
| $T^2S^2$ | 1 | 40.54 | .56 | 7.44 | .98 |
| Time x Rate | 4 | 269.04 | 3.71* | 39.05 | 5.12*** |
| $TR$ | 1 | 1071.46 | 14.79*** | 19.36 | 2.54 |
| $TR^2$ | 1 | 1.98 | .03 | 8.00 | 1.05 |
| $T^2R$ | 1 | .04 | -- | 125.02 | 16.40*** |
| $T^2R^2$ | 1 | 2.67 | .04 | 3.83 | .50 |
| T x S x R | 8 | 6.27 | .91 | 12.53 | 1.64 |
| $TRS$ | 1 | 177.13 | 2.44 | 48.17 | 6.32* |
| $TR^2S^2$ | 1 | 163.63 | 2.26 | | |
| $T^2RS$ | 1 | | | 19.84 | 2.60 |
| Error B | 36 | 72.46 | | 7.62 | |