RETENTION PATTERNS AND LOSS OF ANHYDROUS AMMONIA APPLIED WITH AN UNDERCUTTING BLADE

by

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INTRODUCTION

Greatly increased applications of anhydrous ammonia as an N carrier to improve crop yields have been evidenced since 1950. Ammonia exceeded ammonium nitrate for the first time in 1956 when 344,000 tons of N were applied as ammonia. Seven years later 975,000 tons of ammonia were applied to the soil by farmers. Being the most economical nitrogen carrier on the market today, ammonia applications are likely to continue their upward trend in the future.

In order to save field time and application costs, ammonia is often applied in conjunction with other tillage operations. In western Kansas ammonia is often applied while using an undercutting blade. The undercutting blade is used for controlling weeds and for the conservation of moisture. Proper distribution of ammonia in the soil and loss of ammonia from the soil are two problems that may result from this method of application.

Anhydrous ammonia is usually applied below the soil surface under pressure varying from 60 to 140 psi (depending upon the temperature). Since ammonia boils at -28°C, it vaporizes rapidly as it is released into the soil. Losses of this gaseous ammonia are referred to as volatilization losses. This research was directed to determine the amount of volatilization from a sandy and silt loam soil by varying application methods.

Under some conditions a 40-inch spacing between points of release will cause a "wavy effect" in crops. This occurance has lead to some speculation about the distribution of anhydrous ammonia with the undercutting blade. One theory is that the blade produces a draft so the ammonia is spread evenly across the entire width of the blade. The second phase of this data measured the distribution of ammonia in the soil by varying depth of application, spacing between release points, rates, and soil texture. Ammonia distribution was investigated by soil ammonia analysis, pH change, plant N absorption, and resulting crop yields.

LITERATURE REVIEW

The use of commercial fertilizer has increased greatly in the past few years. Nitrogen has accounted for a large percentage of this increase. Several different carriers of nitrogen are in common usage, but presently more nitrogen is applied as anhydrous ammonia in the U. S. than as any other source. Much of the increased consumption of ammonia has been due to the economy involved in its use. Often, anhydrous ammonia can be applied in conjunction with tillage operations. Since increased consumption of ammonia is likely in the future, additional attention to the problems inherent with its application are justifiable.

Some of the areas requiring additional information in the use of ammonia include development of new equipment for use in application, the handling of ammonia, the effects of ammonia on soil microorganisms, the effect on the acidity of soil, the retention of ammonia, and the distribution of ammonia in the soil. This review will be primarily concerned with factors related to soil distribution and retention of anhydrous ammonia.

Retention and distribution of ammonia in soils are affected by many factors. Some of the main factors related to ammonia distribution and retention are soil moisture, soil texture, cation exchange capacity, and methods of application.

Due to the close relationship of all these factors, it is difficult to discuss one without mentioning others. In addition to the factors mentioned above, research concerning the mechanisms of retention, transformations of ammonia, and nitrogen uptake from the soil will be examined.

Soil Moisture and Ammonia Adsorption

Large amounts of anhydrous ammonia can be retained in the soil under optimum conditions. One factor affecting the retentive capacity of the soil is percent moisture. Adsorption of ammonia may occur over a wide range of soil moisture content. Soil moisture content apparently affects the retention of ammonia, the distribution of ammonia, and also the mechanism of retention.

Ammonia dissolves readily in water McVicker *et al*. (21) and is adsorbed by organic matter and clay particles, thus making it possible for either wet or dry soils to retain ammonia. In the absence of moisture, ammonia may react directly with acid clay to form the ammonium ion or it may be physically adsorbed on the soil particle surface.

One problem in dry soils is the retention of gaseous ammonia in the soil long enough for it to react. Poor soil tilth, i.e. a cloddy structure, may allow ammonia to escape into the atmosphere. Dry soils are frequently cloddy so it becomes more difficult to form a seal over the ammonia injection points. When a seal is formed, Stanley and Smith (33) observed that movement of ammonia was greater in cloddy soil, which resulted in good retention, provided there was good crumb structure. Any loss that did exist was probably a mass outflow because of the pressure created in the soil by the ammonia gas as it vaporized from the liquid form. They also measured the loss of anhydrous ammonia, which was applied at the rate of 100 pounds of nitrogen per acre in 40-inch spacings, from a silt loam soil when applied 3 inches below the surface. Twenty-four hours after application, the wet soil (23% moisture) lost 10% of the ammonia applied, the air-dry soil (2% moisture) lost 12%, and at 15% soil moisture less than 1% escaped from the soil. Obviously, ammonia loss was greatest from the air-dry soil, however, it should be noted that field soil is seldom air-dry to a depth greater than 2 or 3 inches.

Ammonia applied to a wet soil reacts immediately with water to form ammonium hydroxide (aqua-ammonia). The ammonium hydroxide will dissociate into the ammonium and hydroxide ions, thus raising the pH value in the soil. The ammonium is then attracted to the clay particles for adsorption.

When ammonia is applied in a wet soil, the ammonia may be lost to the atmosphere due to improper closure of the soil following the incision made by the applicator. Closure of the soil is not only dependent on soil moisture, but also soil texture.

Parr and Engibous (28) disclosed that under conditions of excessive moisture, rapid and complete closure of the injection channel may not occur and direct loss of gaseous ammonia to the atmosphere is possible.

Ammonia losses from wet soils may also occur because of the upward movement and evaporation of water, as some of the ammonia is dissolved in the water. Stanley and Smith (33) noted that the loss from wet soil was gradual, indicating that the escape of ammonia was not from the knife openings. When anhydrous ammonia equivalent to 100 pounds of nitrogen per acre was applied in 40-inch spacings, some soils were not able to sorb this amount in the diffusion area. As moisture evaporated from the surface, the dissolved ammonia moved upward and was lost. When anhydrous ammonia was released under wet conditions, vertical movement was greater than to the sides or below the point of release.

In a study of distribution patterns of anhydrous ammonia in greenhouse pots, Parr and Engibous (28) found that ammonia came nearer to the surface in moist soils as indicated by soil pH measurements.

Papendick and Parr (26) plotted the distribution of anhydrous ammonia in a Hartsells fine sandy loam by measuring the pH values in the soil mass. The pH of the moist soil at the point of ammonia release 36 hours after application was 9.1 compared to 8.3 for the air-dry condition. It was apparent that a larger soil volume was influenced in the moist soil compared to the air-dry system. The lower pH values observed in the air-dry soil may have resulted from the existence of a more highly reactive state between the ammonia and various soil organic and inorganic components due to the absence of water. Much of the chemically reacted ammonia would not be detectable by pH measurement. Generally, the amount of ammonia retained decreased with increasing distance from the point of injection. Most of the ammonia was found to be retained within a radius of 5 cm around the injection point. The greatest initial movement occured when gaseous ammonia was injected into air-dry soil.

Anhydrous ammonia was applied by Blue and Eno (3) with a knife applicator at 115 pounds per acre on several sandy soils. They contended that the ammonia remained about 2 inches from the point of release immediately after injection in a soil with about 16% moisture. The ammonia moved farther out with a decrease in moisture (up to 3 inches in each direction from the point of injection with 3 percent moisture). When 258 pounds per acre of nitrogen was applied to the same soils at 2.4% moisture, the ammonia moved 4 inches in each direction for an 8 inch diameter pattern.

With increasing soil moisture, soils have a greater "initial capacity" to retain ammonia. This is most likely due to the solvent action of the water for ammonia (31). Due to the fact that ammonia is highly soluble in water it is reasonable to expect a positive relationship between ammonia volatilization and water loss by evaporation.

Parr and Khasawneh (29) suggested that a rapid rate of water evaporation occurs from the immediate area around the release point. Moisture losses ranged from 3.8 percent at the ammonia release point to 0.7 percent at a radial distance greater than 5 cm. Their results indicated that this phenomenon can persist for at least 100 days after application, even when subject to alternate wetting and drying.

Parr and Papendick (30) examined the yield of dry corn forage in the greenhouse from Mountview and Hartsells soils, as influenced by soil moisture at the time of application of anhydrous ammonia. The data showed that the yields continued to increase as the amount of nitrogen applied increased on the Hartsells fine sandy loam soil, but there was no response to nitrogen above a 500 miligram rate of application for the Mountview loam. There was a trend toward slightly higher yields when anhydrous ammonia was applied to moist soil at the high (750 milligram/pot) nitrogen level, although the differences were not statistically significant. However, subsequent studies showed that small decreases in yield can be expected when high levels of NH_3 are applied to soils in an air-dry rather than moist condition. A possible explanation is that, due to the greater chemical reactivity of anhydrous ammonia in air-dry compared to moist soil (17, 26, 31), an increasing percentage of the applied NH_3 was not readily available because of temporary immobilization.

Jackson and Chang (16) determined that the moisture content of soils, air-dry as compared to field-moist, exerted only a slight effect on loss. In general, at a 2 inch depth, the air-dry soil lost less than 5% while the moist soil lost no ammonia. The 4 inch depth of application in the soil resulted in complete conservation of ammonia regardless of moisture content. They concluded that the soil moisture factor, over the range of conditions expected in the field, can be neglected in practical applications of ammonia as a fertilizer.

Maximum retention of anhydrous ammonia can be realized when ammonia is applied to soils at an optimum moisture content, usually 15 to 18 percent. Stanley and Smith (33) revealed that the loss of ammonia was small on a Putnam silt loam with 15% to 18% moisture regardless of the depth of application, but that losses increased as the soil became drier or wetter than optimum.

McDowell and Smith (19) agreed that the loss of ammonia from Putnam silt loam was greater from an air-dry soil than from one of optimum moisture content. The loss of ammonia was reduced from 11.7% at 2% moisture to 1.4% at 17% moisture when anhydrous ammonia was applied to a depth of 3 inches with 40-inch row spacings. At a 6-inch depth the loss was reduced from 5.1% on air-dry soil to 0.8% when soil moisture was 17%.

The retention of ammonia under varying soil moisture conditions has lead to some speculation about the interaction or competition of ammonia and water molecules.

Brown and Bartholomew (6) reported that sorption isotherms indicated considerable interaction between ammonia sorption and the moisture levels of clay. At ammonia pressures below 60 to 100 mm Hg, "dry" bentonite and halloysite sorbed more ammonia than comparable moist clays. At higher ammonia pressures, moist clays sorbed more ammonia than "dry clays" with the greatest amount of sorption occuring at the higher moisture levels. There was evidence of competition between aqueous vapor and ammonia for sorption sites on the clays. As ammonia at a high pressure was introduced into a seemingly dry soil, drops resembling water were seen forming near the sample surface, suggesting that ammonia had competed for the water sites.

Parr and Papendick (31) measured the desorption and subsequent retention of ammonia by Edina silt loam and Lakeland fine sand at different moisture levels when aerated with moist air near 100 percent relative humidity. It was evident in all cases that the rate of ammonia desorption early in the aeration period was inversely related to the soil moisture content. Desorption of ammonia from both soils at the lowest moisture level (air-dry) proceeded very rapidly until a characteristic level of ammonia retention was attained, after which the rate became negligible or approached zero. With increasing soil moisture content, the rate of desorption during the early period of aeration became progressively slower. However, with continued aeration soils tended to retain more ammonia when dry than when moist. This would suggest a possible competitive interaction between ammonia and water molecules for specific sorption sites in the soil system.

Other workers (6, 17, 32, 34) found that when only small amounts of water were initially present at the time of ammoniation, it was apparent that a competitive interaction of ammonia and water occurred.

James and Harward (17) found that the ammonia retained by various minerals upon ammoniation was replaced by water under controlled conditions of relative humidity. They postulated that the mutual competition between water and ammonia molecules could be described by the law of mass action.

It can be determined that with increasing moisture content, the zone of initial ammonia concentration becomes more localized for a given rate of application and results in progressively higher ammonia concentrations within this zone. Due to the solvent action of water; however, desorption and subsequent movement of ammonia from the zone of high concentration, such as would exist under field conditions, would probably occur more slowly in moist soils than in dry soils. Even though the zone of high ammonia concentration would exist longer in moist soils, most of the ammonia would ultimately move to regions of lower concentration where sorption and reaction could again occur at available "active sites", unless the ammonia reached the soil surface where it could evaporate with the water.

Parr and Papendick (25) found that under most conditions, soil is capable of retaining at least 1000-2000 ppm of ammonia. It can be concluded that, in general, soil can retain enough ammonia to supply a crop with adequate nitrogen as soon as the equipment is able to travel over the field, provided proper sealing is accomplished.

It may already be apparent that the water content for optimum soil moisture varies with soil texture. For example, a clay soil may adsorb all of the ammonia applied, whereas, a sandy soil under the same conditions would require more moisture to adsorb the same amount of ammonia.

Soil Texture and Ammonia Adsorption

The texture of the soil can affect the retention and distribution of anhydrous ammonia. Textural effects are primarily due to the porosity of the soil, to the specific surface area, and to the cation exchange capacity. It has been observed (16) that most field soils of any texture will retain sufficient quantities of ammonia for high yields of crops when the soil has had the proper tillage to be in good physical condition. However, soil texture is of enough importance to be considered when making recommendations for application rates. Of course, there had been varying experimental results concerning the amount of movement and retention as affected by various soil textures. These variations are likely due to differences in experimental procedure.

McDowell and Smith (19) reported that the loss of ammonia from sandy soils was greater than from air-dry silt loam or clay soils. Their data indicated that the retentive capacity of a soil for ammonia increases greatly as the texture becomes heavier. The losses from an air-dry, calcareous clay was negligible even at the 3-inch depth of application. A loss of 8.8% from an air-dry sandy soil at a 6-inch depth was over 1½ times the loss of 5.1% from a silt loam soil, and was 44 times the loss from a clay soil receiving ammonia at a comparable moisture level and depth.

A sandy soil, which possesses a relatively low cation exchange capacity, may lose as much as 20% of the ammonia applied even though other factors are favorable for adsorption. Blue and Eno (3) in dealing with Coastal Plain sandy soils suggested that losses of ammonia may be great enough to prevent its economical use on these soils with the present methods of application.

In the same field study Blue and Eno reported losses of ammonia on sandy soils at rates as low as 58 pounds of nitrogen per acre when applied at a 5-inch depth and substantial losses of ammonia at 258 pounds of nitrogen. Under the same conditions a lower loss of ammonia was measured with a soil having a higher percentage of moisture and naturally higher losses of ammonia occurred as the rate of nitrogen increased.

Stanley and Smith (33) noted that an increased clay content raised the capacity of a soil to adsorb ammonia. At a 6-inch application depth a sandy soil lost about 14% of the ammonia, whereas, a silt loam lost only 4% of the ammonia applied. A clay soil lost virtually no ammonia. A greater loss from the sandy soils was correlated with the small cation exchange capacity of 4.1 millequivalents (meq) per 100 grams of air-dry soil compared to the higher exchange capacity of 14.5 meq for an equally dry silt loam.

With some contrast to reports of high losses of ammonia from sandy soils, Jackson and Chang (16) observed that a coarse-textured soil (Plainfield sand) retained the gaseous ammonia with about as great efficacy as did a fine-textured soil (Crosby silt loam). This was especially true under moist, neutral conditions. Even in an air-dry condition, this sand contained enough clay and organic matter, approximately 6% and 0.5% respectively, to provide adequate sorption capacity for the ammonia. They concluded that if a soil is of intermediate texture, moisture content, and pH, an application of 60 pounds of nitrogen per acre in the form of anhydrous ammonia at a depth of 2 inches is practically all sorbed instantly and there should be little loss by gaseous diffusion.

Mortland (23) studied the adsorption of ammonia on various adsorbants such as bentonite, kaolinite, and muck which are directly related to different textures and exchange capacities. He found the muck to adsorb the most ammonia and kaolinite the least with bentonite in between. This lends support to the hypothesis that the coarser-textured soil adsorbs less anhydrous ammonia.

The characteristics of a coarse-textured soil can allow the ammonia to diffuse more rapidly because of the porous structure and this will result in a wider retention band. The higher cation exchange capacity and the greater surface area per unit mass of soil afforded by medium- and heavy-textured soils aid in the retention of anhydrous ammonia.

Cation Exchange Capacity and Ammonia Adsorption

When ammonia enters the soil, it reacts with hydrogen to form an ammonium ion (NH_4^+) which has a positive charge. These ammonium ions may replace other cations held on the surface of negatively-charged clay or organic matter particles. Thus, the clay and organic matter particles are primarily responsible for the cation exchange capacity (CEC) of a soil. In general, a soil with a high CEC is able to hold a high quantity of ammonia compared to a soil of low CEC.

Some researchers believe that nearly 50% of the ammonia is held in the organic matter fraction of an average soil. Sohn and Peech (32) destroyed the organic matter in 12 different soils with peroxide. An average of the 12 soils revealed that 48.5% of the ammonia was retained in the organic matter. The amount of adsorption was also directly proportional to the organic matter content.

Brown and Bartholomew (5) claimed that ammonia may be sorbed on clay mineral systems by mechanisms involving physical, chemical, or a combination of physical and chemical forces. When the interaction between ammonia and clay was weak, the mechanism was spoken of as physical adsorption (van der Waals adsorption). Chemisorbed ammonia was believed to be that which had gained a proton and underwent exchange reactions with the exchangable cations and that which had reacted with the weakly dissociated hydroxyl groups of the lattice edges. Their experiment was performed with oven-dry clays which were saturated with ammonia.

Two salient concepts were revealed from this study. One is that dry clays are able to retain adequate amounts of ammonia for plant growth. They noted that 1 meq of ammonia per gram of clay was equivalent to 100 meq of ammonia per 100 grams of clay (CEC) or about 34,000 pounds of ammonia per acre (pure clay). Secondly, basic soils (pH 8-10) are capable of retaining large amounts of anhydrous ammonia and little difference of retention was noted between these pH values.

Mortland (23) made studies on the characteristics of adsorption isotherms of ammonia by clays and mucks. Hydrogen-saturated bentonite adsorbed more ammonia than did that saturated with calcium. Also, the heat of adsorption was high, indicating a strong bond between the ammonia and clay surface. These factors suggest the formation of an ammonium clay.

Young (34) found the retention of ammonia by ammoniated air-dry samples to be approximately 0.7 meq of nitrogen per each meq of soil CEC. In the surface horizons retention of ammonia was roughly 0.3 and 2.6 meq of nitrogen per 100 grams of soil for each percent clay and organic carbon, respectively.

Parr (27) described the effect of glucose and corn stover on the retention of anhydrous ammonia by Webster silty clay loam following 400 hours of desorption. Glucose-ammended soils retained more ammonia than systems receiving corn stover. The application of glucose (one percent, oven-dry soil weight basis) caused a 56 percent increase in ammonia retention by each soil. Where Webster and Hartsells soils were ammended with corn stover just prior to injection, ammonia retention was increased by 35 and 28 percent, respectively. This indicated that freshly incorporated plant residue can substantially increase the ammonia retention capacity of soils, which may have practical application to field situations.

Cation exchange capacity is an extremely important factor in determining the amount of ammonia a particular soil can retain and it is related to the amount of clay and organic matter in the soil. Soils can prevent anhydrous ammonia from volatilizing into the atmosphere by several different retention mechanisms.

Mechanisms of Retention

To get a concept of the retention of ammonia one must be familiar with some of its theoretical retention mechanisms and subsequent transformations in the soil. Immediately upon entrance into the soil the ammonia may be converted to the ammonium ion, held in the soil solution, contained as a gas, or else it may escape into the atmosphere. The applied anhydrous ammonia may eventually be subject to some of the following reactions: ammonification, nitrification and denitrification (24).

The ammonium ion is a result of the ammonia reacting with a hydrogen ion.

$$NH_3 + H^+ \longrightarrow NH_4^+$$

The hydrogen may be obtained from acid clay particles, soil water, or organic compounds.

$$NH_3 + \begin{matrix} HOH \\ H\text{-}CLAY \\ H\text{-}OM \end{matrix} \longrightarrow NH_4^+$$

The ammonium ion is then subject to adsorption, to use by microorganisms and higher plants, or to further chemical reaction. The conversion of ammonia to the ammonium ion may take place prior to the attachment to the clay particle or it may occur simultaneously.

Adsorption of ammonia, which prevents the escape of ammonia molecules into the atmosphere, commonly occurs by adsorption of the positively charged ammonium on the negative sites of the soil colloids.

$$NH_4^+ + \begin{matrix}- \\ -\end{matrix}\boxed{\text{COLLOID}}\begin{matrix}- \\ -\end{matrix} \longrightarrow \begin{matrix}NH_4 \\ NH_4\end{matrix}\boxed{\text{COLLOID}}\begin{matrix}NH_4 \\ NH_4\end{matrix}$$

Cornet (11) and Bushwell (8) agreed that ammonia and hydrogen clay reacted to form ammonium clay.

Bonds for retention range from chemical adsorption reactions to physical adsorption. The chemical adsorption reactions require specific negative sites on the surface of the clay mineral and the bond is electrical in nature.

The physical adsorption process takes place only when there is a positive pressure of ammonia in the soil. This is the attachment of ammonia--not the ammonium ion--around the clay particle.

$$X\ NH_3 + COLLOID \qquad \begin{array}{c} NH_3\ NH_3\quad NH_3\quad NH_3 \\ COLLOID\quad NH_3\ NH_3 \\ H_3N\quad NH_3\quad NH_3 \end{array}$$

As soon as the pressure decreases, the ammonia will desorb and diffuse through the soil for further chemical reaction or perhaps volatilization into the atmosphere (24).

The last method by which ammonia is retained in the soil is fixation. The ammonium ions become fixed within the layers of clay particles and thus become relatively unavailable for other processes.

$$NH_4^+ \qquad NH_4^+$$

internal spaces $\qquad NH_4^+ \qquad$ clay particle

Burge and Broadbent (7) related the fixation of ammonia to organic matter in soils. Ammonia fixation in organic soils was found to be linearly correlated with percent carbon. In the presence of oxygen 1 molecule of ammonia was fixed per 29 atoms of carbon and 1 for every 45 atoms of carbon in the absence of oxygen.

Sohn and Peech (32) concluded that soils with the greatest capacity of sorb ammonia generally fixed the greatest amounts of ammonia because the interlayer fixation of NH_4^+ by clay minerals should increase with an increasing degree of saturation of the clay with NH_4^+ ions.

Other researchers have determined that the amount of ammonia which was fixed in the soil was related to the texture of the soil. Young and McNeal (36) observed that montmorillonite fixed very small quantities of NH_3 or NH_4^+ under wet or air-dry conditions, but showed roughly a 20-fold increase in NH_4^+ fixation resulting from drying at 105°C. Vermiculite minerals under wet or air-dry conditions fixed quantities of NH_4^+ greatly in excess of amounts fixed by other minerals.

Young and Cattani (35) noted that the fixation of anhydrous ammonia varied greatly between soils and between horizons within individual profiles. Values ranged from 6 to 1015 ppm nitrogen which appeared large enough to have possible practical significance in some soils. Mineral fixation of anhydrous ammonia by air-dry samples generally exceeded the wet fixation of nitrogen from aqua ammonia by several fold.

A study by McDowell and Smith (19) lent support to the theory of fixation. They concluded that unrecovered nitrogen in their NH_3 loss investigation was fixed in some form making it nonextractable by the chemical methods used, or else it was changed to other forms of nitrogen, and thus lost as a gas. They also agreed that the amount of ammonia fixed increased with an increasing clay content of the soil. The total of nitrate and ammonium nitrogen retained in the Dexter fine sandy loam was 93.9% of that injected while Putnam silt loam and Huston black clay fixed or lost 19.8% and 27.4%, respectively.

Soil Reactions of Ammonia

Even though some of the ammonia may be fixed by soil, most of it remains in the available form. Metabolic processes within the plant involved in the formation of amino acids and protein require that nitrogen be in the ammonium or amino (NH_2^-) form before it can be utilized; therefore, some of the NH_4^+ is absorbed directly by the roots, especially in younger plants. The amount of ammonia in the soil, which is not fixed or used directly by the plant, is eventually converted to nitrates under normal field conditions (24). The speed of this reaction is dependent upon, among other things, soil temperature and the mechanism of soil retention. Several intermediates

$$\text{Nitrification} \quad NH_4^+ \xrightarrow{\text{Nitrosomonas}} NO_2^- \xrightarrow{\text{Nitrobacter}} NO_3^-$$

are possible during the nitrification process, but one that has been detected is nitrite (NO_2^-). Nitrite can be used by plants, but it is extremely toxic in high concentrations.

Eno and Blue (13) compared the rates of nitrification for anhydrous ammonia, urea, and ammonium sulfate in the laboratory on three acid sandy soils. Anhydrous ammonia stimulated the nitrification process more than equivalent applications of ammonium sulfate in limed and unlimed soil. They concluded that the ammonia raised the pH into a more nearly optimum range for nitrification and that the ammonia initially provided a base for the neutralization of the nitric acid. This effect may also occur in field applications.

Another study by Eno *et al*. (14) showed that at 14- and 28-day measurements, nitrate production increased at levels up to 300 ppm ammonical nitrogen after which it decreased.

Nitrification of ammonia is made possible by two groups of microorganisms from the genus *Nitrosomonas* and *Nitrobacter*. *Nitrosomonas* are tolerant of high pH and thus are able to work around the periphery of the retention zone to oxidize the ammonium to nitrite. This conversion produces conditions which are favorable to the genus *Nitrobacter*, whose organisms are sensitive to high pH and free ammonia. The *Nitrobacter* oxidize the nitrite to nitrate, which the plant may readily utilize. Normally the conversion of nitrite to nitrate is faster than the conversion of ammonium to nitrite so the toxic nitrite exists in the soil for only a short time.

Some of the ammonium nitrogen is used by the soil microorganisms for the production of various proteins necessary for their metabolic activities. These organisms compete with the plants for some of the nitrogen. This competition may cause a deficiency of nitrogen in the higher plants if the microorganisms occur in large numbers. When the organisms die, generally when the crop residues are depleted, the nitrogen in the protein of their cells is gradually converted back to ammonium nitrogen with the aid of other microorganisms by a process called ammonification (24).

$$\text{Protein} \xrightarrow[\text{HOH}]{\text{microorganisms}} NH_3 + \text{organic acid}$$

The purpose of this conversion is to get the nitrogen in a form which is most usable by the plant, namely nitrate nitrogen. The disadvantage of the nitrate form (NO_3^-) of nitrogen is that it may be readily leached by water percolating through the soil because the negatively charged nitrate ions are not electrically held to the negative soil particles.

Another mechanism of nitrogen loss from the soil is via the process of denitrification. Denitrification involves the conversion of nitrate or nitrite to gaseous products which escape into the atmosphere resulting in an overall decrease of nitrogen in the soil.

$$NO_3^- \quad NO_2^- \quad \text{questionable intermediates} \quad N_2O$$
$$NO \qquad\qquad N_2$$

This process is most likely to occur in the absence of oxygen (waterlogged soils). When soils become waterlogged, microorganisms substitute the nitrogen in nitrite and nitrate in place of oxygen as a terminal electron acceptor in their metabolic processes. Neutral to alkaline soils, high temperatures, and large amounts of oxidizable organic matter also enhance this reaction.

Methods and Results of Application

Even though many studies have been done on technical aspects of anhydrous ammonia application, in actual field applications farmers are ultimately concerned with the amount of loss which occurs and the distribution of ammonia in the soil.

The distribution and loss of ammonia are affected by rates of application, space between points of release, and depth of application in relation to the methods of application.

Blue and Eno (3) measured the lateral distribution of ammonia in 1-inch increments from the point of application at a depth of approximately 5 inches. The percent soil moisture was 2.7 for the 58 pound rate and 3.0 for the 258 pound rate. It was apparent that the ammonia was distributed nearer the surface with greater lateral movement from the injection point with the higher application of nitrogen. With the 58 pound rate most of the ammonia extended radially about 1 inch from the point of injection, whereas at the 258 pound application rate the ammonia had a radius of 2 inches. Also, the resulting pH of the soil was found to be directly related to the amount of ammonia present.

McDowell and Smith (19) applied anhydrous ammonia to Putnam silt loam at various depths, spacings, and soil moisture. At 2% soil moisture the loss of ammonia was lowered from 12% to 5% on 40-inch spacings when applied at a depth of 3 and 6 inches, respectively. A similar effect was found with the 16-inch spacing. At the 3-inch depth 4% of the ammonia was lost, whereas at the 6-inch depth only 2% of the ammonia was lost with 2% soil moisture. In all cases much less ammonia was lost generally less than 1%, with 17% soil moisture. An 18.1% loss from an air-dry sandy soil when ammonia was applied at a 3-inch depth suggested that the ammonia should be applied at a greater depth on dry soils of light texture. This study indicates the necessity for closer placement and less concentrated release of ammonia in soils if proper adsorption is to be obtained. In general, losses were reduced by more than 60% when the 40-inch spacing was narrowed to 16 inches.

In a study concerned with the depth of application, Jackson and Chang (16) applied 60 pounds of ammonia to air-dry, cultivated Plainfield sand which was moderately limed. They found a 6% loss of ammonia or about 4 pounds per acre when applied at a depth of 2 inches. They concluded that if the anhydrous ammonia was applied at depths of 1 to 4 inches in the soil, the soil can retain a large amount of ammonia. For best retention the ammonia must come into contact with a considerable amount of soil. They stated that soils could retain at least 600 pounds of nitrogen per acre as NH_3 when it is applied 4 inches deep. Even when anhydrous ammonia was applied on the surface of the soil, over half of it was conserved under some conditions.

Anhydrous ammonia was applied by Baker _et_ _al_. (1) on silt loam soils at various rates up to 260 pounds of nitrogen per acre. The soils had a pH from 5 to 7 with optimum moisture content. Under these conditions ammonia loss from application at a depth of 8 inches was less than 0.1% while at a 4-inch depth loss was still less than 0.5%.

A loss of ammonia may seem apparent when visible vapors are seen emanating from the soil, but this is not necessarily true. In a Cornell study (32) anhydrous ammonia was applied at a rate of 100 lb N/A and the vapor was analyzed only to find no loss. However, at higher rates this "cloud effect" occurs more frequently, which indicates that a loss of ammonia is more likely to occur.

Blue and Eno (3) contended that another indication of ammonia loss to the air was the burned appearance of grass sod along the line of injection from a knife or coulter application. Their experiment showed this burning to be continuous at the high rate and intermittent at the medium rate. The foliage burn occurred near the injector row within a short time after application. Whole plants were not necessarily affected. This eliminated the possibility of root injury or toxicity due to high concentrations of ammonia in the soil. The ammonia burn was not a serious practical factor, but was another positive indication of escaping ammonia.

Parr and Papendick (31) subjected ammoniated soils to continuous aeration with air near 100 percent relative humidity.

They found that the rate of anhydrous ammonia desorption decreased markedly from Edina silt loam when the level of concentration was from 3000 to 3500 ppm and from 1200 to 1800 ppm in Hartsell fine sandy loam. Although the rate of desorption had slowed considerably after 168 hours, it was still measurable after more than 300 hours of aeration, even at the lowest concentration of 1000 ppm in the soil.

Young (34) reported that anhydrous ammonia, which was lost by diffusion and/or water vapor displacement, desorbed for many weeks and while total retention was decreasing, mineral-fixed values were generally increasing.

A linear relationship was observed by Chao and Kroontje (10) between the rate of ammonia applied (up to 600 ppm) and the amount of ammonia volatilized.

There is some controversy as to the amount of ammonia a particular soil can hold. Papendick and Parr (25) found that Edina silt loam retained 2000 ppm after complete aeration of the soil, but noted that many of these discrete numerical values are not dependent only upon soil properties, but also upon experimental procedure. They also found (31) that Hartsells fine sandy loam retained nearly 1000 ppm NH_3-N.

Young and Cattani (35) showed that the retention of ammonia in the soil varied from 770 ppm nitrogen in Walla Walla to 9190 ppm in Tillamook. They also found variation of retention within the individual soil profiles.

Stanley and Smith (33) figured that a 7-inch plow layer of an average silt loam (17 meq CEC)--if completely saturated with adsorbed ammonia--could hold about 5000 pounds of nitrogen provided no other elements were present.

Blue and Eno (3) showed that soils are capable of retaining from 335 to over 4000 ppm of ammonical nitrogen. Of course, the quantity of ammonia held increased with an increase in the cation exchange capacity. Also, the quantity of ammonia held increased with increasing soil moisture. This increase apparently resulted from dissolving ammonia in the soil moisture, since upon drying the amount of ammonia decreased to approximately the same level as where ammonia was applied to soils in the air-dry condition. The Arredondo loamy fine sand (CEC=3 meq) held 893 ppm of ammonium nitrogen at 10% soil moisture by the laboratory procedure employed. On the same soil a field sample with 11% moisture, taken with a 1-inch soil tube in the center of the retention zone and parallel to the injector line at a 115 pound rate. Theoretically, maximum retention values of a soil and the highest concentrations near the line of injection of field applications should be similar. The above values show that the retentive capacity of the soil was approached at the line of injection.

It can be concluded from the reported results that most soils under average conditions are adequate retainers of ammonia.

Other Factors

Some other factors to consider prior to and after an application of anhydrous ammonia are temperature, the effect on soil microbes, and the effect on pH.

Cold soils are able to retain ammonia very well (28), but Sohn and Peech (32) found the uptake of ammonia by mineral soils to decrease upon heating, presumably because of the volatilization of ammonia held by hydrogen bonding and hydrolysis of NH_4^+ held by weakly acidic groups.

Khasawneh and Parr (18) tested thermal changes from ammonia injected into Mountview silt loam. An increase of approximately 11°C was observed at a radial distance of 1.85 cm and progressively smaller changes were recorded with increasing distance from the release point. After 15 minutes most of the heat appeared to have dissipated toward the periphery of the ammonia retention zone.

The temperature effect is not of as much agronomic importance as the effect of ammonia on soil microbes. Parr (27) reported on the recovery of microbial activity subsequent to ammonia application in Webster silty clay loam and Hartsells fine sandy loam. The time elapsed before recovery of activity was dependent on the ammonia concentration applied. With an initial concentration of 1000 ppm of ammonia recovery began after a desorption-incubation period of 25 hours, compared to 125 hours for a 12,500 ppm level. Initially, the anhydrous ammonia caused a marked reduction in the saprophytic population of both soils. Bacteria and actinomycete counts increased during the desorption-incubation period, while numbers of fungi remained very low.

Eno *et al.* (14) observed that the number of fungi and nematodes were reduced by all levels of ammoniacal nitrogen from 136 to 741 ppm. Compared to untreated soil, only 0.6% of the nematodes and 4.9% of the fungi survived when 608 ppm of nitrogen were present in the soil. This level of ammoniacal nitrogen occurs only in the retention zone when ammonia is applied in the field. The largest reduction in both nematodes and fungi occurred above 365 ppm.

In a different study Eno and Blue (12) made a number of observations on the effect of anhydrous ammonia on the microbial population in sandy soils, but concluded that from a total population standpoint, none of the changes noted were likely to permanently disturb the ecological balance in the soil. The changes in the microbial population were found to be noticeable only while high concentrations of ammonia were present and were restricted to a 3-inch zone centered on the injector row.

Soil pH does not affect the retention of ammonia as much as ammonia affects the pH value of the soil. The soils retention capacity for ammonia could be expected to be primarily a function of the exchangeable hydrogen, but Sohn and Peech (32) found this not to be true. Although the original pH values of the soils tested were either equal to or higher than 6.5, the soils possessed fairly high ammonia retention capacities. Even at a pH of 7.32, one soil sorbed 7.02 meq of ammonia per 100 grams of soil, which is equivalent to 1965 pounds of ammonia per two million pounds of soil.

Jackson and Chang (16) applied 60 pounds of ammonia per acre on a Plainfield sand at a depth of 2 inches. When the sand was excessively limed (pH 7.7) about 18% of the ammonia was lost compared to about 6% under moderate liming conditions; however, an increased pH value did not prevent satisfactory retention of gaseous ammonia by the field moist soils when the placement was at a depth of 4 inches.

Eno and Blue (13) found that anhydrous ammonia increased the pH of Leon fine sand from 5.1 initially to 9.6 after ammoniation. Limed Leon fine sand had an initial pH of 7.6 and increased to as high as 9.8 with additions of anhydrous ammonia. The reaction of Klej fine sand increased from pH 5.1 to 8.5 with additions of ammonia in the unlimed soil and from 6.6 to 8.9 in the limed soil.

Papendick and Parr (26) showed that the distribution patterns of ammonia after injection are initially correlated with a marked increase in soil pH. They measured the distribution of ammonia on Hartsells fine sandy loam by the change in pH values. The ammonia distribution pattern after injection into moist soil was oriented towards the soil surface in a tear-shaped pattern perhaps due to the void created by the injection tube. In the case of ammonia injected into air-dry soil, the distribution was more circular around the point of injection.

Parr and Engibous (28) found that in most soils within several hours after the injection of anhydrous ammonia the pH in the center of the retention zone is usually somewhere between 9.5 to 10.0. Twenty-four hours after injection the pH dropped about one unit and then continued to drop more slowly.

At the end of a greenhouse investigation of crop response to ammonium and nitrate nitrogen by Morris and Giddens (22) the pH values of soil receiving the ammonium source were 5.1 and 6.6 for the unlimed and limed soil, respectively, as compared to 5.9 and 7.2 for soils receiving the corresponding nitrate treatments. It was concluded that even though ammonia initially raises the pH in the retention zone, it may eventually have an acidifying effect.

The type and amount of soil minerals and organic matter present, soil moisture, soil texture, method of application, and other soil properties are definitely interrelated in determining the retention and distribution patterns of anhydrous ammonia. When all factors are considered to be optimum, nearly all the ammonia is retained in the soil. Thus, one can conclude that under most field applications at a 6-inch depth practically no ammonia will be lost from the soil.

METHODS AND MATERIALS

Two locations were used in measuring the loss from and distribution of anhydrous ammonia in the soil from undercutting blade applications. The two locations involved radically different soil conditions.

One location was on the KSU North Agronomy farm at Manhattan. This soil was classified as Geary silt loam with a cation exchange value of 15 meq/100 g. The pH before the ammonia application ranged from 5.6 to 5.8 and the soil moisture varied from 15 to 25% throughout the sampling period.

The other location was situated on a light-textured soil at the Ashland Agronomy farm in the Kansas River Valley south of Manhattan. The soil was classified as Cass fine sandy loam with a cation exchange value of 4 meq/100 g. The pH before the application of ammonia ranged from 7.8 to 8.0 and soil moisture varied from 8 to 12 percent throughout the area sampled.

Anhydrous ammonia was applied at the two locations with an undercutting blade. A John Blue Nitrolator was used to regulate the ammonia flow. The ammonia was released into a non-galvanized steel pipe running down each side of the v-shaped blade. Collars with inside threads were welded onto the pipe at 6-inch intervals (Fig. 1). Solid plugs or plugs with an orifice could then be placed in the selected holes to

Figure 1.--Ammonia distribution manifold on undercutting blade. Arrows denote points of ammonia release.

Figure 2.--Ammonia absorption pans in the field.

make several possible distances between the points of ammonia release.

Combinations of the following variables were used at each location in this project.

1. Depth of application - 2" 4"
2. Space between points of release - 6" 16" 40"
3. Rate (lb. N/A) - 50# 100# 200#
4. Orifice size - 2/32" 3/32"

The ammonia was applied in 50-foot strips with each combination of variables selected. A 200 lb N/A rate of application at a 2-inch depth on 40-inch spacing between the points of release was selected at the North Agronomy farm for the first measurements of ammonia retention. When no loss was found under these adverse conditions, other treatments were applied to measure the distribution of ammonia. See Table 1 for the treatments involved at the North Farm and Ashland.

Table 1.--Ammonia application variables at the North Agronomy Farm and the Ashland Agronomy Farm for measurement of loss and distribution patterns.

North Farm			
Treatment	Depth of Applic. inches	Spacing inches	Rate of Applic. lb N/A
1	2	40	100
2	2	40	200
3	2	6	50
4	2	6	100
5	4	6	50
6	4	6	100
7	4	16	50
8	4	16	100
9	2	16	50
10	2	16	100

Table 1 continued

Ashland			
Treatment	Depth of Applic. inches	Spacing inches	Rate of Applic. lb N/A
A	2	6	200
B	2	40	200
C	4	40	200
D	4	6	200

Measuring Ammonia Losses

Pyrex absorption pans with dimensions of 1½" x 8" x 13" were used to absorb escaping ammonia. About ½" of fiberglass insulation was glued to the bottom of each pan. Glass wool could also have been used. The insulation was saturated with 40 ml of 1 N H_2SO_4 to absorb the ammonia lost from the soil. The outside of each absorption pan was sprayed with aluminum paint to reduce temperature effects.

Immediately after making an application of ammonia, absorption pans were inverted over the 6-foot width of application. Soil was mounded around the edges to prevent escape of ammonia from the perimeter of the absorption pans (Fig. 2). Thermometers were placed under the inverted absorption pans to measure the actual temperature and also thermometers were inserted into the soil.

On the silt loam soil the adsorption pans were removed and replaced by another set at 1-hour, 4-hour, and 18-hour periods. When no loss was detected during this time, the last set of plates was left for a total of 7 days. At Ashland the absorption pans were left for 1 day. Again no loss was found so the second set was left for an additional 6 days.

After the 7 days had elapsed, the absorption pans were removed for recovery of the ammonium sulfate, which is the product of the ammonia and sulfuric acid reaction.

First, each absorption pan was soaked with 700 ml of distilled water to dissolve the ammonium salt. This solution was poured into a one liter volumetric flask with the aid of a funnel. Then the adsorption pan was set up in a wash rack for further washing. This solution was added to the contents of the volumetric flask. Lastly, the absorption pan was rinsed with about 100 ml of 0.1 N H_2SO_4 to remove any free ammonia which may be present in the insulation. This solution was also poured into the volumetric flask and the flask was brought to volume.

A 50 ml sample was saved from the flask for later analysis on the micro-Kjeldahl unit, however, only a 5 ml aliquot was used for this analysis of ammonia.

Direct Spray Method of Ammonia Distribution

The procedure used for obtaining photographs of the ammonia distribution in the soil was the direct spray method. In preparation for use of this method in the field, ample soil was removed to expose a smooth, vertical cross-section of the area which included the ammonia retention zone. In this case a pit was dug 72 inches long, 18 inches wide, and 12 inches deep. A cement trowel aided in smoothing the surface of the pit.

Once the face of the pit was smoothed, the surface was moistened with water to aid the action of the indicator. A suspension of calcium carbonate in isopropyl alcohol (a ratio of 9 grams $CaCO_3$ to 20 ml isopropyl alcohol) was then sprayed directly on the retention zone and adjacent areas. Best results were obtained when the calcium carbonate was finely ground so that it remained in suspension more readily. A weed sprayer worked very well in applying this suspension, which was agitated continuously during the application to prevent the calcium carbonate from settling. The alcohol evaporated from the suspension leaving behind a white background.

After allowing several minutes for the alcohol to evaporate, phenol red indicator was sprayed over the approximate location of the ammonia retention zone and the adjacent area. The spray bottle was held 8 to 10 inches from the face of the cross-sectional surface. Where the pH was high enough, a reddish color developed. The diffusion pattern was immediately recorded photographically since the color tended to fade. The above procedure was followed within 10 to 15 minutes after the application of ammonia to assure a good photograph because the pH in the retention zone tended to decrease within an hour after application.

Depending on latent soil pH and the desired color change, a number of different indicators and mixed indicators could be used with this method. Phenol red indicator was quite satisfactory. The phenol red solution was prepared by dissolving 0.1 grams of indicator with 28 ml of 0.01 N NaOH. This solution was then diluted to 250 ml with distilled water.

Measuring the Ammonia Distribution

The same pit was used for quantitative measurement of the distribution as was used in taking photographs of the ammonia distribution by the direct spray method. The calcium carbonate was removed from the surface or else the opposite face of the pit was used in order to prevent a change in the pH measurement.

For ammonia distribution sampling a portable grid was constructed by making a rectangular frame 72 inches long and 12 inches wide (Fig. 3). This grid was placed on the face of the pit. Cores were taken with a 1-inch diameter soil probe on every 2-inch center. The probe was pushed perpendicularly into the face of the pit to a depth of 8 inches. Three horizontal rows were collected. These rows were referred to as 0-2, 2-4, and 4-6 inch depth of samples.

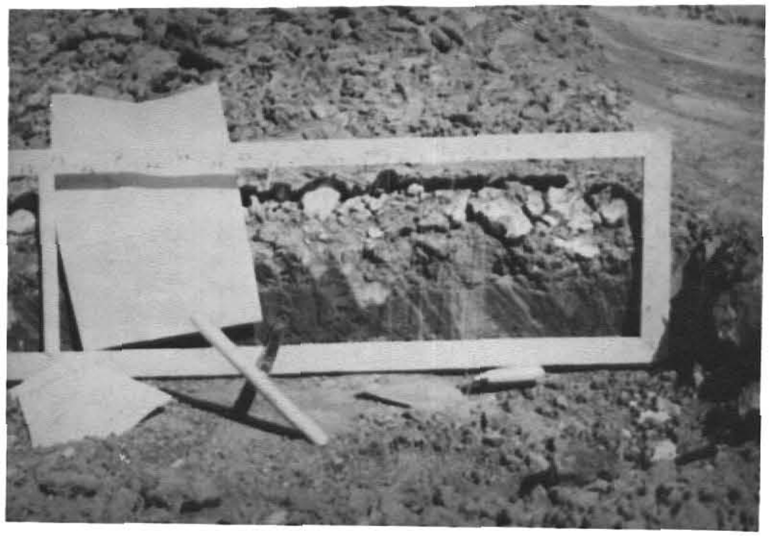
The soil was then placed in soil sample bags. As soon as possible, the samples were placed in a freezer to stop the nitrification process until the ammonia determinations could be made. The ammonia distribution patterns were exhibited by plotting the concentration of each soil core in ppm.

Measuring the pH

A battery-operated, single electrode pH meter was used to determine *in situ* soil pH. The pH readings were taken

Figure 3.--Grid for collection of soil samples across applicator swath.

Figure 4.--Technique for collection of soil samples within and between drill rows.



directly in the field by placing the probe on each 2 x 2 inch grid square and reading the pH value directly off the meter.

However, since this pH meter was not available until the last two treatments, most of the readings were taken in the laboratory. Five grams of soil was placed in a poly-lined souffle cup. Five ml of water were added to each cup with the soil and allowed to set about 30 minutes to assure equilibrium. The pH meter was calibrated with buffers pH 7 and pH 5. The soil was mixed with a stirring rod just before each reading. The electrodes were placed in the solution part of the mixture.

Drying Process

After the ammonia determinations were made and after the 5 g of soil for the pH determination was taken out, the percent moisture was determined so the results could be expressed on a dry weight basis. The soil samples were dried in an oven 24 hours at 100°C. Soil moisture was determined gravimetrically.

Determination of Cation Exchange Capacity of Soils

The cation exchange capacity of the experimental soils was determined by placing a 5 gram sample of the silt loam soil in a 250 ml Erlenmeyer flask. A 10 gram sample was used for the sandy soil. Then 25 ml of 1.0 N ammonium acetate were added to the flask, mixed thoroughly, and allowed to stand for 30 minutes with an occasional swirling. After 30 minutes the flask contents were transferred to Whatman 2 filter paper by washing the Erlenmeyer flask with methyl alcohol. The soil and filter paper were then washed with successive portions of methyl alcohol until the filtrate was free of NH_3. Nessler's solution was used to test the filtrate for ammonia. After the filtrate was free of NH_3, the soil and filter paper were transferred to a 300 ml micro-Kjeldahl flask. Then 0.2 gram of MgO and 20 ml of distilled H_2O were added to the flask. After the addition of MgO and distilled H_2O, the flask was connected to a steam distillation apparatus. The distillate was collected in a 50 ml Erlenmeyer flask containing 10 ml of 2% boric acid-methyl purple indicator solution. After the volume reached 30 ml in the Erlenmeyer flask the contents were titrated with 0.0359 N H_2SO_4. At the end-point the color change was from green to a permanent, faint blue. The results were expressed in milliequivalents of NH_4^+ per 100 grams of soil.

Determination of Ammonium-Nitrogen

Ammonium-nitrogen determinations on soil samples and solutions measuring anhydrous ammonia loss were carried out by the steam distillation method of Bremner (4).

Five ml of 2 percent boric acid-methyl purple indicator solution was added to a 50 ml Erlenmeyer flask marked to indicate a volume of 30 ml and the flask was placed under the condenser of a steam distillation apparatus.

A 5 ml aliquot of the experimental solution was pipetted into a distillation flask. In the case of soil a moist 2 gram sample was placed in a distillation flask and diluted with 15 ml of deionized water. Then 0.2 gram of dry MgO was added to the distillation flask by means of a dry funnel. After the addition of MgO, the distillation flask was attached to the distillation apparatus and distillation was allowed to proceed. After the distillate reached the 30 ml volume mark on the receiver Erlenmeyer flask, the flask was removed from the condenser and ammonium nitrogen in the distillate was determined by titration with 0.0052 N H_2SO_4 from a 5 ml microburette graduated at 0.01 ml intervals. The color change at the end-point is from green to a permanent, faint blue. Blanks of deionized water were determined, subtracted from the sample, and the results were calculated in ppm NH_4^+-N on a dry weight basis.

Comparison of Soil and Plant Nitrogen Concentrations

Wheat plant absorption of soil nitrogen was examined under field conditions to determine which of the established distribution patterns provided the most uniform N uptake. Wheat plots were located in Saline county, McPherson county, Stafford #1 county (cooperator's farm), Stafford #2 county (Sandyland experimental farm), and Kiowa county. Kiowa county and Stafford #2 county were selected for comparison of soil and plant nitrogen concentrations because plant growth differences were evident early in the spring.

Wheat plant tissue and soil samples were taken early in the spring for nitrogen analysis on a silt loam soil (CEC=19.4) in Kiowa county and on a sandy soil (CEC=2.4) at the Stafford

#2 county. These samples were collected across the path of the 6-foot undercutting blade. The wheat drill rows were parallel to the direction of blade travel. Seven rows were included in this width at Stafford County while 8 wheat rows were included at Kiowa county. This difference was due to different spacings between the drill rows.

Approximately 1 foot of each drill row was clipped near the soil surface for analysis. The tissue samples were dried at 55°C for 30 hours, then ground with a Wiley mill using a 20 mesh screen to obtain a homogeneous sample. Total nitrogen content of wheat tissue was determined by the macro-Kjeldahl method.

In order to determine the inorganic nitrogen concentration in the soil, samples were taken within and between each wheat drill row (Fig. 4). The within-soil cores were collected 6 inches deep from the area immediately below the point where the tissue samples were harvested. The between-soil cores were collected to a 6-inch depth between each wheat row across the blade width to construct a profile of the inorganic soil nitrogen content. The soil was dried 48 hours at 80°C, then ground. A 5 g sample was then analyzed for ammonium and nitrate nitrogen by the steam distillation method of Bremner and Keeney (4).

These plant and soil samples were collected approximately 7 months after the preplant applications of anhydrous ammonia on the test plots. The treatments in Table 2 were selected for nitrogen analysis.

Wheat Yields

In addition to determining treatment effects on wheat tissue composition, wheat yields were also measured to determine effects of ammonia placement and rate.

A random complete block design with 4 replications was used at 5 locations. Plots were located in McPherson, Kiowa, Stafford #1 (cooperator's farm), Stafford #2 (Sandyland experimental farm), and Saline counties. The treatments in Table 3 were made for comparing wheat yields.

The ammonia treatments were applied preplant with an undercutting blade. A cooperating farmer planted the plots concurrently with his field using his variety of wheat.

A self-propelled combine was used to harvest the grain from 12' x 50' plots. Only the center 6 feet of each plot was harvested. The combine ran for a 30-second cleaning period between each plot. The yields were reported at 12.5 percent moisture. An analysis of variance and least significant difference were calculated to determine differences of wheat yields. Test weight and protein were included in the analysis.

Table 2.--Ammonia treatments selected for correlation of plant nitrogen content with soil nitrogen concentration at a Kiowa county site and the Stafford #2 county site (Sandyland experimental farm).

Lb N/A	Spacing between points of ammonia release
0	0
50	6
50	16
50	40
100	40

Table 3.--Ammonia treatments applied at five Kansas locations to measure differences in wheat yields.

Lb N/A	Spacing between points of ammonia release
0	0
25	40
50	40
75	40
100	40
25	16
50	16
75	16
100	16
25	6
50	6
75	6
100	6

RESULTS AND DISCUSSION

Ammonia Losses from Blade Applications

North Agronomy Farm

Absorption pan measurements of ammonia losses from blade applications of ammonia indicated only small amounts of volatilization. No anhydrous ammonia loss was detected from applications to a Geary silt loam soil (CEC=15 meq). Two applications were made to measure the loss. Initial application variables were selected for combinations which would provide the best possible conditions for loss to occur. If no losses occurred under the adverse conditions, it was theorized that losses would be unlikely to occur under more favorable conditions for retention.

The first application was at a 2-inch depth, 40-inch spacing at the rate of 100 lb N/A. This combination concentrated a large amount of ammonia in the soil around the 40-inch retention centers. No measurable loss was found at the 100 lb N rate. A 200 lb N/A application was carried out 2 inches below the soil surface with a 40-inch spacing between the points of release. A trace of ammonia was lost from the soil with this combination, but the loss was less than 1 lb N/A.

These applications were conducted with optimum soil moisture and good soil tilth both of which aided in the retention of ammonia in this soil. The moderately high CEC of this soil apparently provided adequate adsorption sites for ammonia retention at the shallow depth of release.

In comparison, Stanley and Smith (33) applied ammonia at a 3-inch depth and reported a loss of 12% on a silt loam soil while a clay soil lost less than 2% ammonia. McDowell and Smith (19) reported a loss of 5.1% on silt loam soil and very little on a clay soil at a 6-inch depth, however, they employed different application methods.

Ashland

The ammonia loss experiment conducted on the Geary silt loam was repeated on a soil with a CEC of 4 meq (Cass fine sandy loam) at the Ashland Agronomy farm near Manhattan. The applications in Table 4 were included at the Ashland site.

Table 4.--Ammonia losses from a Cass fine sandy loam at the Ashland Agronomy farm - Riley County

Treatment	Depth	Spacing	Rate (N/A)	Loss (lb N/A)
A	2 inches	6 inches	200	13.0
B	2 "	40 "	200	12.8
C	4 "	40 "	200	14.4
D	4 "	6 "	200	1.2

In treatment A the plates were removed 24 hours after application, but no loss had occurred during this time period. After 7 days of collection, treatment A induced volatilization of 13.0 lb N/A. This suggested that the ammonia did not escape immediately, but moved slowly upward.

A pit was dug in the area of treatment A shortly after the time of application to measure NH_3 distribution in the soil. The odor of free ammonia was detected in the retention zone which was evidence that the ammonia was not adsorbed immediately at the 200 lb N rate. Apparently, there were insufficient exchange sites available for all the ammonia to be absorbed before it had risen to the soil surface.

Treatment B produced volatilization losses of 12.8 lb N/A during a 7 day period after the time of application. The 2-inch depth of application was too shallow for 200 lb N/A to contact a sufficient number of adsorption sites particularly with the high concentration of ammonia created by the wide spacing between points of release.

Treatment C, which was applied at a depth of 4 inches, still lost 14.4 lb N/A with the 40-inch spacing. All the preceeding ammonia losses on the Cass fine sandy loam had similar values. This suggests that there may be a maximum (threshold) concentration of ammonia that a soil can retain. Once the soil had its colloids saturated with ammonia, the remaining ammonia was then subject to upward movement thru the soil into the atmosphere.

Parr and Papendick (31) found the retention of ammonia by Hartsells fine sandy loam after desorption to be around 1000 ppm NH_4^+-N, whereas Edina silt loam retained over 2500 ppm NH_4^+-N.

The concentration of ammonia in the retention zone of treatments A, B, and C was measured at 1000 ppm NH_4^+-N or greater in some soil cores (Appendix Tables 11, 12, 13). Since the threshold concentration was probably exceeded, the excess ammonia either diffused from the retention zone to more colloids or was lost to the atmosphere. Theoretically, a soil with a CEC of 4 meq could adsorb 560 ppm or 1120 lb N/AFS (14 mg/meq x 4 meq = 56 mg N/100 g soil = 56,000 micrograms/100 g = 560 ppm N).

Treatment D produced minute losses of only 1.2 lb N/A. The 6-inch spacings between release points distributed the ammonia evenly so the threshold concentration of ammonia was not reached in the retention zones. The highest soil concentration of ammonia recorded for treatment D was 483 ppm (Appendix Table 14). Another reason that losses were lower with treatment D compared to treatment A was because of the increased depth of application (4 inches) in the case of treatment D. This allowed the ammonia to come into contact with more soil and consequently more adsorption sites.

These results agree with those of McDowell and Smith (19) who reported an 8.8% loss of ammonia on an air-dry soil.

Stanley and Smith (33) noted a 14% loss of ammonia on a sandy soil when applied at a depth of 6 inches.

Blue and Eno (3) concluded that soils with a relatively low CEC may lose as much as 20% of the applied ammonia even though other factors are favorable for adsorption.

Young (34) found the retention of ammonia by air-dry samples to be approximately 0.7 meq of N per each meq of soil CEC.

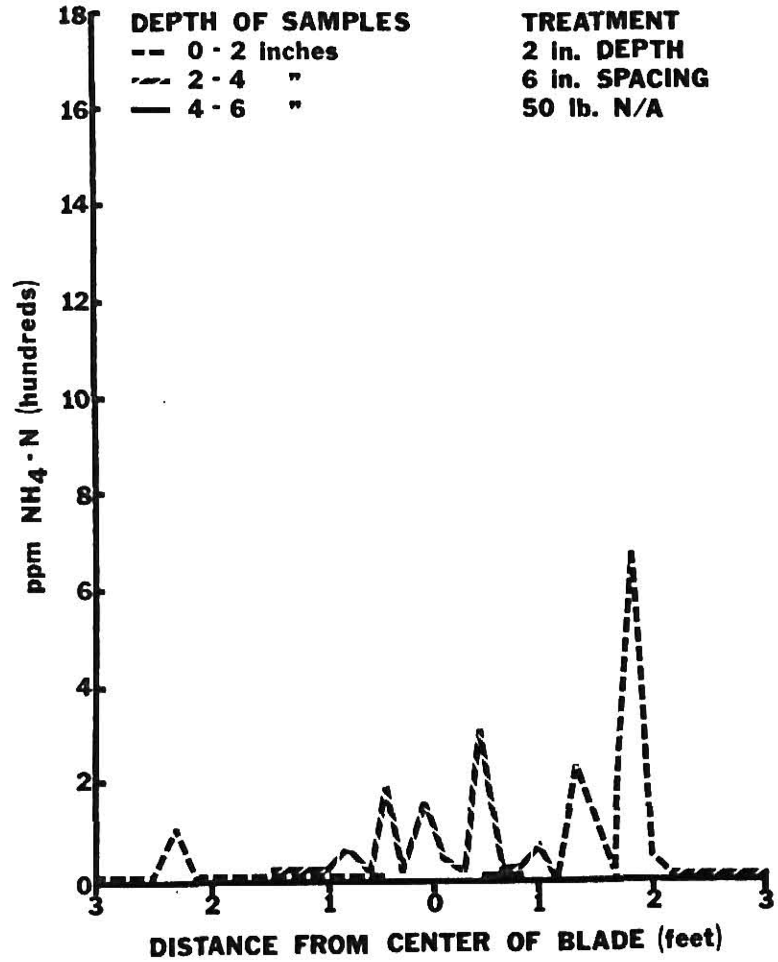
Effect of Rate of Application on Ammonia Distribution

Rate of application had a definite effect on the distribution of ammonia with the system used in this study. Early in the investigation it was determined that a positive pressure was necessary in the delivery manifold in order for the ammonia to be discharged evenly from all release points. However, at low rates using several release points, a positive pressure was not formed in the distribution line as indicated by a pressure gauge.

A 50 lb N application with 6-inch spacings produced an undesirable distribution on the silt loam soil while using a 3/32 inch orifice (Fig. 5). The concentration of ammonia at each release point was variable. Even though some of the orifices delivered more ammonia than others, ammonia was found in small concentrations across the blade width.

Another uneven distribution pattern was noted with a 50 lb N application at a 2-inch depth and 16-inch spacing (Fig. 6). The two peaks left of center were considerably higher than the peaks right of center at the 50 lb rate. Increasing the rate to 100 lb N/A with the same spacing resulted in more uniform peaks at approximately 300 ppm NH_4^+-N. Apparently the ammonia tended to move laterally to a total width of 12 inches compared to an 8-inch width at the 50

Figure 5.--Ammonia distribution patterns produced by a 50 lb N rate applied on a Geary silt loam using a 6-inch spacing between ammonia release points - Riley County.


DEPTH OF SAMPLES
-- 0 - 2 inches
2 - 4 "
— 4 - 6 "
TREATMENT
2 in. DEPTH
6 in. SPACING
50 lb. N/A
ppm NH_4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

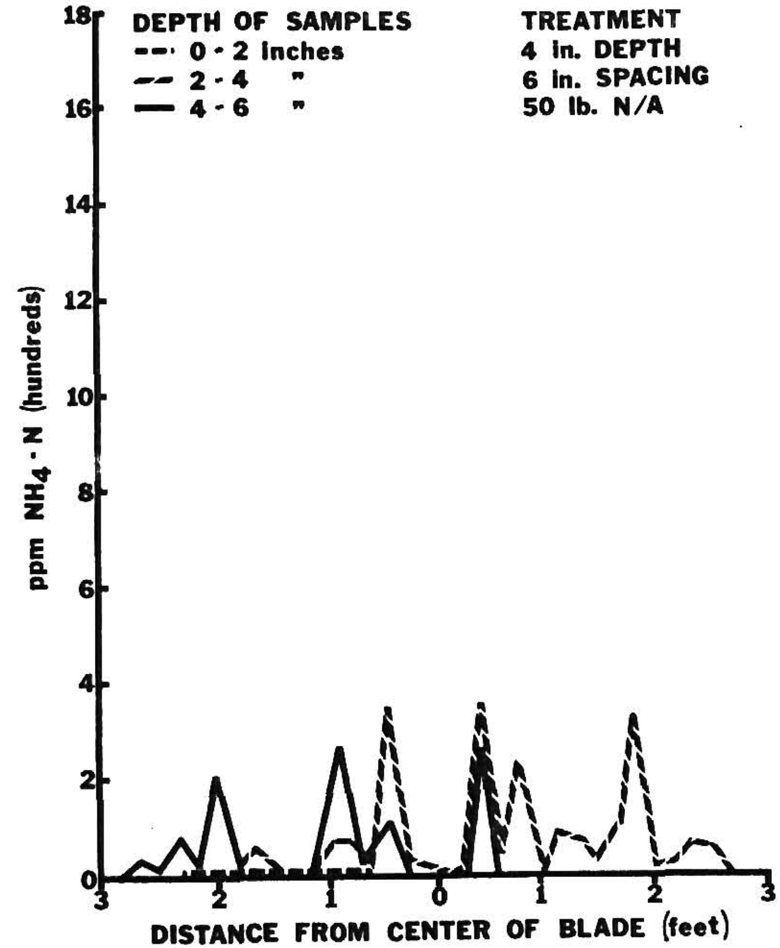
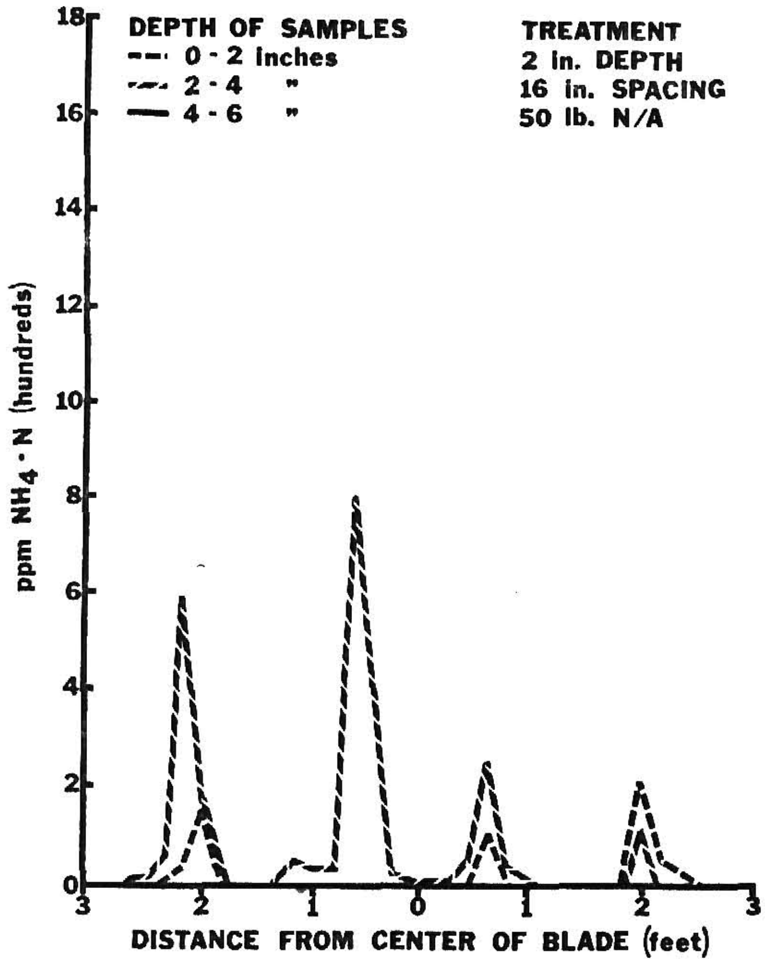
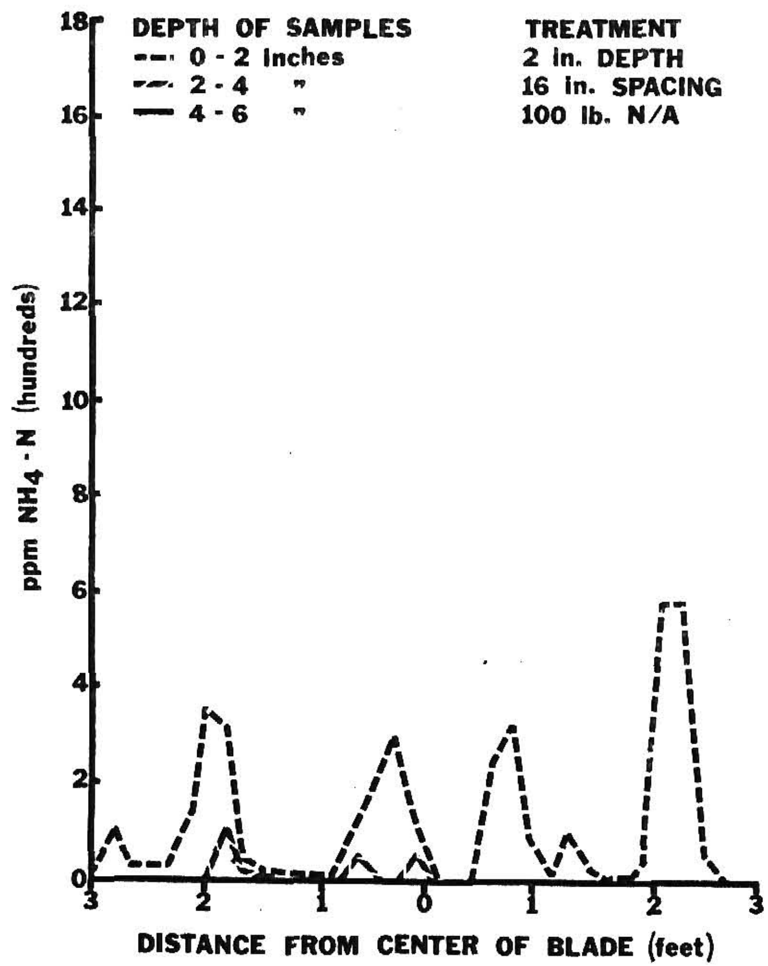

DEPTH OF SAMPLES
-- 0 - 2 inches
2 - 4 "
— 4 - 6 "
TREATMENT
4 in. DEPTH
6 in. SPACING
50 lb. N/A
ppm NH_4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

Figure 6.--Effect of rate of nitrogen application on the distribution of ammonia in a Geary silt loam - Riley County.


DEPTH OF SAMPLES
0 - 2 Inches
2 - 4 "
4 - 6 "
TREATMENT
2 In. DEPTH
16 In. SPACING
50 lb. N/A
ppm NH4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)

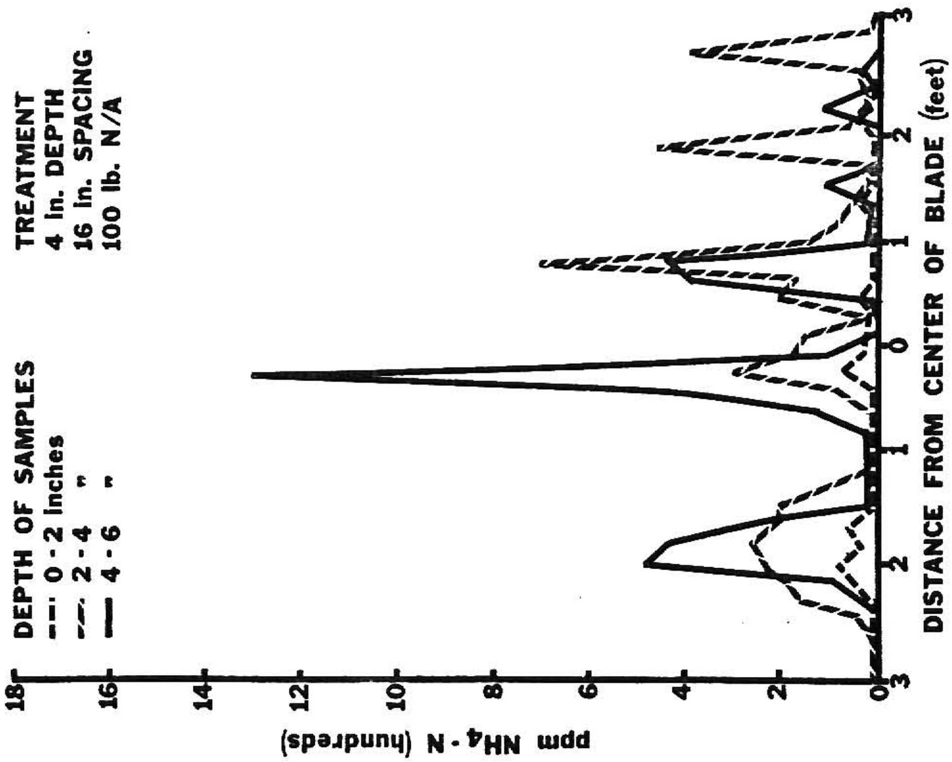

DEPTH OF SAMPLES
0 - 2 Inches
2 - 4 "
4 - 6 "
TREATMENT
2 In. DEPTH
16 In. SPACING
100 lb. N/A
ppm NH4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)

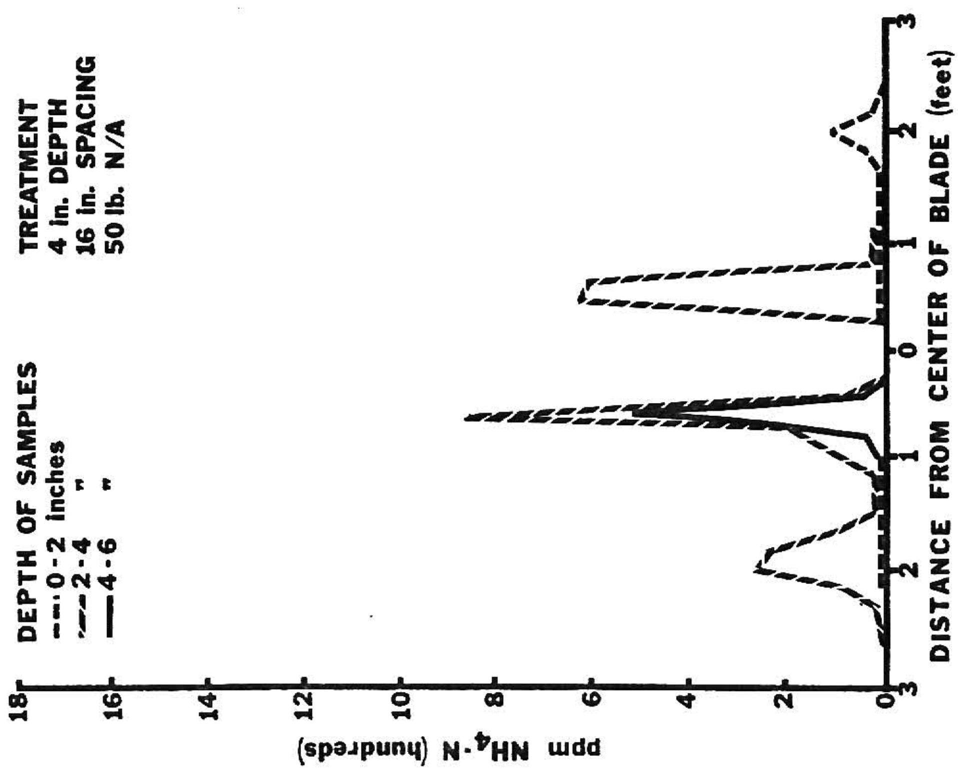
lb N rate. Greater lateral movement would make the ammonia supply more available to plants. The peaks less than 100 ppm ammonium nitrogen at the 100 lb rate may have been caused by ammonia leakage around the solid plugs placed in the distribution line. A slight leakage was evident around the plugs when the applicator was out of the soil.

At the same location, similar distribution patterns occurred at the 4-inch application depth (Fig. 7). At a 50 lb N/A rate the inside peaks were higher than the two outside peaks. This was probably due to a low line pressure. A pressure in the distribution line was difficult to maintain in some cases since ammonia was able to be released faster than it was being supplied because of a large orifice size, too many orifices, or a low nitrogen rate. The ammonia probably flowed out the points of least resistance and in this treatment it happened to be the two points nearest the center of the blade. Most of the ammonia was retained 2-4 inches below the soil surface.

By increasing the rate of application from 50 lb to 100 lb N/A the concentration of ammonia at the retention points increased. Also noticeable was an extra peak on the extreme right. The only explanation for this phenomenon is the possibility of ammonia leakage around the right plug. The lateral distribution of ammonia across the blade path was improved at the 100 lb rate. The ammonia was concentrated in both the 2-4 and the 4-6 in horizontal sampling depths.

Figure 7.--Ammonia distribution patterns produced from varying rates applied at a depth of 4 inches in a Geary silt loam soil - Riley County.


TREATMENT
4 in. DEPTH
16 in. SPACING
100 lb. N/A
DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
ppm NH4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)


TREATMENT
4 in. DEPTH
16 in. SPACING
50 lb. N/A
DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
ppm NH4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

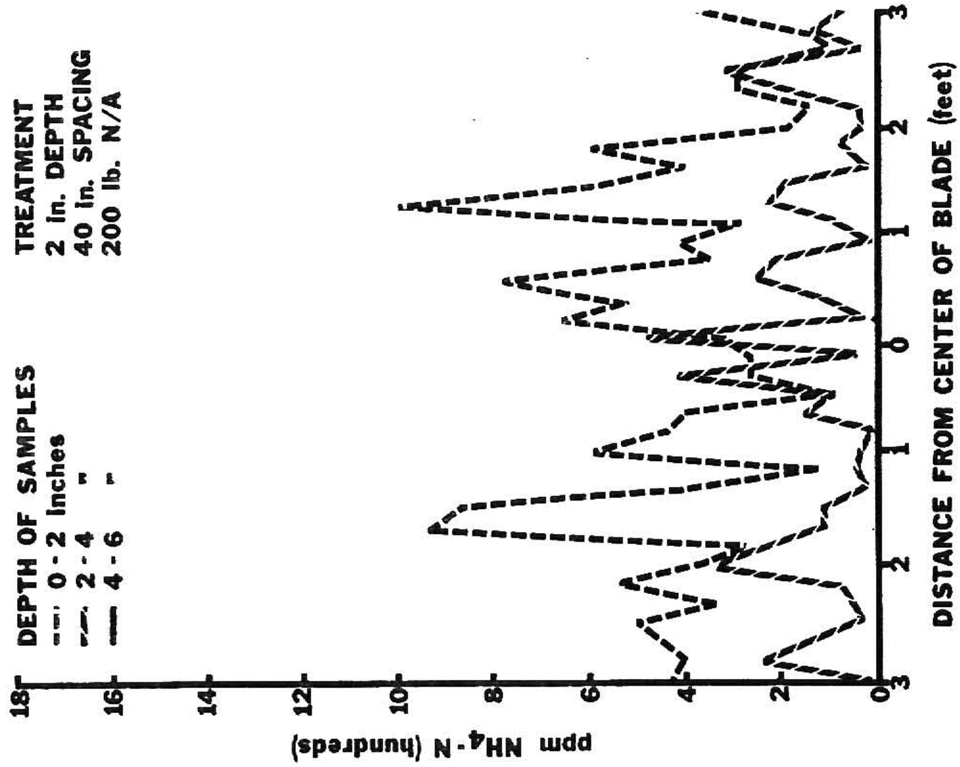
Thus far 6-inch and 16-inch spacings have been considered in the Geary silt loam soil. Figure 8 compares 100 and 200 lb/A N applications applied with 40-inch spacings between points of release. When 100 lb N/A was applied at a 2-inch depth, nearly all the ammonia was concentrated in the area from 0-2 inches below the soil surface. Two distinct levels of high concentration (500 ppm ammonium nitrogen) can be observed with the lateral movement of 5 inches each side of the release point. If a cross-sectional view were taken of this distribution pattern, an oval-shaped pattern with the dimensions 2 inches high by 10 inches wide would be seen.

Knifed ammonia applications reported by Blue and Eno (3) indicated a circular retention pattern with a 4- to 8-inch diameter depending upon soil conditions and also wider retention bands were a result of higher N rates. In the laboratory Parr and Engibous (28) agreed that a round pattern was formed, especially in dry soils.

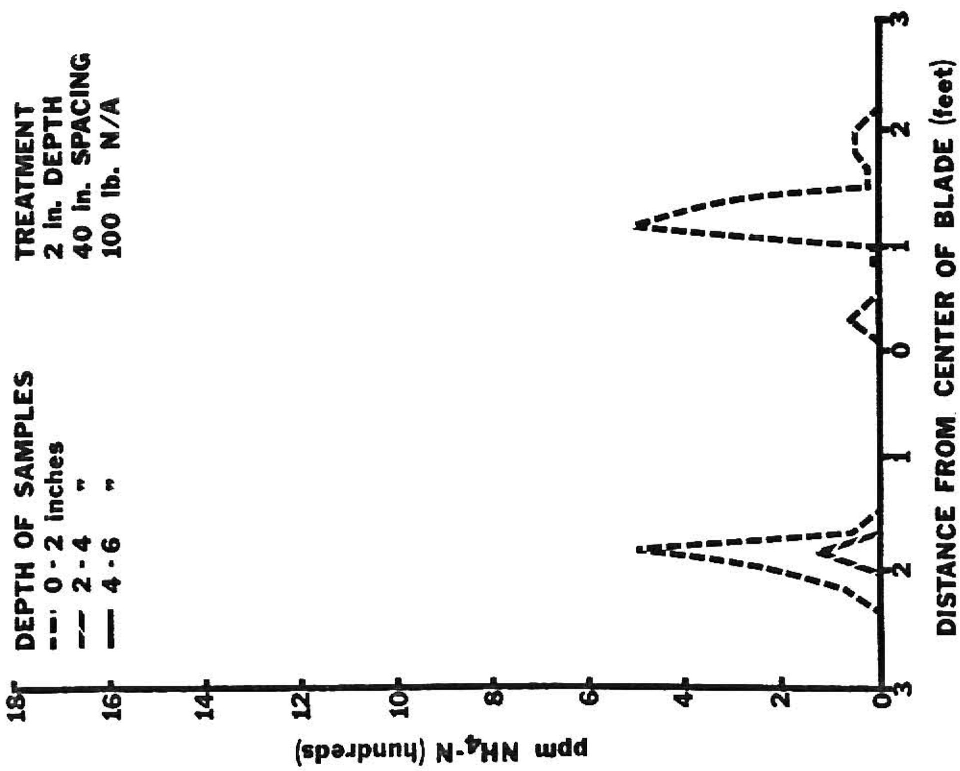
The oval-shaped pattern found in this study suggested that a "draft effect" was produced by the blade thus allowing some lateral movement of the ammonia, but not across the entire width of the blade.

Increasing the rate to 200 lb N/A produced an entirely different situation on the Geary silt loam. Two peaks approaching 1000 ppm NH_4^+-N were detected, but ammonia was dispersed across the entire width of the blade. This closely resembles the distribution exhibited by the 6-inch spacing. The only explanation that can be offered is that ample pressure

Figure 8.--Effect of 100 lb and 200 lb N/A on ammonia distribution patterns in a Geary silt loam soil - Riley County.



DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
40 in. SPACING
200 lb. N/A
ppm NH_4-N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)



DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
40 in. SPACING
100 lb. N/A
ppm NH_4-N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

was created by this high rate to force the ammonia through the porous friable soil mass as it flowed over the surface of the blade. This phenomenon was not observed on a sandy soil at the 200 lb N rate.

Effect of Spacing Between Points of Release on Ammonia Retention Patterns

When 100 lb of N/A was applied at a depth of 2 inches in the Geary silt loam soil, the 6-, 16-, and 40-inch spacings between release points produced different distribution patterns. The concentration of ammonia at the points of release generally ranged from 300 to 500 ppm NH_4^+-N with these three treatments.

The two ammonia release points of the 40-inch spacing can be seen in the top photograph of Figure 9. Compare this release pattern with the left chart of Figure 10. With the 40-inch spacing two peaks approached 500 ppm ammonium nitrogen. These peaks were uniform in height and were about 8 inches wide at the base. They occurred about 40 inches apart corresponding to the release pattern. When this spacing was used for field applications, it subsequently produced a "wavy effect" in test plots of wheat.

Ammonia released by the undercutting blade with 6-inch spacing between release points can be seen in the bottom photograph of Figure 9. At the 100 lb N rate the 6-inch spacing produced a uniform distribution of ammonia across the blade path. The phenol red indicator of the direct spray

Figure 9.--Ammonia release patterns from an undercutting blade with release points spaced at 40, 16, and 6 inches (Top to bottom).

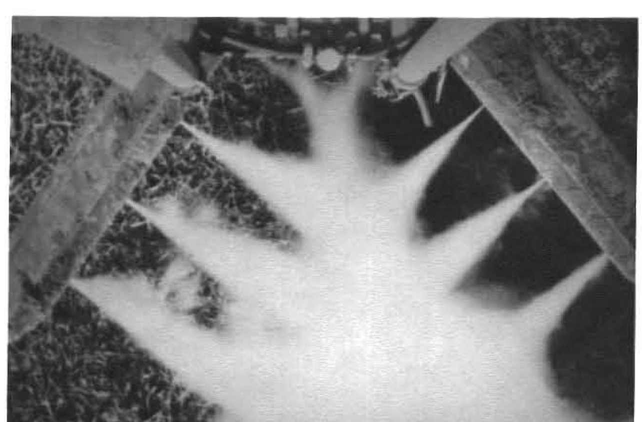
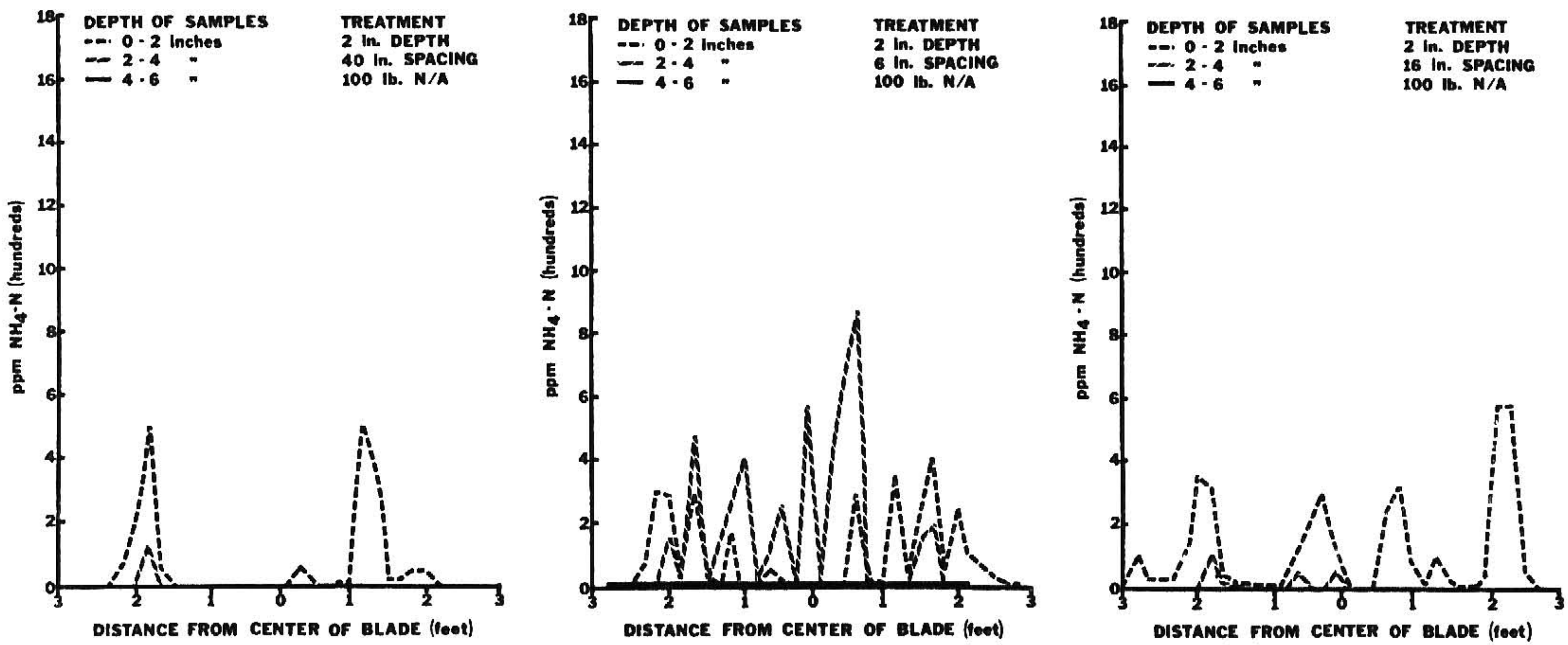


Figure 10.--Effects of release point spacings on ammonia distribution patterns in a Geary silt loam - Riley county.


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
40 in. SPACING
100 lb. N/A
ppm NH4-N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)
DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
6 in. SPACING
100 lb. N/A
ppm NH4-N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)
DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
16 in. SPACING
100 lb. N/A
ppm NH4-N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)

method showed the distribution pattern as demonstrated in Figure 11. A high concentration of ammonia must be present for the indicator to change color. This distribution pattern provided adequate nitrogen to the root zone for an even growth of wheat. Also, test plots of wheat plants showed greatly improved growth when compared to no treatment.

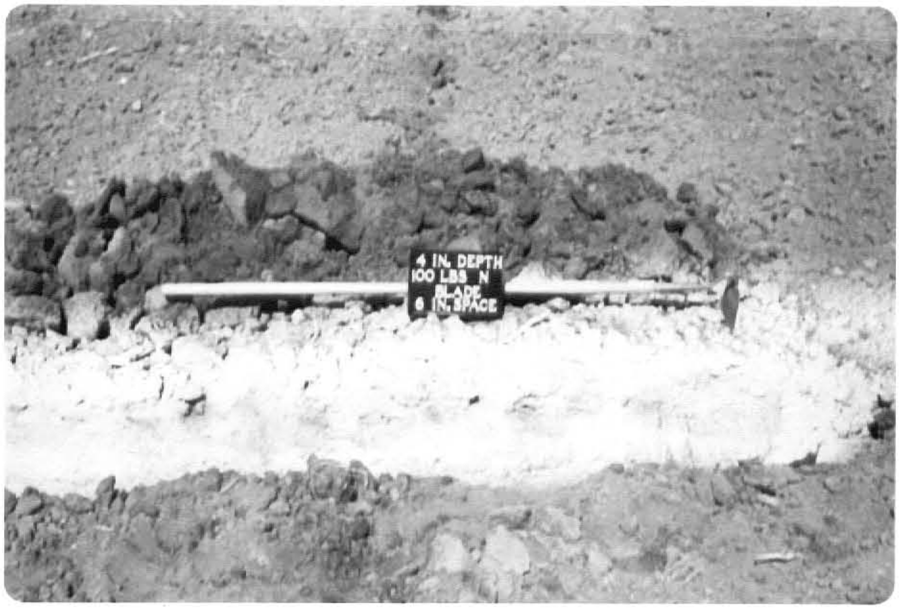
A 16-inch spacing released the ammonia at 4 points (Fig. 9). A photograph showing the half of the distribution left of center can be seen in Figure 12. This photograph indicates two points of high ammonia concentration left of center which are confirmed by the curve in Figure 10. Ammonia analysis of the soil samples indicated a total of 4 points of ammonia concentration higher than 300 ppm ammonium nitrogen corresponding to the release points. The ammonia was dispersed 4 inches right and left of the release point to form an eliptical pattern about 2 inches high. A good wheat response was evident with the 16-inch spacing in test plots.

Visual comparisons of wheat growth in test plots revealed that the 16-inch spacing produced as good of crop response as did the 6-inch spacing. The 40-inch spacing, however, exhibited uneven crop growth from ammonia applications.

Ammonia applications of 200 lb N/A on a Cass fine sandy loam soil produced much the same type of results as reported in the preceeding spacing data (Fig. 13). The 40-inch spacing at the 4-inch application depth gave two distinct points of release, but each retention zone was wider and had a higher concentration of ammonia than did the 100 lb N rate. A

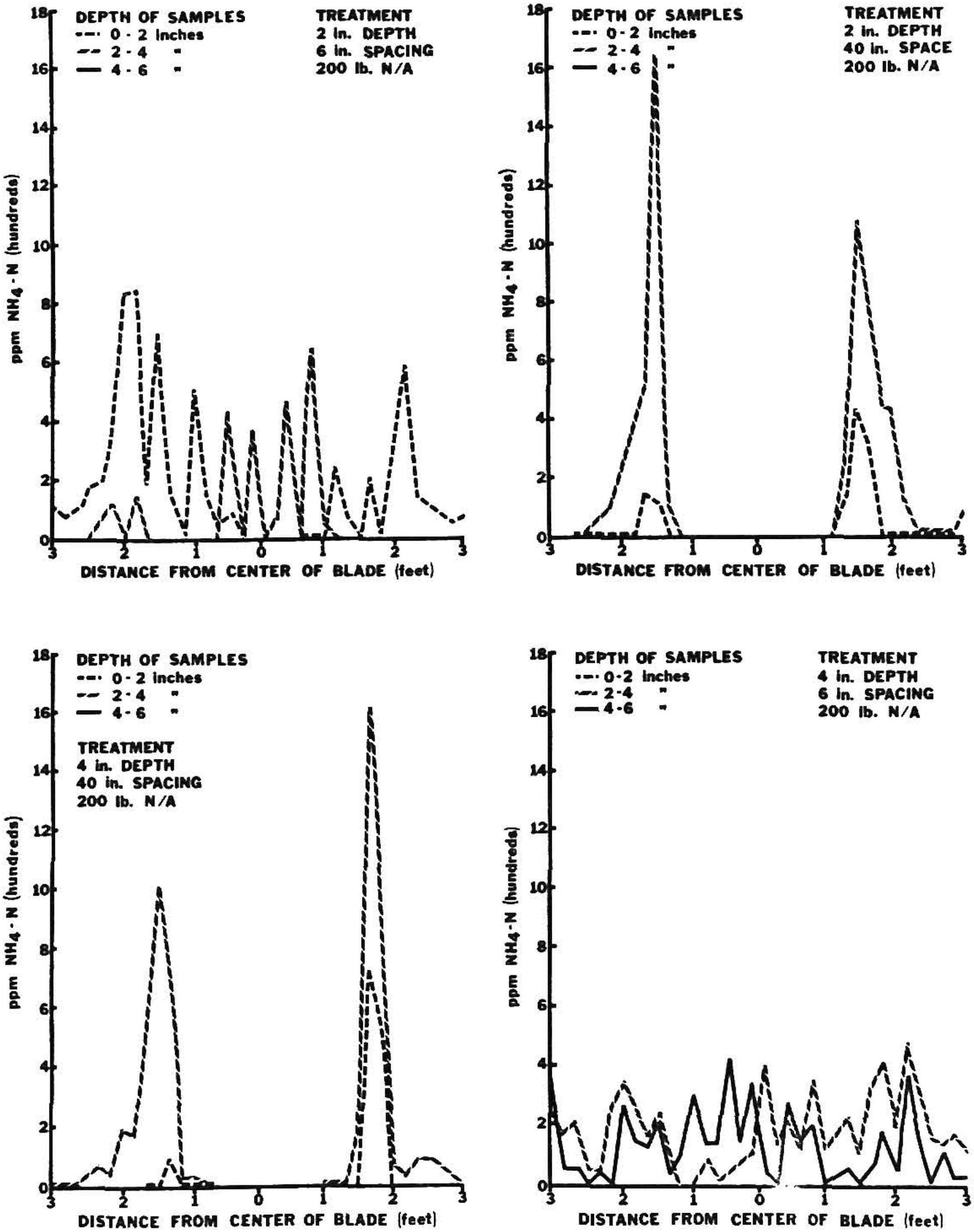
Figure 11.--Direct spray method for determination of ammonia retention patterns in the field. Ammonia was released at 6-inch intervals.

Figure 12.--Ammonia retention patterns produced by release at 16-inch intervals. Reddish areas correspond to points of high ammonia concentration.


4 IN. DEPTH
100 LBS N
BLADE
6 IN. SPACE


4 IN. DEPTH
100 LBS N
BLADE
16 IN. SPACE

Figure 13.--Effects of depth of application and release point spacing on ammonia distribution in a Cass fine sandy loam - Riley county.



DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
6 in. SPACING
200 lb. N/A
ppm NH4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)
DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
40 in. SPACE
200 lb. N/A
ppm NH4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)
DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
4 in. DEPTH
40 in. SPACING
200 lb. N/A
ppm NH4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)
DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
4 in. DEPTH
6 in. SPACING
200 lb. N/A
ppm NH4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)

2-inch application depth produced a similar pattern. Ammonia concentrations at the release points exceeded 1000 ppm and one approached 1600 ppm NH_4^+-N. Total lateral movement was about 18 inches. The 40-inch spacing at this 200 lb rate could provide an adequate distribution of nitrogen for crop growth on this sandy soil. The 6-inch spacing, however, yielded an excellent distribution of ammonia across the entire width of the blade.

Effect of Orifice Size on Ammonia Distribution

As was previously implied, a uniform distribution pattern requires a backpressure in the distribution line. In order to form a backpressure, sufficient resistance must be placed in the flow beyond the metering device by the use of a small orifice. These orifices were made by drilling a hole in a solid steel plug and then tapping this plug directly into the distribution line. Initially, the correct orifice size was determined by trial and error.

A 3/32 inch orifice was tried first. This worked well when there were only two release points, i.e. on the 40-inch spacing. However, when closer spacings of 6- and 16-inches were used, the ammonia was not uniformly dispersed from all release points. This was especially true at rates below 100 lb N/A (Fig. 5 and 6).

The next orifice size used was 2/32 inch. This size was slightly better than the 3/32 inch orifice. At the 50 lb N rate this orifice was still not small enough to produce the desirable distribution. A 2/32 inch drill bit was the smallest available, so this orifice was accepted for use. If this method of application were to be used for practical applications, further investigation concerning orifice size would certainly be desirable.

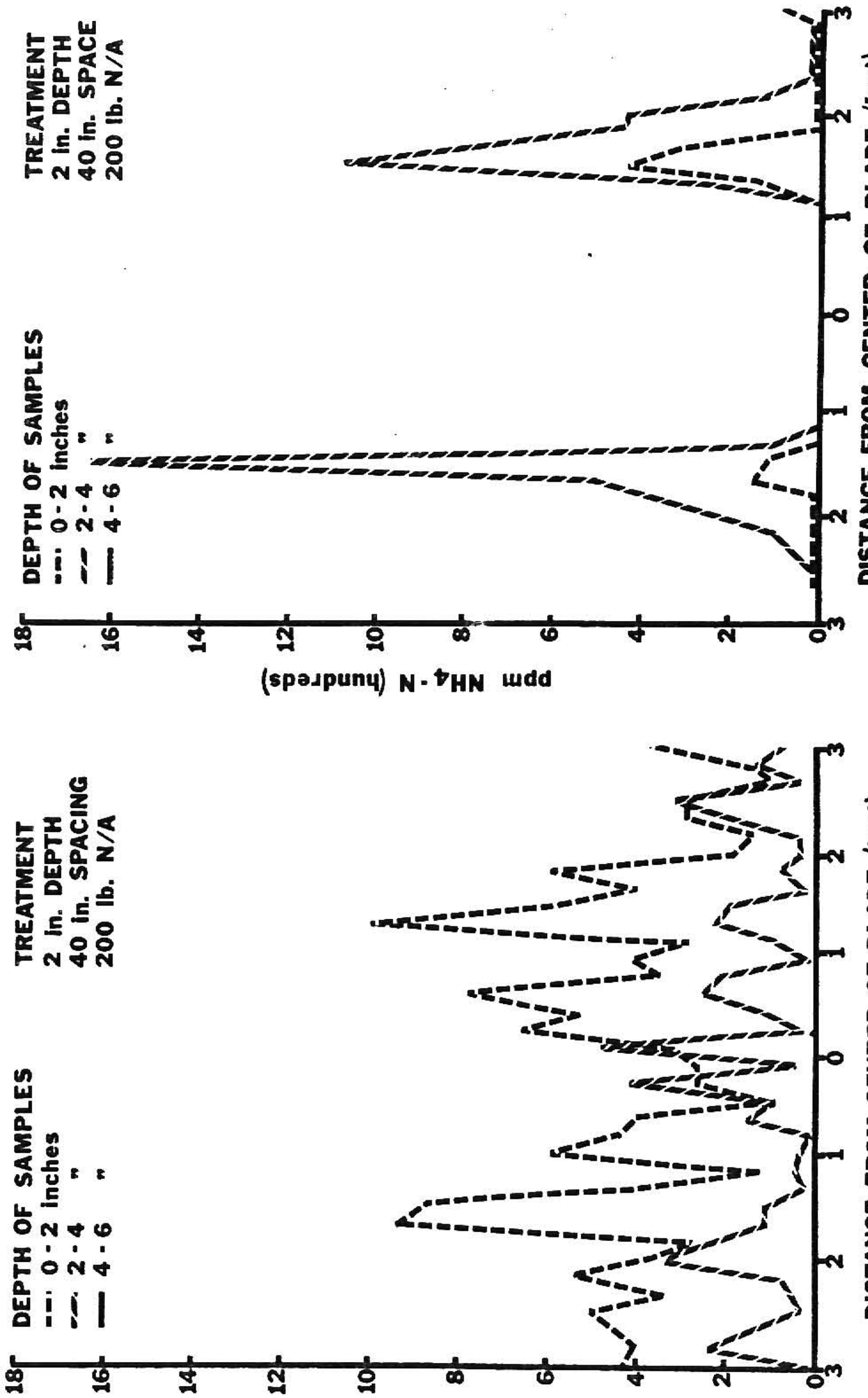
Effect of Soil Texture on Ammonia Distribution Patterns

Three factors are important in forming a distribution pattern in a given soil texture. The cation exchange capacity is an inherent quality that restricts the amount of ammonia 100 g of soil can retain. Soil moisture is interrelated with soil texture. For example, a sandy soil requires less moisture to be in optimum condition than a clay soil. Lastly, the porosity of the soil influences the movement of ammonia through the soil.

In order to determine the effects of soil texture on ammonia retention patterns, application depth, spacing between release points, and rate variables were held constant at 2 inches, 40 inches, and 200 lb N, respectively.

Anhydrous ammonia was applied to a Cass fine sandy loam soil (CEC=4 meq) and a Geary silt loam soil (CEC=15 meq). The retention pattern for the silt loam is dipicted on the left of Figure 14 while that for the fine sandy loam is on the right. With a 40-inch spacing there are two high concentration peaks corresponding to the two points of release with each soil.

Figure 14.--Comparison of ammonia retention patterns in a Geary silt loam (left) and a Cass fine sandy loam (right).


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
40 in. SPACE
200 lb. N/A
ppm NH4-N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)
DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
40 in. SPACING
200 lb. N/A
ppm NH4-N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)

Applications on a silt loam soil resulted in lateral movement of ammonia across the entire width of the blade. This was the only rate with a 40-inch spacing that yielded this type of distribution. The ammonia was retained primarily in the 0-2 inch layer, however, some did penetrate the 2-4 inch layer. The two peaks approached 100 ppm ammonium nitrogen. Distribution appeared to be good on this soil texture at the 200 lb N rate.

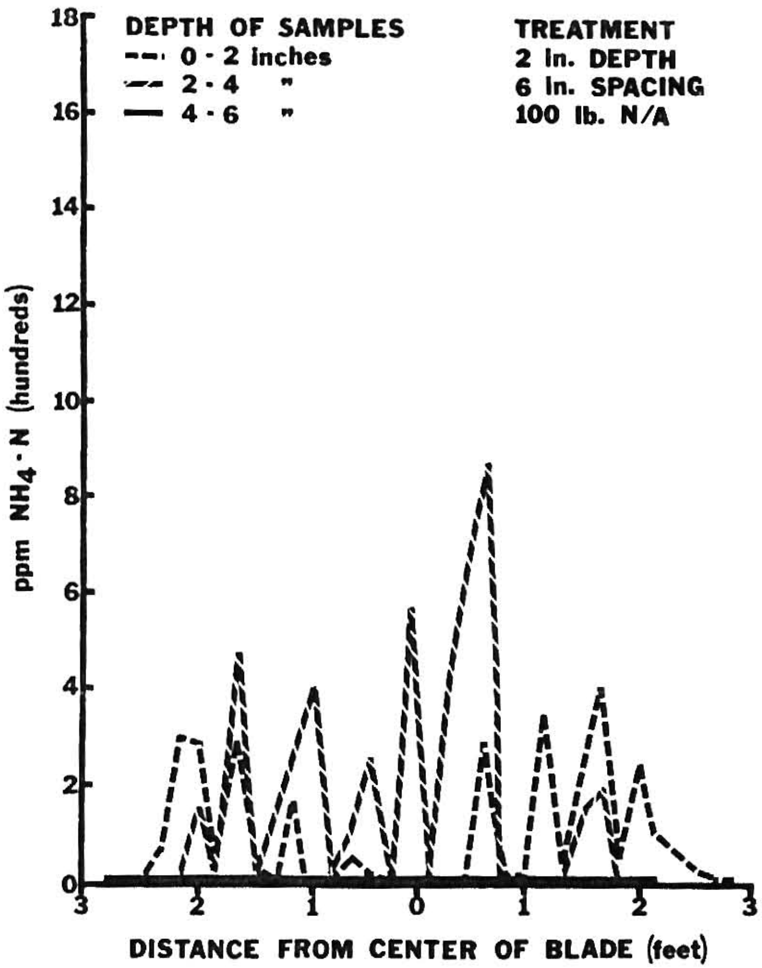
In the sandy soil the retention peaks were higher, but the lateral movement was limited to about 16 inches. It appears that the sandy soil restricted lateral movement more than the silt loam soil under these conditions, thus a higher concentration of ammonia was present in the retention zone. Perhaps the silt loam soil was impermeable enough to form a pressure, hence forcing the ammonia through the friable soil across the width of the blade, while the porosity of the sand allowed the pressure to be exhausted before the ammonia moved across the blade.

<u>Effect of Application Depth on Ammonia Distribution</u>

Depth of ammonia application does not appreciably affect ammonia distribution, but could be an important consideration in halting ammonia escape from the soil. Several treatments were made in this research varying only the depth of application primarily to measure the loss of ammonia.

Ammonia was generally retained within the horizontal level where the ammonia was applied (Fig. 15, 16, 17, 18, 19).

Figure 15.--Effect of application depth on ammonia retention patterns in a Geary silt loam (100 lb N/A, 6 inch spacing).


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 In. DEPTH
6 In. SPACING
100 lb. N/A
ppm NH_4 - N (hundreds)
0
2
4
6
8
10
12
14
16
18
3 2 1 0 1 2 3
DISTANCE FROM CENTER OF BLADE (feet)

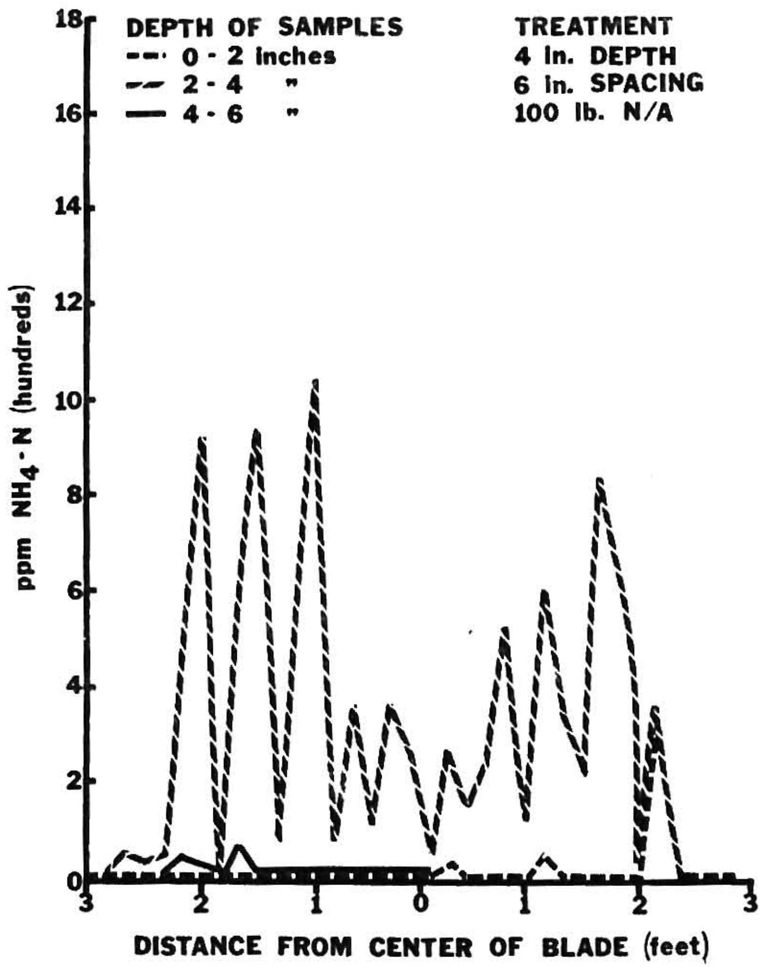
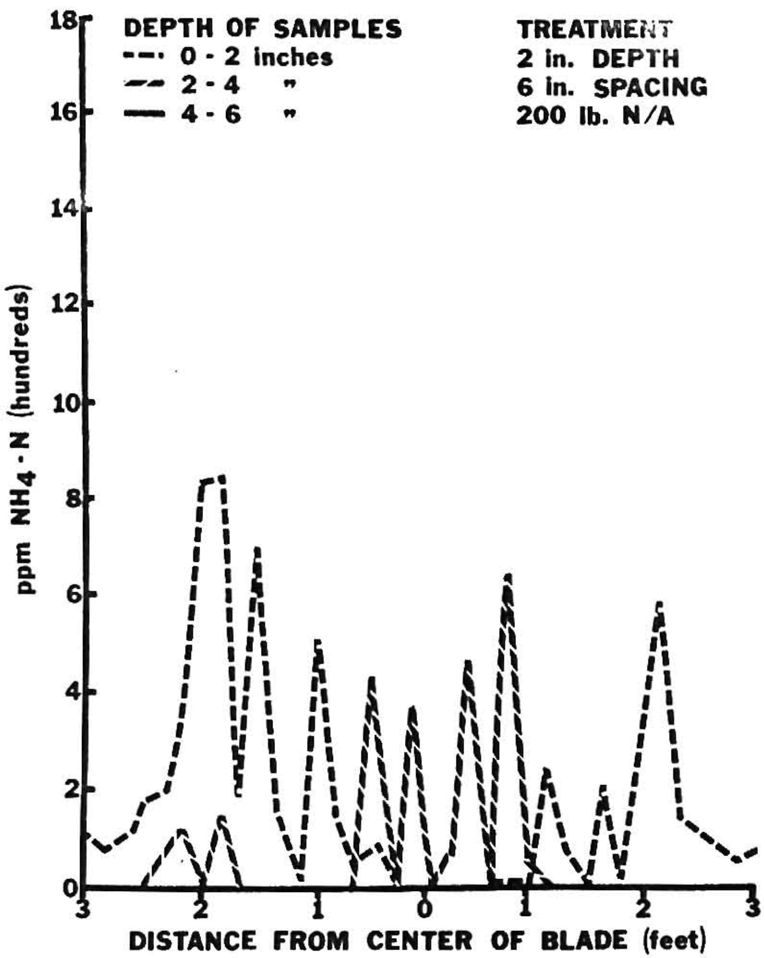

DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
4 In. DEPTH
6 In. SPACING
100 lb. N/A
ppm NH_4 - N (hundreds)
0
2
4
6
8
10
12
14
16
18
3 2 1 0 1 2 3
DISTANCE FROM CENTER OF BLADE (feet)

Figure 16.--Effect of application depth on ammonia retention patterns in a Geary silt loam (200 lb N/A, 6 inch spacing).


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
6 in. SPACING
200 lb. N/A
ppm NH4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

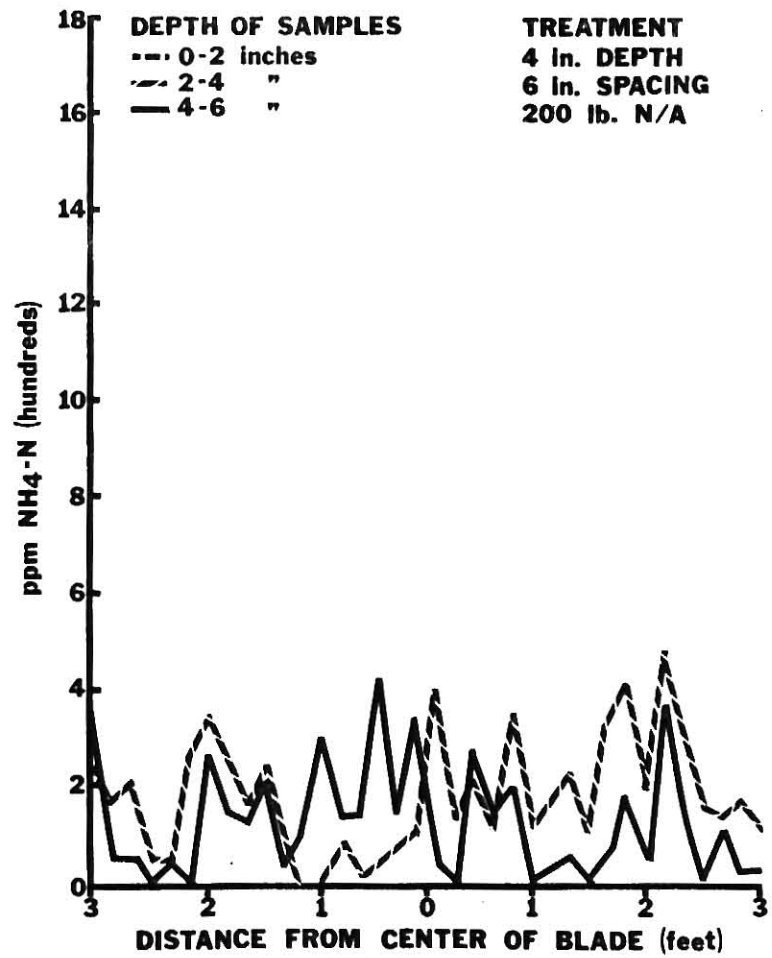
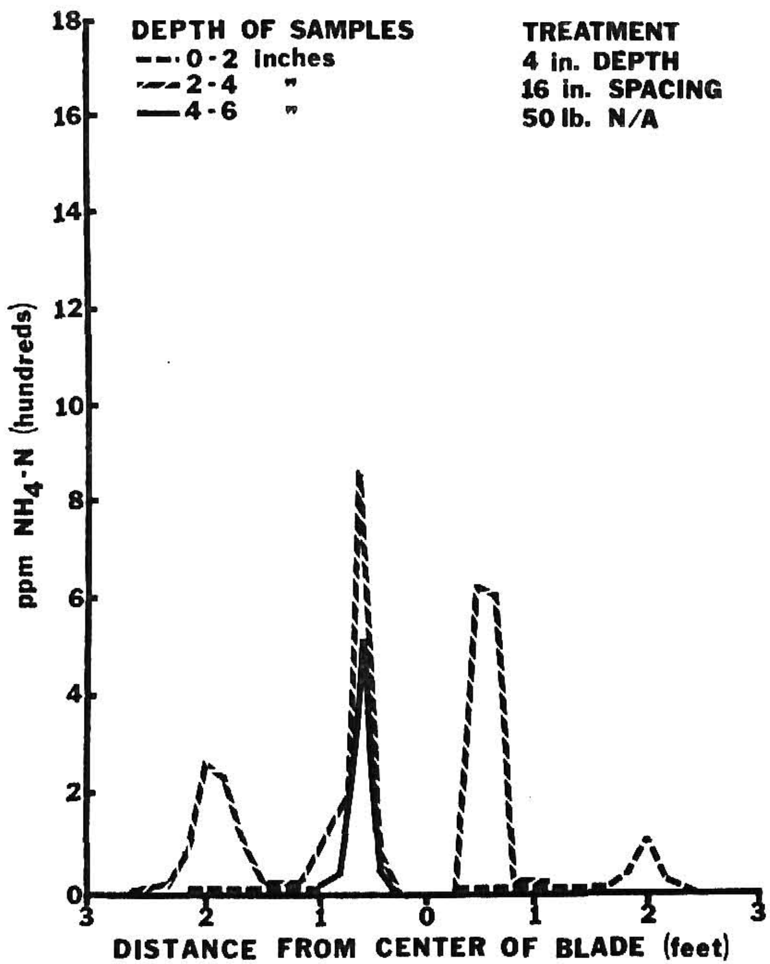
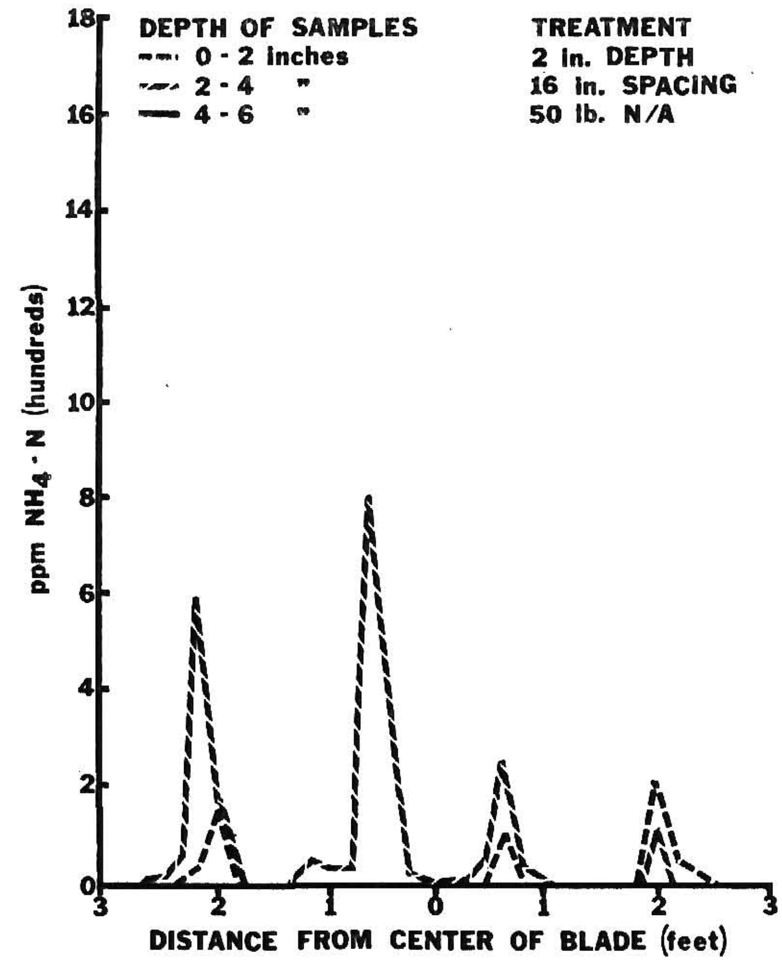

DEPTH OF SAMPLES
0-2 inches
2-4 "
4-6 "
TREATMENT
4 in. DEPTH
6 in. SPACING
200 lb. N/A
ppm NH4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

Figure 17.--Effect of application depth on ammonia retention patterns in a Geary silt loam (50 lb N/A, 16 inch spacing).

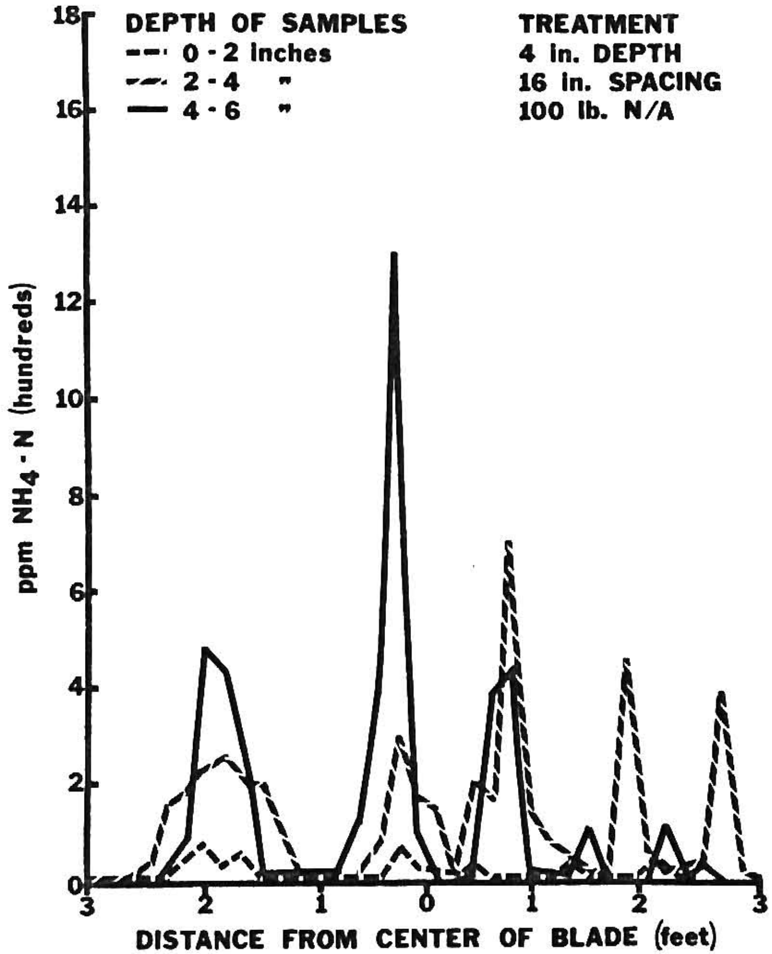


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
4 in. DEPTH
16 in. SPACING
50 lb. N/A
ppm NH_4-N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)



DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
16 in. SPACING
50 lb. N/A
ppm NH_4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)

Figure 18.--Effect of application depth on ammonia retention patterns in a Geary silt loam (100 lb N/A, 16 inch spacing).


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
4 in. DEPTH
16 in. SPACING
100 lb. N/A
ppm NH4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)

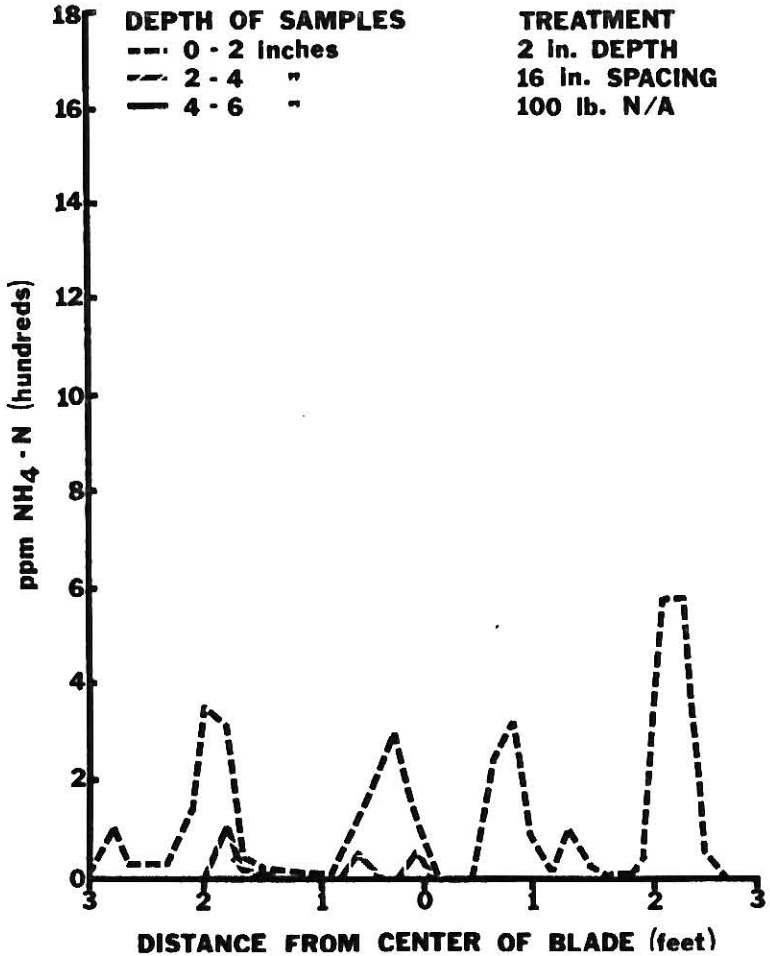
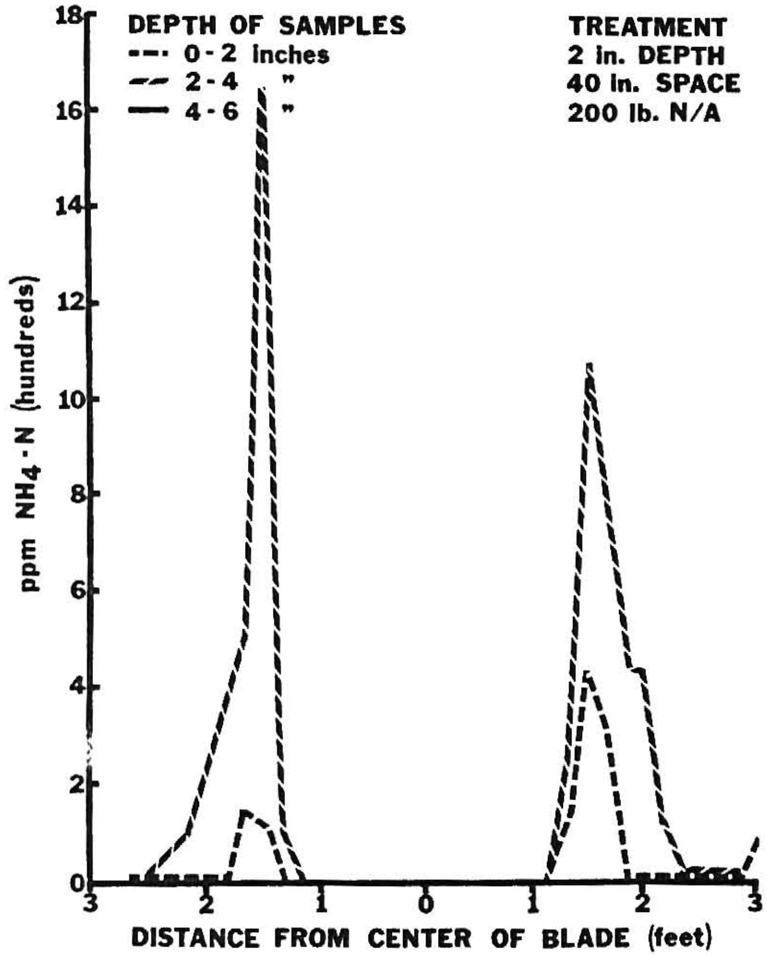
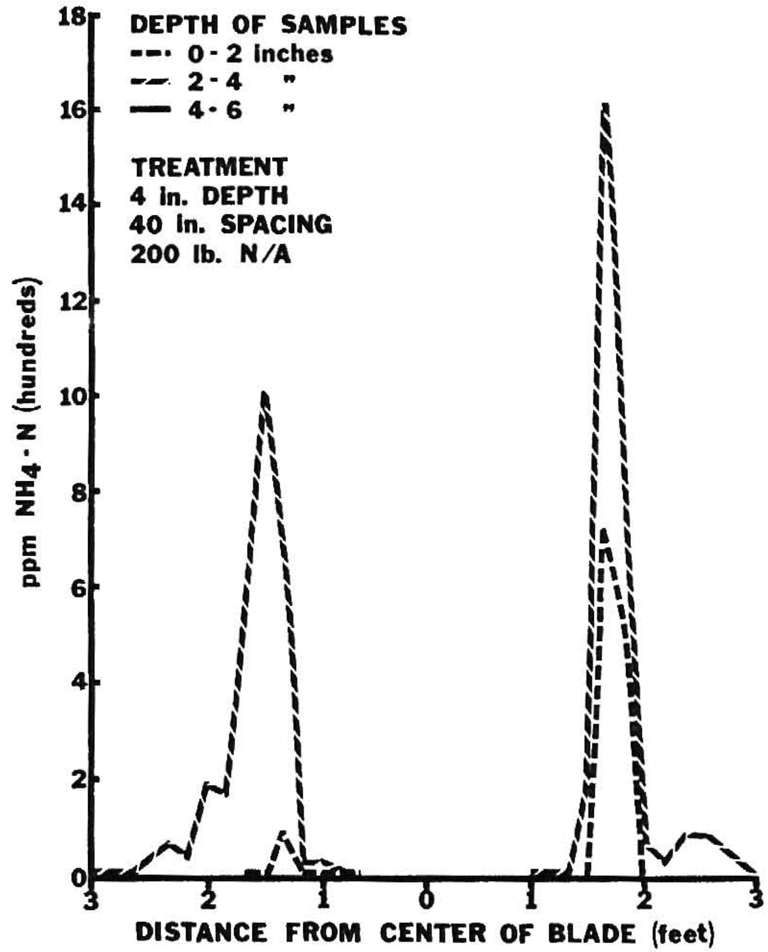

DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
16 in. SPACING
100 lb. N/A
ppm NH4 - N (hundreds)
DISTANCE FROM CENTER OF BLADE (feet)

Figure 19.--Effect of application depth on ammonia retention patterns in a Geary silt loam (200 lb N/A, 40 inch spacing)


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
40 in. SPACE
200 lb. N/A
ppm NH4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
4 in. DEPTH
40 in. SPACING
200 lb. N/A
ppm NH4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

For example, applying 100 lb N/A on 16-inch spacings (Fig. 18) at a 2-inch depth produced retention of the ammonia largely in the 0-2 inch portion of the soil.

At the 4-inch depth of placement, ammonia was retained at the 2-4 inch and occasionally the 4-6 inch level in the soil. Some of the variation can be accounted for because the tool bar did not always remain parallel to the soil surface and the depth of application was difficult to maintain at a constant value.

The vertical and lateral movement of ammonia was not greatly affected by the application depth. Likewise, the concentration of ammonium nitrogen was not altered to any large degree by application depth.

Relationship Between Ammonia Concentration and Soil pH

Parr and Engibous (28) among other workers (13, 26) have established that high ammonia concentrations increase soil pH. In this study pH values were determined on individual soil samples from all treatments.

A 100 lb/A N application at a 2-inch depth was selected to illustrate the pH effect of the three spacings on the Geary silt loam soil. Soil pH was strongly correlated to the ammonia concentration in the soil at all three spacings (Fig. 20, 21, 22). This close correlation provides the basis for the use of the direct spray method in determining NH_3 distribution patterns. Other pH values for soil cores are listed in Appendix tables 1 through 14.

Figure 20.--Comparison of ammonia concentrations and pH values resulting from an application of 100 lb N/A on a Geary silt loam (6 inch spacing).

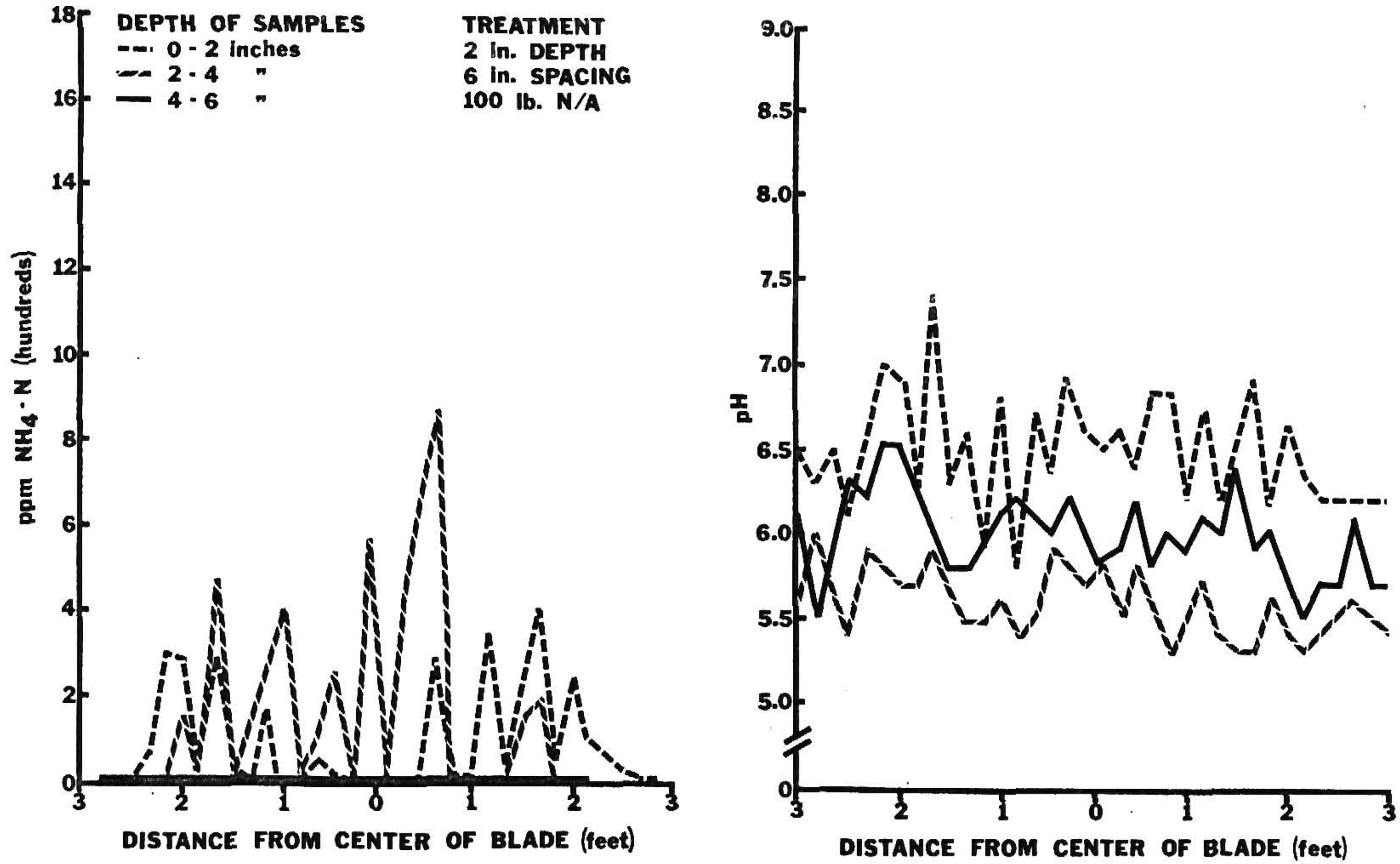

DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
6 in. SPACING
100 lb. N/A
ppm NH_4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)
pH
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

Figure 21.--Comparison of ammonia concentrations and pH values resulting from an application of 100 lb N/A on a Geary silt loam (16 inch spacing).

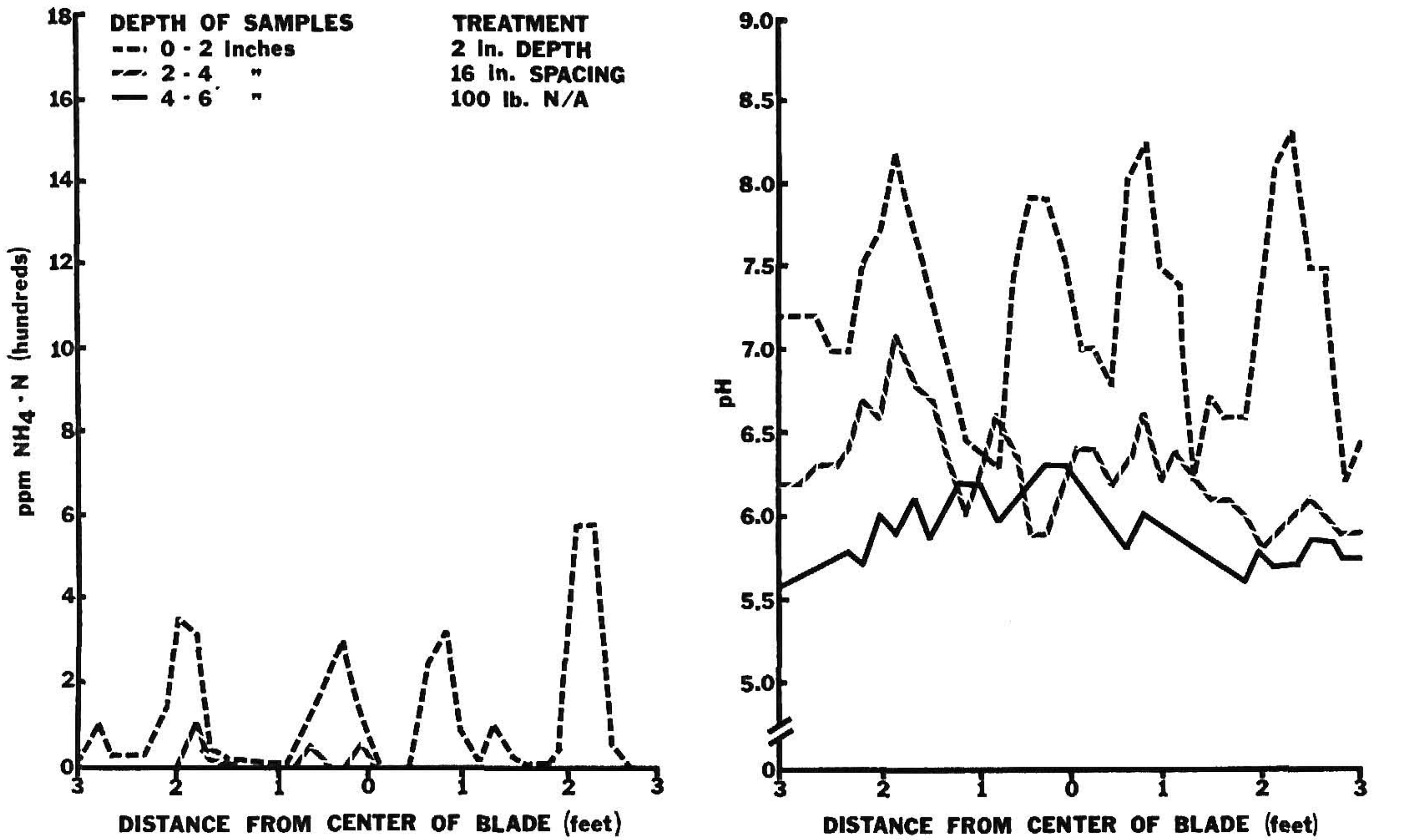
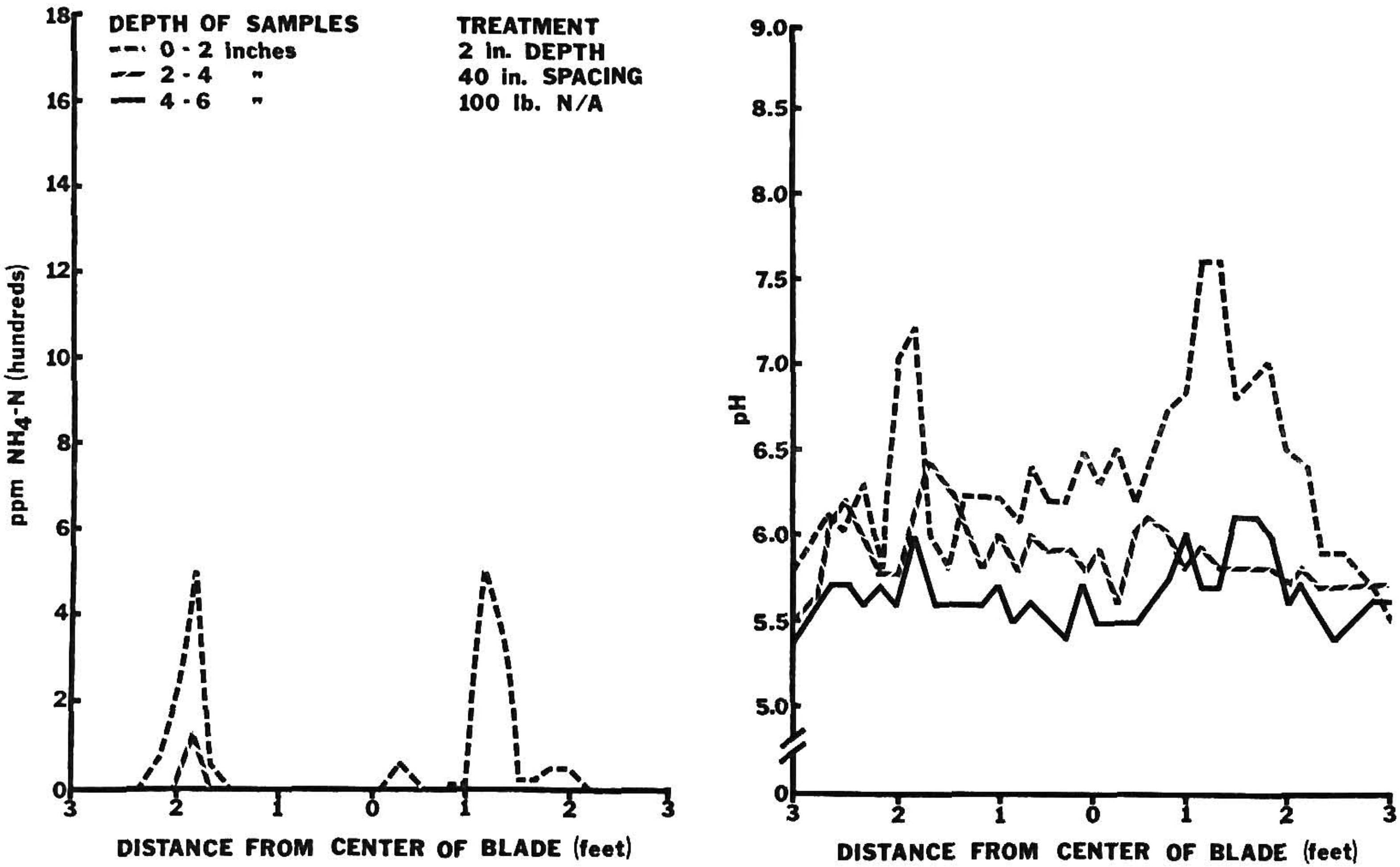

DEPTH OF SAMPLES
0 - 2 Inches
2 - 4 "
4 - 6 "
TREATMENT
2 In. DEPTH
16 In. SPACING
100 lb. N/A
ppm NH_4 - N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)
pH
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

Figure 22.--Comparison of ammonia concentrations and pH values resulting from an application of 100 lb N/A on a Geary silt loam (40 inch spacing).


DEPTH OF SAMPLES
0 - 2 inches
2 - 4 "
4 - 6 "
TREATMENT
2 in. DEPTH
40 in. SPACING
100 lb. N/A
ppm NH4-N (hundreds)
18
16
14
12
10
8
6
4
2
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)
pH
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF BLADE (feet)

Comparison of Plant Nitrogen Concentration with Soil Nitrogen Distribution

Distribution of anhydrous ammonia in the soil is of particular importance as it affects the utilization of nitrogen by the crop growing on the area. In order to study blade ammonia application effects on plant growth, ammonia was applied prior to wheat planting on various soil types at five locations in Kansas.

Nitrogen applications were made at Kiowa county (silt loam soil), Stafford #1 county (loamy sand), Stafford #2 county (sandy soil), McPherson county (silty clay loam), and Saline county (Niles silt loam). Anhydrous ammonia was applied at depth of 3 to 4 inches in order to prevent loss. Nitrogen rates were 25, 50, 75, and 100 lb/A. Release points were centered at 6-, 16-, and 40-inch spacings.

Locations at Kiowa county and Stafford #2 county were selected for correlation between wheat plant nitrogen content and soil inorganic nitrogen distribution because visible differences in growth were observed between treatments early in the spring. A 50 lb/A N application at the three spacings was compared to the check because this was a common N rate for wheat. A 100 lb rate applied on a 40-inch spacing was also selected for comparison. These soil and wheat tissue samples were taken in the spring 7 months after ammonia applications.

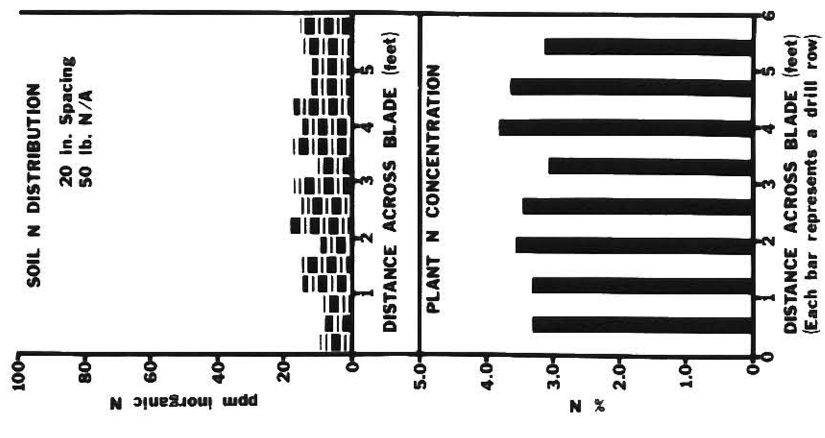
One foot of each wheat drill row across the blade path was clipped above the soil surface for analysis of the nitrogen percentage. A soil core was taken to a depth of 6 inches within each wheat row. Additional soil cores were taken between each wheat row to the same depth. Soil nitrogen distribution was plotted directly above the corresponding plant nitrogen content for the same treatments. Soil nitrogen concentrations between wheat rows was plotted adjacent to within-row values.

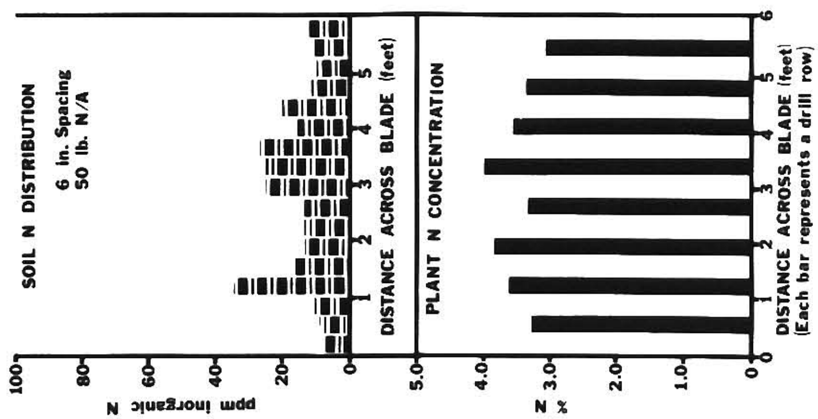
The soil nitrogen content within the row and a mean value of soil nitrogen within and on each side of the wheat row were correlated with the total nitrogen content of the wheat. Statistical correlations between soil inorganic nitrogen (NH_4^+-N and NO_3^--N) and wheat tissue total nitrogen concentrations were significant at both locations.

At the Kiowa county site on a silt loam soil the mean soil nitrogen level was correlated with wheat tissue N concentrations by an r value of 0.3423. An r value of 0.2834 was calculated between the row soil nitrogen and wheat nitrogen. The rejection region ($R_{0.05}$ 100) equaled 0.1946. Both soil nitrogen values were significant due to the large number of samples, but the mean soil nitrogen value was more highly correlated than nitrogen directly in the row. This may have been due to wheat roots extending into the area adjacent to the wheat row, thus absorbing nitrogen in this area.

Graphical evidence of the significant statistical correlation from Kiowa county can be seen in Figures 23 and 24. It was observed that ammonia applications increased the soil inorganic nitrogen concentration in all cases over values reported in the check. Plant nitrogen concentrations were

Figure 23.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Kiowa county) Read vertically to compare plant and soil nitrogen concentrations.


SOIL N DISTRIBUTION
20 in. Spacing
50 lb. N/A
ppm inorganic N
100
80
60
40
20
0
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
5.0
4.0
3.0
2.0
1.0
0
N %
0 1 2 3 4 5 6
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)


SOIL N DISTRIBUTION
6 in. Spacing
50 lb. N/A
ppm inorganic N
100
80
60
40
20
0
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
5.0
4.0
3.0
2.0
1.0
0
N %
0 1 2 3 4 5 6
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)

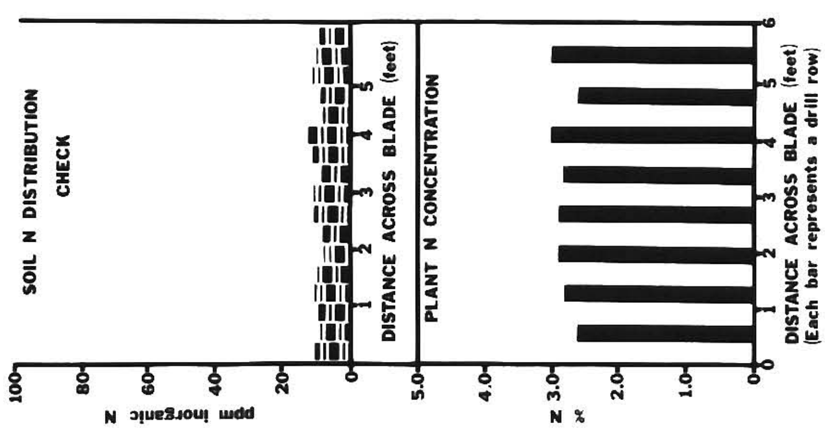
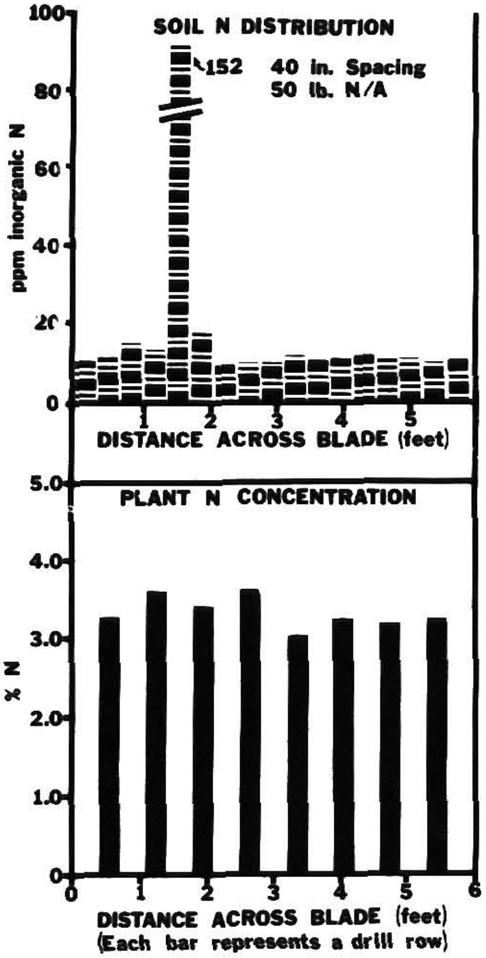
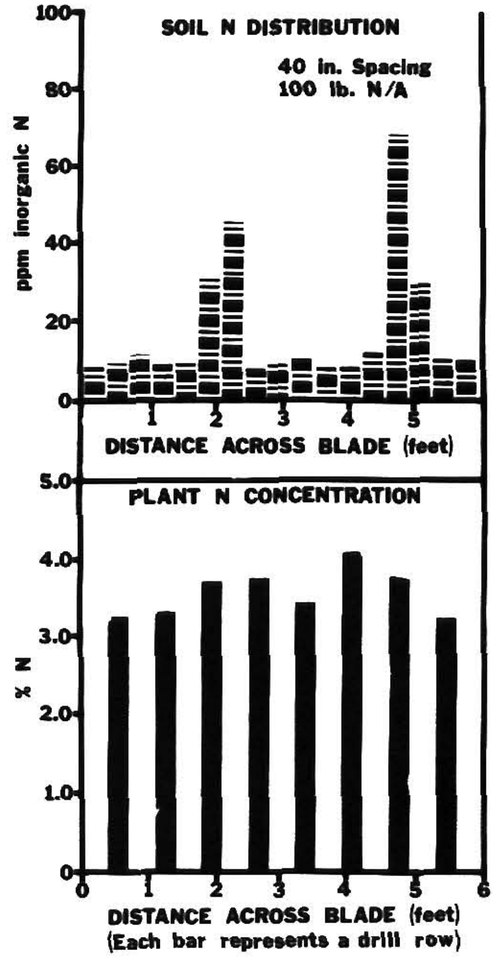

SOIL N DISTRIBUTION
CHECK
ppm inorganic N
100
80
60
40
20
0
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
5.0
4.0
3.0
2.0
1.0
0
N %
0 1 2 3 4 5 6
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)

Figure 24.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Kiowa county) Read vertically to compare plant and soil nitrogen concentrations.


SOIL N DISTRIBUTION
152
40 in. Spacing
50 lb. N/A
ppm inorganic N
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
% N
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)


SOIL N DISTRIBUTION
40 in. Spacing
100 lb. N/A
ppm inorganic N
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
% N
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)

also higher than the check where ammonia was applied. Comparisons of plant nitrogen and soil nitrogen indicated that a high level of soil nitrogen frequently corresponded to an increased plant nitrogen content. The most relationship apparent was in the case of the 40-inch spacing with 100 lb N/A. Soil nitrogen concentrations were approximately 45 ppm and 65 ppm at 2 and 5 feet across the blade, respectively. Reading down the figure directly below these soil concentrations, it is evident that plant nitrogen was higher in the vicinity of these concentrations. An anomaly existed at the 40-inch spacing with the 50 lb N rate in the form of an excessively high plant N concentration on the left side of the bar graph. This may be explained partially by the fact that these samples were extracted 7 months after ammonia application and may have encountered some dilution effect during that time.

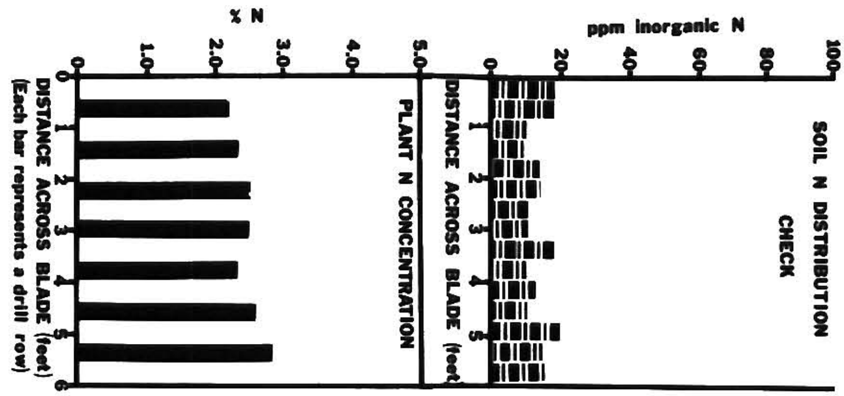
At the Stafford #2 county site on a Carwile sandy loam soil (CEC=2.4 meq) higher correlations were observed between soil and plant N concentrations. The correlation between the mean soil nitrogen values and plant nitrogen of each row had an r value of 0.5448. Soil nitrogen (within the row) and plant nitrogen correlations produced an r value of 0.4456. The rejection region was the same for this location ($r_{0.05}$ 100 = 0.1946). Again the mean soil nitrogen values were more highly correlated with wheat nitrogen content than were the within-row soil nitrogen values.

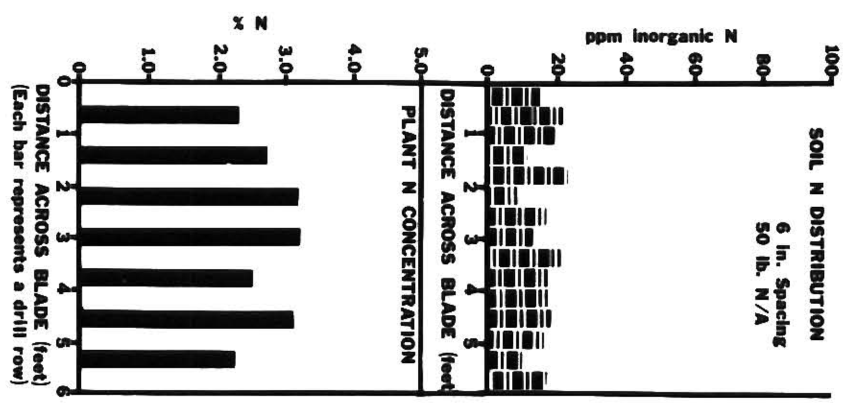
Graphical representations of plant response to ammonia applied with different spacings at Stafford county can be compared to the check (Fig. 25 and 26). In general the wheat absorbed more nitrogen where the soil nitrogen concentrations were higher. This suggests that a more uniform soil nitrogen distribution, which occurred at the 6- and 16-inch spacing, would produce more uniform plant nitrogen content. The check displayed a relatively low soil nitrogen concentration while the 6-inch spacing at the 50 lb rate showed increasing soil and plant nitrogen concentrations. In some areas the 16-inch spacing showed higher concentrations than the 6-inch spacing.

Plants from the Stafford county site exhibited the same type of response to soil nitrogen as the Kiowa county site, except the visual relationship was more evident. Wheat responses to ammonia treatments were photographed at Stafford county (Fig. 27, 28, 29, 30, 31). The 6- and 16-inch spacings produced uniform plant growth, however, the 40-inch spacing at both 50 lb and 100 lb N rates yielded poor plant growth between the release points.

These results agree with the research reported by Carpenter _et_ _al_. (9) in 1952. They found the quantities of nitrogen obtained from wheat clippings at tillering, jointing, heading, and dough stages of growth were correlated with nitrogen content of the top 6 inches of soil and with the 6- to 12-inch soil layer, except at heading. High correlations

Figure 25.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Stafford county) Read vertically to compare plant and soil nitrogen concentrations.


SOIL N DISTRIBUTION
CHECK
ppm inorganic N
0
20
40
60
80
100
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
% N
0
1.0
2.0
3.0
4.0
5.0
0
1
2
3
4
5
6
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)


SOIL N DISTRIBUTION
6 in. Spacing
50 lb. N/A
ppm inorganic N
0
20
40
60
80
100
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
% N
0
1.0
2.0
3.0
4.0
5.0
0
1
2
3
4
5
6
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)

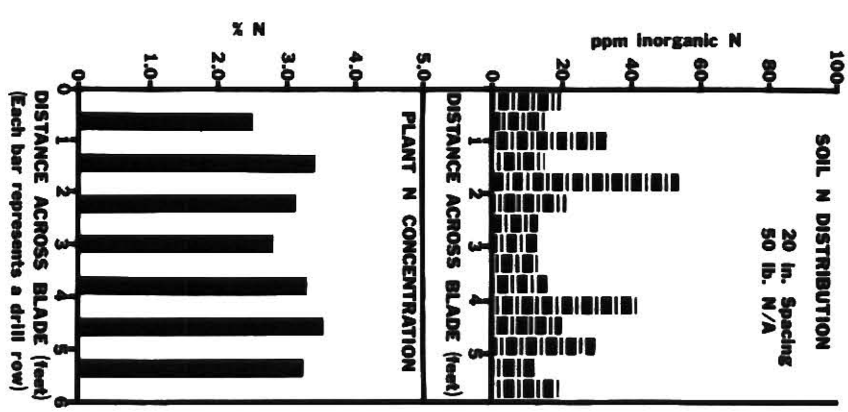
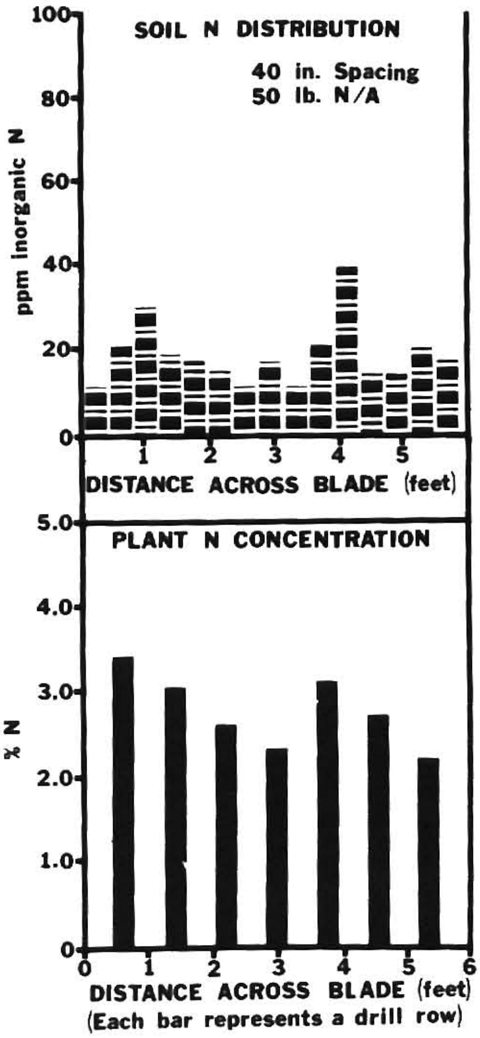

SOIL N DISTRIBUTION
20 in. Spacing
50 lb. N/A
ppm inorganic N
0
20
40
60
80
100
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
% N
0
1.0
2.0
3.0
4.0
5.0
0
1
2
3
4
5
6
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)

Figure 26.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Stafford county) Read vertically to compare plant and soil nitrogen concentrations.


SOIL N DISTRIBUTION
40 in. Spacing
50 lb. N/A
ppm Inorganic N
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
% N
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)

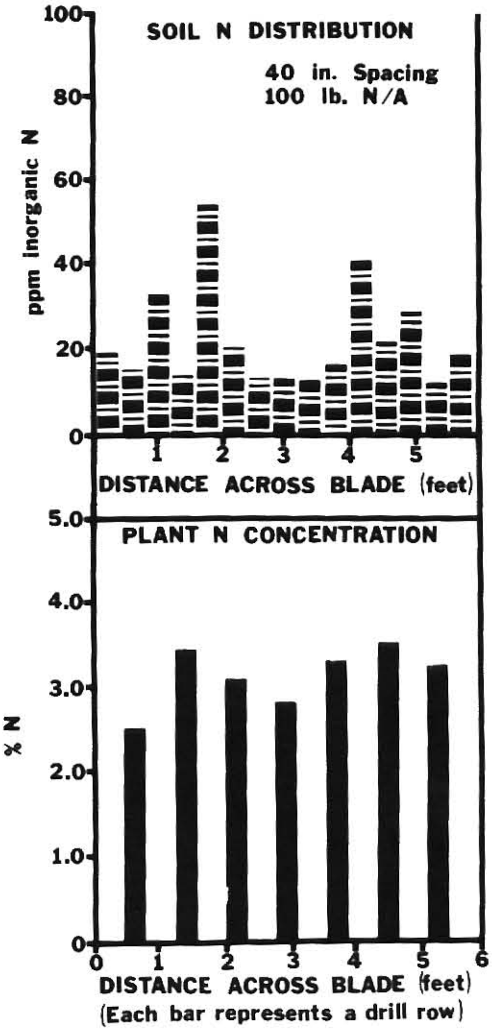

SOIL N DISTRIBUTION
40 in. Spacing
100 lb. N/A
ppm Inorganic N
DISTANCE ACROSS BLADE (feet)
PLANT N CONCENTRATION
% N
DISTANCE ACROSS BLADE (feet)
(Each bar represents a drill row)

Figure 27.--Wheat check plot, no N applied - Stafford county.

Figure 28.--Wheat growth resulting from an application of 50 lb N/A with 6 inch spacings (Compare to Fig. 27).


BLADE, RATE AND
SPACING STUDY
STAFFORD COUNTY
0 INCH SPACING
0 LBS. N/A


BLADE, RATE AND
SPACING STUDY
STAFFORD COUNTY
6 INCH SPACING
60 LBS. N/A

Figure 29.--Wheat growth resulting from an application of 50 lb N/A with 16 inch spacings (Compare Figs. 27 to 31).

Figure 30.--Wheat growth resulting from an application of 50 lb N/A with 40 inch spacings (Note wavy growth pattern).


BLADE, RATE AND
SPACING STUDY
STAFFORD COUNTY
20 INCH SPACING
50 LBS.


BLADE, RATE AND
SPACING STUDY
STAFFORD COUNTY
40 INCH SPACING
50 LBS.

Figure 31.--"Wavy effect" produced by ammonia application with 40 inch spacings between ammonia release points - Stafford county.


BLADE, RATE AND
SPACING STUDY
STAFFORD COUNTY
40 INCH SPACING
100 LBS. N/A

were obtained between grain yields and the quantity of nitrogen in plants at all stages, with the amount in plants at jointing giving the best estimate of yield.

Wheat Yields Resulting from Ammonia Applications

Wheat yields resulting from ammonia applications were taken at Saline, McPherson, Stafford #1 (cooperator's farm), Stafford #2 (Sandyland experimental farm), and Kiowa counties. An analysis of variance on the wheat yields indicated significant differences at Stafford #1 county, at Saline county, and at McPherson county. The rejection region was $F_{.10}$ (12, 36) = 1.77 (Tables 5, 7, 9). An ordered array of the yields indicated that proper selection of N rate and spacing between release points has the potential to improve yields (Tables 6, 8, 10). Identical letters under LSD indicate no statistical difference between those two treatments.

At the three locations where yield differences were statistically significant, applications of 50 lb N/A with the 16-inch spacing ranked high indicating perhaps that by using a narrower spacing less ammonia was needed for an adequate nitrogen supply to the plants. A poorer distribution pattern with the 6-inch spacing (Fig. 5) may have accounted for the somewhat lower wheat yields with this spacing. The 40-inch spacing frequently had yields on the lower end of the ordered array.

The effect of application rate and spacing were separated statistically (Table 9). Only the nitrogen rate at

Table 5.--Analysis of variance for wheat yield at the Stafford #1 county site.

Source	D.F.	SS	MS	F
Total	51	1074.7		
Replicates	3	77.3	25.8	
Treatment	12	416.1	34.7	2.15
Error	36	518.3	16.1	

$F_{.10}$ (12, 36) = 1.77

Table 6.--An ordered array of wheat yields from the largest to the smallest at the Stafford #1 site.

Treatment	lb N/A	Spacing	Bu/A	LSD
9	100	16	44.8	a
7	50	16	41.9	b
12	75	6	41.0	b c
4	75	40	40.7	b c
8	75	16	40.2	b c
5	100	40	39.9	b c
11	50	6	38.8	b c
13	100	6	37.6	b c
10	25	6	37.3	b c d
2	25	40	37.3	b c d
3	50	40	36.7	c d
6	25	16	32.7	d
1	0	0		

L.S.D. .10 = 4.8

Table 7.--Analysis of variance for wheat yields at the McPherson county site.

Source	D.F.	SS	MS	F
Total	51	1011.2		
Replicates	3	286.6	95.5	
Treatment	12	311.6	25.9	2.26
Error	36	413.0	11.4	

$F_{.10\ (12,\ 36)} = 1.77$

Table 8.--Ordered array of mean wheat yields from the largest to the smallest at the McPherson county site.

Treatment	lb N/A	Spacing	Bu/A	LSD
7	50	16	39.7	a
9	100	16	39.3	a
12	75	6	39.1	a
4	75	40	39.1	a
5	100	40	38.9	a
13	100	6	38.1	a b
6	25	16	36.8	a b c
10	25	6	36.7	a b c
8	75	16	36.0	a b c
2	25	40	35.8	a b c
11	50	6	34.6	b c d
3	50	40	33.7	c d
1	0	8	31.3	d

LSD .10 = 4.0

Table 9.--Analysis of variance for wheat yields at the Saline county location.

Source	D.F.	SS	MS	F
Total	51	755.0		
Replicates	3	397.8	132.6	
Treatment	12	139.5	11.6	1.92
Error	36	217.6	6.0	

$F_{.10\ (12,\ 36)} = 1.77$

Table 10.--An ordered array of mean wheat yields from the largest to the smallest at the Saline county location.

Treatment	lb N/A	Spacing	Bu/A	LSD
4	75	40	36.4	a
11	50	6	35.9	a b
8	75	16	35.0	a b c
10	25	6	35.0	a b c
13	100	6	35.0	a b c
12	75	6	34.7	a b c
7	50	16	34.7	a b c
5	100	40	34.5	a b c
3	50	40	33.3	b c d
9	100	16	33.3	b c d
1	0	0	32.2	c d
6	25	16	31.5	d
2	25	40	30.8	d

LSD .10 = 2.96

Saline county and Stafford #1 county was significant with values of 3.01 and 2.50, respectively (Table 11). Even though other values were not significant, certain trends tended to develop. The 75 and 100 lb N rates generally yielded higher, while the 25 and 50 lb rates ranked nearer the bottom (Table 12). Concerning the spacing between points of ammonia release, the 6- and 16-inch spacing shared the top two ranks while the 40-inch spacing ranked last in 4 out of the 5 locations.

Field observations early in the spring revealed no visible wheat growth responses at Saline county, Stafford #1 county, and very little response at the McPherson county site. The Kiowa county site exhibited increased wheat growth from ammonia treatments. The Stafford #2 county site showed excellent wheat response to ammonia applications, however, wheat yields (Table 13) were not significant at this location with an alpha level of .10 due to the large error term. Much of the error was caused by poor wheat growth on the right side of the test plots. Test weight and protein analysis were made on a composite sample of each treatment (Table 14). No great differences were noted between test weight values of the treatments. Likewise, no great differences were noted between protein analysis of grain, except for one treatment. Applying 100 lb N/A with a 6-inch spacing between release points produced wheat grain with the highest protein content at all five locations. At McPherson county the protein content with this treatment was over 0.5% higher than any of the other treatments.

Table 13.--Wheat yield data resulting from nitrogen and spacing combinations at five Kansas locations.

N Treatment (lb N/A)	Spacing of NH_3 Release Points (inches)	McPherson* county	Saline* county	Stafford #1* county	Stafford #2 county	Kiowa county
0	0	31.3	32.2	32.7	16.2	29.0
25	40	35.7	30.7	37.2	25.5	30.6
50	40	33.7	33.3	37.2	33.0	31.2
75	40	39.0	36.4	40.7	28.3	32.0
100	40	38.8	34.5	39.9	37.1	27.3
25	16	36.7	31.5	36.7	25.6	27.4
50	16	39.7	34.7	41.8	31.2	32.0
75	16	35.9	35.0	40.2	39.5	31.4
100	16	39.3	33.3	44.7	38.9	30.5
25	6	37.6	35.0	37.5	33.5	30.5
50	6	34.5	35.9	39.8	31.9	30.0
75	6	39.1	34.7	41.0	36.0	31.6
100	6	38.0	35.0	38.8	33.4	30.5
LSD .10		4.80	2.96	4.08	NS	NS

*Significant at 0.10

Table 14.--Effect of nitrogen and spacing treatments on test weight and percent protein at five Kansas locations.

Treat.	McPherson		Saline		Stafford #1		Stafford #2		Kiowa	
#	Test Wt.	% Prot.	Test Wt.	% Prot.	Test Wt.	% Prot.	Test Wt.	% Prot.	Test Wt.	% Prot.
1	60.75	9.58	60.90	10.72	62.20	10.89	61.45	10.43	58.45	11.14
2	60.80	10.03	60.45	11.80	62.20	10.94	60.45	11.46	59.10	11.86
3	60.30	10.60	60.00	13.34	62.20	11.63	60.45	10.66	59.25	12.71
4	60.40	9.98	60.20	12.94	62.05	12.83	61.80	11.34	59.05	13.22
5	60.60	11.17	60.20	13.11	62.10	12.37	61.30	12.20	55.70	14.25
6	60.30	9.86	60.50	11.29	62.60	10.89	61.20	10.72	58.90	12.08
7	60.80	10.37	59.75	12.20	62.10	11.86	60.90	9.92	60.00	12.65
8	60.75	10.37	60.45	12.71	62.15	12.37	62.20	11.12	59.35	13.62
9	60.80	11.12	59.65	13.11	62.35	12.94	61.60	11.74	58.45	14.76
10	60.55	10.32	60.10	11.00	62.65	10.66	60.40	9.18	59.85	12.03
11	60.70	10.15	60.45	12.43	62.15	12.03	60.35	10.20	59.15	12.88
12	60.50	10.55	60.40	12.31	62.30	12.03	60.90	10.77	58.55	14.14
13	61.25	11.91	60.65	13.56	61.70	13.05	61.00	12.48	58.10	14.99

SUMMARY AND CONCLUSIONS

Ammonia retention capacity of soils with varying physical and chemical properties for anhydrous ammonia was examined from applications with an undercutting blade. Ammonia retention was excellent on a Geary silt loam (CEC=15 meq) with no ammonia losses being detected when applying 200 lb N/A on a 40-inch spacing at a 2-inch application depth. This indicated that heavy-textured soils, when in good tilth, are capable of retaining large amounts of ammonia.

Ammonia applications at the 2-inch depth on a Cass fine sandy loam (CEC=4 meq) produced some volatilization loss. From 6-8% ammonia loss was detected at both the 6-inch and 40-inch spacing between release points. Increasing the application depth to 4 inches still resulted in ammonia volatilization when applied on 40-inch centers. Decreasing the spacing between release points to 6 inches virtually halted ammonia losses from this sandy soil. By dispersing the ammonia across the blade path with the 6-inch spacing, a sufficient quantity of soil colloids were contacted for complete ammonia retention. Ammonia losses can certainly be minimized by using a closer spacing between release points and by lowering the application depth.

Soils which have a high CEC are capable of retaining large quantities of ammonia in contrast to soils with a low CEC.

Soils with a low CEC are capable of retaining enough ammonia for excellent crop growth, but proper application methods should be utilized to prevent ammonia loss.

The rate of N application with an undercutting blade affected ammonia distribution in the soil. Higher rates of N caused higher concentrations of ammonia in the retention zone. Higher N applications rates also increased the width of the ammonia retention zone.

A low application (50 lb N/A) produced a poor distribution on a Geary silt loam at the 6- and 16-inch spacing because sufficient backpressure was not formed in the delivery manifold to force the ammonia uniformly through all orifices. Applications of 100 lb N/A or greater afforded the best distribution patterns using 6- and 16-inch spacings.

Spacing between the points of ammonia release affected the distribution in two ways. The 6-inch spacing had more release points across the width of the blade, so there was a more uniform distribution than with the closer spacing. Secondly, when there were more points of release for a given application rate, less ammonia will pass through each orifice, hence a lower concentration of ammonia at each release point. For example, the 40-inch spacing deposited more ammonia at each release point than the 6-inch spacing.

It is questionable whether the 40-inch spacing will always provide an adequate dispersion to prevent a "wavy effect" in crops. The 16-inch spacing appears to furnish a satisfactory ammonia distribution for crop growth because once ammonia is converted to nitrate, it is subject to some lateral movement and also the crop's roots may penetrate into the retention zone. A 6-inch spacing was very effective in dispersing the ammonia across the blade width, except at 50 lb N/A. This inadequate distribution may be improved with smaller orifice sizes, but more research will be needed to confirm this hypothesis.

Application depth had relatively little influence on ammonia retention patterns. Depth of application may affect distribution indirectly by allowing ammonia to contact areas with differing moisture content, soil tilth, and cation exchange capacity, but radical differences are not likely. Application depth is most important in prevention of ammonia volatilization. A depth of 4 inches appears to be satisfactory for most ammonia applications.

Soil texture affected ammonia distribution to some degree. At the 200 lb N rate the sandy soil exhibited a more restricted retention pattern than did the silt loam soil at the same N rate, however, too few comparisons were made to draw valid conclusions concerning the texture effect.

Orifice size at the release points can become critical in ammonia retention patterns if backpressure fails to form in the distribution line. A low backpressure, which occurred at low N rates, yielded an uneven distribution in these studies. This phenomenon occurred in several treatments, but was most evident at the 6-inch spacing with a 50 lb N rate.

A 2/32 inch orifice would be acceptable for most rates above 50 lb N/A. At rates below 50 lb N/A a smaller orifice size would be suggested. At rates higher than 200 lb/A a 3/32 inch orifice may be justified. Also, orifice sizes are somewhat dependent on the number of release points in the distribution line. A greater number of release points requires smaller orifices in order for sufficient backpressure to form.

Ammonia applications initially raised the soil pH. The magnitude of increase was directly related to the ammonia comcentration in the soil. Maximum pH values recorded were around 10.0. The pH values supported evidence of distribution patterns determined by the steam distillation technique.

Nitrogen absorption by plants was correlated with soil nitrogen content. Ammonia placement had distinct effects on the nitrogen content of wheat plants. Field observations indicated that the 6- and 16-inch spacings created a more uniform plant growth in the field than did the 40-inch spacing.

Wheat yield differences were statistically significant at three of five test plots in Kansas. Even though isolated effects of spacing and N rate were not statistically significant on influencing wheat yields, there was a trend for the 6- and 16-inch spacing to produce higher yields of wheat than the 40-inch spacing between release points.

The primary objective of this study was to measure the retention and distribution of anhydrous ammonia applied with an undercutting blade on various soil textures. Ammonia distribution patterns produced by the 6- and 16-inch spacings were vastly improved over the dispersion delivered by the 40-inch spacing. The ammonia did not spread across the blade path due to a draft effect produced by the blade as was previously hypothesized. Ammonia retention was excellent on a silt loam soil. Ammonia losses were detected on a fine sandy loam soil when applied on 40-inch centers. Two retention zones of high ammonia concentration were produced with the 40-inch spacing, hence more ammonia was present in these areas than the sandy soil could retain. Using a 6-inch spacing not only dispersed the ammonia uniformly across the blade path for availability to plants, but also dispersed the ammonia evenly in the soil to minimize ammonia losses.

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APPENDIX

Table 1.--Ammonium distribution and soil pH values in a silt loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (2 inch depth, 40 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	11	0	36	5.8	5.5	5.8
0	4	0	34	6.0	5.6	6.0
0	0	0	32	6.1	6.1	6.1
0	0	0	30	6.0	6.2	6.0
0	0	0	28	6.3	6.0	6.3
0	0	76	26	5.8	5.8	5.8
7	0	200	24	7.0	5.8	7.0
0	114	486	22	7.2	6.2	7.2
0	12	45	20	6.0	6.4	6.0
0	11	0	18	5.8	6.3	5.8
0	0	0	16	6.2	6.1	6.2
0	0	0	14	6.2	5.8	6.2
0	0	0	12	6.2	6.0	6.2
0	9	0	10	6.1	5.8	6.1
0	8	0	8	6.4	6.0	6.4
0	12	0	6	6.2	5.9	6.2
0	0	0	4	6.2	5.9	6.2
0	0	5	2	6.5	5.8	6.5
0	0	7	0	6.3	5.9	6.3
0	0	57	2	6.5	5.6	6.5
0	0	17	4	6.2	6.0	6.2
0	0	0	6	6.4	6.1	6.4
0	0	33	8	6.7	6.0	6.7
0	0	10	10	6.8	5.8	6.8
0	0	501	12	7.6	5.9	7.6
9	0	384	14	7.6	5.8	7.6
0	0	18	16	6.8	5.8	6.8
0	0	18	18	6.9	5.9	6.9
0	0	34	20	7.0	5.8	7.0
0	0	45	22	6.5	5.7	6.5
0	0	7	24	6.4	5.8	6.4
0	0	0	26	5.9	5.6	5.9
0	0	0	28	5.9	5.7	5.9
0	0	0	30	5.7	5.6	5.7
0	0	0	32	5.8	5.6	5.8
0	0	0	34	5.5	5.6	5.5
0	0	0	36	5.6	5.6	5.6

Table 2.--Ammonium distribution and soil pH values in silt loam soils following the application of 200 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (2 inch depth, 40 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	13	422	36	5.5	5.6	7.0
0	237	403	34	5.6	6.3	7.0
0	65	434	32	5.6	5.9	7.1
0	46	496	30	5.7	5.4	7.0
0	50	341	28	5.7	5.6	6.9
0	72	527	26	5.9	5.3	7.2
0	327	372	24	6.0	6.4	7.1
0	953	258	22	5.7	7.4	6.7
0	116	930	20	6.1	6.0	7.8
0	117	868	18	5.9	6.5	7.9
0	24	403	16	5.8	5.9	7.2
0	45	124	14	5.6	6.1	7.0
5	32	589	12	5.7	5.4	7.1
9	5	434	10	5.8	5.5	7.1
0	152	403	8	5.6	5.9	6.9
0	111	93	6	5.7	6.4	6.7
0	414	258	4	5.9	7.1	6.6
0	53	258	2	5.6	5.5	6.3
0	476	310	0	5.4	6.9	6.9
0	28	651	2	5.6	5.7	7.5
17	98	527	4	5.4	6.0	7.1
0	237	775	6	5.6	6.9	7.6
0	207	372	8	5.7	6.7	6.9
0	15	403	10	5.7	5.8	7.2
0	80	279	12	5.7	6.1	6.7
4	199	992	14	5.6	6.5	7.9
0	188	589	16	5.7	6.5	7.4
0	22	403	18	5.8	5.8	7.3
0	70	589	20	5.9	6.1	7.5
0	23	186	22	6.0	6.0	6.6
0	22	124	24	6.0	5.8	6.9
0	310	279	26	5.7	6.4	7.2
0	24	279	28	5.6	5.9	6.9
0	120	93	30	5.6	6.3	6.3
0	72	124	32	5.7	6.4	6.6
0	35	341	34	5.5	6.1	6.9
0	0	310	36	5.4	5.6	7.0

Table 3.--Ammonium distribution and soil pH values in silt loam soil following the application of 50 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (2 inch depth, 6 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	0	10	36	5.8	6.5	6.1
0	0	4	34	5.8	6.1	6.5
0	4	8	32	6.2	6.4	6.3
0	0	6	30	6.2	6.4	6.6
0	12	115	28	6.4	6.1	7.3
0	0	4	26	6.3	6.3	6.9
0	9	4	24	6.4	6.2	7.0
0	1	20	22	5.8	5.8	7.0
0	0	3	20	6.3	5.7	6.7
0	27	5	18	6.6	6.3	6.4
0	14	6	16	6.0	6.5	6.6
0	5	4	14	6.1	6.7	6.5
0	30	4	12	6.3	6.9	7.0
5	76	3	10	5.9	6.4	7.0
0	19	2	8	5.9	6.5	6.7
0	185	0	6	6.1	6.6	6.9
8	15	4	4	6.2	6.3	6.6
0	152	0	2	6.3	7.2	6.6
0	42	6	0	6.3	6.5	6.9
5	14	0	2	6.2	6.8	6.8
14	292	8	4	6.1	6.5	6.4
21	26	0	6	5.9	6.3	6.3
12	26	0	8	6.0	6.4	6.7
9	54	6	10	6.3	6.8	6.4
0	0	0	12	6.1	6.5	6.3
0	0	222	14	6.4	6.3	7.5
0	7	130	16	6.1	6.2	6.9
0	0	7	18	5.9	5.8	6.8
0	1	673	20	5.8	5.6	8.1
0	0	44	22	5.7	6.0	7.1
0	0	5	24	5.8	5.9	7.2
0	0	2	26	6.0	6.1	6.7
0	6	2	28	6.2	5.9	6.6
0	3	0	30	6.1	5.7	6.9
0	4	4	32	6.0	5.9	6.6
0	6	3	34	5.8	5.9	6.3
0	0	0	36	5.7	5.8	6.5

Table 4.--Ammonium distribution and soil pH values in silt loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (2 inch depth, 6 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
12	0	3	36	6.1	5.6	6.5
13	0	2	34	5.5	6.0	6.3
11	0	4	32	5.8	5.6	6.5
14	0	13	30	6.3	5.4	6.1
17	2	65	28	6.2	5.9	6.6
11	0	297	26	6.5	5.8	7.0
8	154	291	24	6.5	5.7	6.9
5	28	42	22	6.2	5.7	6.3
10	472	289	20	6.0	5.9	7.4
5	9	31	18	5.8	5.6	6.3
14	134	3	16	5.8	5.5	6.6
5	0	164	14	5.9	5.5	5.9
6	402	0	12	6.1	5.6	6.8
4	20	0	10	6.2	5.4	5.8
6	87	48	8	6.1	5.5	6.7
5	255	1	6	6.0	5.9	6.4
33	9	18	4	6.2	5.8	6.9
3	573	0	2	5.9	5.7	6.6
7	15	3	0	5.8	5.8	6.5
5	395	5	2	5.9	5.5	6.6
3	21	1	4	6.2	5.8	6.4
2	867	284	6	5.8	5.6	6.8
7	22	8	8	6.0	6.3	6.8
2	1	7	10	5.9	5.5	6.2
9	5	352	12	6.1	5.7	6.7
4	11	41	14	6.0	5.4	6.2
6	133	217	16	6.4	5.3	6.4
3	184	402	18	5.9	5.3	6.9
0	0	54	20	6.0	5.6	6.2
1	0	241	22	5.7	5.4	6.6
1	3	106	24	5.5	5.3	6.3
1	0	59	26	5.7	5.4	6.2
2	0	24	28	5.7	5.5	6.3
0	0	9	30	6.1	5.7	6.0
3	0	10	32	5.7	5.5	6.2
2	0	1	34	5.7	5.6	6.2
4	0	0	36	5.9	5.5	6.3

Table 5.--Ammonium distribution and soil pH values in silt loam soil following the application of 50 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (4 inch depth, 6 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	0	0	36	6.4	6.3	6.3
0	0	0	34	6.2	6.2	6.3
25	0	0	32	6.2	6.0	6.3
13	0	0	30	6.2	6.2	6.2
69	3	10	28	6.2	5.8	6.0
24	0	8	26	6.5	6.6	6.0
203	0	10	24	7.3	6.2	5.8
34	20	8	22	6.4	6.2	6.0
9	44	10	20	6.2	6.8	6.1
12	4	8	18	6.0	6.1	6.0
0	4	10	16	6.5	5.8	6.2
0	0	0	14	6.3	5.8	6.0
269	67	15	12	6.3	6.5	6.1
15	70	13	10	6.3	6.4	6.1
40	33	13	8	6.3	6.8	6.2
90	348	0	6	6.1	7.8	6.1
0	26	0	4	6.2	6.8	6.1
0	15	0	2	6.9	6.4	6.1
0	14	0	0	6.4	6.4	6.1
0	0	0	2	6.2	6.5	6.5
253	356	0	4	6.0	7.0	6.3
0	45	3	6	6.4	6.4	6.0
0	224	0	8	6.4	6.6	6.5
0	0	0	10	6.2	6.3	6.1
0	80	0	12	6.4	6.5	6.6
0	67	0	14	6.8	6.4	6.0
0	33	0	16	6.1	5.9	6.1
0	89	0	18	6.1	6.7	6.2
0	321	7	20	6.1	7.2	6.3
0	27	0	22	6.3	6.2	6.2
0	22	0	24	6.2	6.4	6.1
0	62	0	26	6.3	6.8	6.2
0	55	0	28	6.6	6.5	6.1
0	4	0	30	6.1	6.1	6.2
0	7	0	32	6.1	6.0	6.1
0	0	0	34	5.9	6.2	6.0
0	0	0	36	5.9	6.2	6.1

Table 6.--Ammonium distribution and soil pH values in silt loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (4 inch depth, 6 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
4	8	8	36	5.7	6.3	6.0
4	4	7	34	6.2	6.1	6.1
0	51	12	32	6.2	6.4	6.1
0	40	12	30	5.8	6.5	6.2
0	51	19	28	5.9	6.8	6.2
43	493	9	26	6.1	8.5	6.3
31	925	7	24	6.5	8.9	6.3
11	32	4	22	5.7	6.7	6.3
66	595	6	20	5.7	8.2	6.3
7	940	3	18	6.1	8.7	6.7
10	86	20	16	6.0	7.2	6.3
12	548	6	14	5.7	8.1	6.6
16	1,043	4	12	5.8	8.5	6.2
15	87	10	10	5.7	7.0	6.4
7	349	9	8	6.1	8.0	6.5
2	123	2	6	6.3	6.8	6.4
14	367	5	4	5.9	7.6	6.4
8	279	6	2	6.3	7.9	6.2
6	58	16	0	6.2	6.4	6.7
0	260	36	2	5.9	7.6	6.8
3	158	16	4	6.2	7.4	6.7
0	228	12	6	6.1	7.8	6.8
0	519	5	8	6.0	8.3	6.6
0	133	3	10	6.3	7.0	6.7
0	599	42	12	6.0	8.4	6.6
0	352	15	14	6.1	8.4	7.0
0	232	21	16	6.0	7.5	6.5
0	832	8	18	6.4	8.7	6.6
3	643	7	20	6.4	8.6	6.5
5	41	0	22	6.3	6.7	6.8
0	338	302	24	6.5	8.0	7.8
0	12	19	26	5.8	6.7	6.8
0	4	5	28	5.9	6.7	6.5
0	0	1	30	5.7	6.2	6.9
0	0	4	32	5.7	6.3	6.5
0	0	0	34	5.8	6.5	6.8
0	0	0	36	5.8	6.3	6.6

Table 7.--Ammonium distribution and soil pH values in silt loam soil following the application of 50 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (4 inch depth, 16 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	0	0	36	5.7	5.9	5.7
0	10	0	34	5.7	5.9	5.7
0	7	0	32	4.9	5.9	5.7
6	32	0	30	5.6	5.8	5.9
2	80	11	28	5.7	6.1	5.8
2	259	10	26	5.7	6.7	5.6
0	218	13	24	5.6	6.3	5.8
0	84	9	22	5.6	6.0	5.8
0	5	0	20	5.8	5.8	5.9
0	25	17	18	5.8	5.8	5.8
0	25	5	16	5.7	5.9	6.4
0	37	5	14	5.5	5.9	6.2
45	92	0	12	5.5	6.0	6.2
61	158	0	10	5.7	6.2	6.3
528	874	0	8	7.3	8.2	6.2
47	73	0	6	5.9	6.6	6.2
8	11	0	4	6.3	5.8	5.4
0	0	0	2	5.5	5.8	6.4
10	0	0	0	5.5	5.9	6.2
0	5	0	2	5.2	5.8	6.3
30	629	0	4	5.3	7.7	6.2
12	617	7	6	5.8	8.1	6.2
0	25	4	8	5.5	5.9	6.1
0	47	3	10	5.6	6.1	6.3
13	29	6	12	5.5	5.8	6.4
0	26	7	14	5.8	5.9	6.2
0	9	4	16	5.6	5.9	6.1
0	23	4	18	5.5	5.9	6.2
0	0	43	20	5.6	6.0	5.8
0	47	103	22	5.4	6.6	6.7
0	10	29	24	5.4	5.7	6.0
0	0	12	26	5.4	5.8	5.8
0	0	0	28	5.5	5.9	5.8
0	0	0	30	5.6	5.9	5.9
0	0	0	32	5.6	5.8	5.9
0	0	0	34	5.7	5.7	5.8
0	0	0	36	5.5	5.4	5.8

Table 8.--Ammonium distribution and soil pH values in silt loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (4 inch depth, 16 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
10	15	4	36	6.1	6.8	6.0
0	16	5	34	6.2	6.8	5.9
6	7	9	32	5.8	6.8	6.1
0	28	3	30	6.0	6.6	6.0
5	153	17	28	5.8	6.5	6.7
83	179	50	26	6.6	7.4	6.9
478	239	68	24	8.1	7.0	6.9
441	252	37	22	8.0	7.6	6.8
275	208	51	20	6.7	6.9	6.7
11	201	4	18	6.2	7.2	5.9
16	101	6	16	5.7	7.1	6.1
8	8	3	14	5.6	6.3	6.0
31	14	6	12	6.0	6.3	6.1
30	0	3	10	6.3	6.3	5.8
116	6	7	8	6.2	6.1	5.7
358	72	5	6	7.5	6.7	5.9
1291	297	73	4	8.0	7.6	7.2
109	168	32	2	7.4	6.9	6.8
31	125	21	0	6.0	6.9	6.6
0	16	16	2	5.5	7.2	6.2
13	207	24	4	5.8	7.4	6.6
395	157	0	6	7.6	7.7	6.2
436	703	10	8	7.5	7.9	6.8
20	132	3	10	6.1	7.2	6.1
20	80	9	12	5.7	6.8	6.0
13	49	29	14	5.9	6.8	6.7
94	11	6	16	6.8	6.5	6.2
6	16	8	18	6.1	6.3	6.4
0	464	11	20	5.8	6.4	6.5
0	60	44	22	5.8	8.1	6.8
125	32	21	24	6.1	7.6	6.6
0	35	4	26	5.6	6.8	5.8
31	42	5	28	6.1	6.2	6.0
1	394	0	30	5.7	6.2	5.7
0	18	3	32	5.6	6.5	5.9
2	6	1	34	6.1	6.2	5.8
19	3	3	36	6.0	6.2	5.9

Table 9.--Ammonium distribution and soil pH values in silt loam soil following the application of 50 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (2 inch depth, 16 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	0	6	36	5.6	6.0	5.7
0	0	0	34	5.9	6.1	6.3
0	7	0	32	6.1	6.1	6.1
0	12	5	30	6.0	6.3	6.1
0	42	0	28	6.0	6.6	6.2
0	592	32	26	5.6	7.5	6.3
0	178	152	24	6.0	7.1	6.8
0	13	3	22	6.0	6.4	6.3
0	0	0	20	5.9	6.2	6.2
0	0	0	18	5.8	6.3	6.2
0	0	6	16	6.0	6.2	6.2
0	39	13	14	6.1	6.4	6.2
0	33	0	12	6.2	6.5	6.4
0	34	0	10	6.3	6.6	6.3
0	809	0	8	5.9	8.2	6.3
0	444	7	6	6.2	7.8	6.3
0	28	0	4	5.9	6.5	6.1
0	13	0	2	6.0	6.5	6.2
0	0	0	0	5.7	6.4	6.3
0	0	0	2	5.9	6.5	6.3
0	34	0	4	6.0	6.3	6.3
0	247	96	6	5.7	8.0	6.7
0	23	7	8	5.9	6.5	6.2
0	5	5	10	6.0	6.3	6.2
0	11	0	12	6.1	6.5	6.3
0	0	6	14	6.2	6.4	6.3
0	0	0	16	6.1	6.1	6.1
0	0	6	18	5.9	6.4	6.1
0	0	0	20	6.0	6.4	6.2
0	95	209	22	5.6	6.1	6.6
0	0	51	24	5.8	6.5	6.4
0	0	22	26	6.0	6.6	6.2
0	0	7	28	6.1	6.4	6.2
0	0	0	30	6.0	6.5	6.2
0	0	0	32	5.9	6.6	6.2
0	0	0	34	5.7	6.6	6.2
0	0	0	36	5.6	6.7	6.1

Table 10.--Ammonium distribution and soil pH values in silt loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (2 inch depth, 16 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	0	16	36	5.7	6.2	7.2
0	0	94	34	5.7	6.2	7.2
0	0	27	32	5.8	6.3	7.2
0	0	26	30	5.8	6.3	7.0
0	4	30	28	5.9	6.4	7.0
0	0	111	26	5.8	6.7	7.5
0	6	347	24	6.0	6.6	7.7
0	93	331	22	5.9	7.1	8.2
0	25	42	20	6.1	6.8	7.8
0	6	15	18	5.9	6.7	7.4
0	3	10	16	6.0	6.4	6.9
0	0	4	14	6.2	6.0	6.5
0	2	7	12	6.2	6.2	6.4
0	8	8	10	6.0	6.6	6.3
4	51	123	8	6.1	6.4	7.4
0	0	230	6	6.2	5.9	7.9
0	0	296	4	6.3	5.9	7.9
0	56	110	2	6.3	6.1	7.6
0	0	5	0	6.1	6.4	7.0
0	0	3	2	6.0	6.4	7.0
0	3	5	4	5.9	6.2	6.8
0	0	229	6	5.8	6.3	8.0
0	10	303	8	6.0	6.6	8.2
0	0	88	10	5.9	6.2	7.5
0	0	7	12	5.9	6.4	7.4
0	0	98	14	5.8	6.2	6.2
0	0	25	16	5.7	6.1	6.7
0	0	0	18	5.7	6.1	6.6
0	0	5	20	5.6	6.0	6.6
0	0	36	22	5.8	5.8	7.3
0	0	576	24	5.7	5.9	8.1
0	0	583	26	5.8	6.0	8.3
0	0	71	28	5.9	6.1	7.0
0	0	8	30	5.9	6.0	7.0
0	0	8	32	5.8	5.9	6.2
0	0	0	34	5.8	5.9	6.4
0	0	0	36	5.7	6.0	6.4

Table 11.--Ammonium distribution and soil pH values in a fine sandy loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (2 inch depth, 6 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	0	101	36	7.6	7.6	7.7
0	0	75	34	7.7	7.6	7.7
0	0	101	32	7.9	7.8	7.7
0	25	165	30	8.0	8.0	7.8
0	64	195	28	7.9	8.1	8.1
0	110	334	26	8.1	8.2	8.3
0	0	827	24	8.0	7.8	8.4
22	144	837	22	8.0	8.2	8.5
0	0	185	20	8.0	7.8	8.0
0	16	688	18	7.9	8.1	8.1
0	0	137	16	7.6	7.6	7.6
0	0	15	14	7.7	7.7	7.5
0	0	487	12	7.8	7.7	8.1
0	0	146	10	7.8	7.6	7.7
0	0	42	8	7.9	7.5	7.4
0	433	78	6	8.0	8.8	7.6
0	0	0	4	8.1	7.8	7.5
0	359	0	2	7.9	8.7	7.5
0	0	0	0	7.7	7.9	7.5
0	49	0	2	7.8	8.1	7.5
0	460	0	4	8.4	9.0	7.6
0	6	7	6	8.3	7.9	7.4
0	650	12	8	8.4	9.1	7.4
0	25	32	10	7.9	8.0	7.4
0	0	234	12	7.8	7.7	7.5
0	0	76	14	7.8	7.9	7.8
0	0	9	16	7.9	7.9	7.6
0	0	204	18	7.8	7.8	7.5
0	0	16	20	7.7	7.8	7.9
0	0	72	22	7.7	7.7	7.6
0	0	586	24	7.9	7.7	7.7
0	0	154	26	7.6	7.8	8.1
0	0	113	28	7.7	7.8	7.9
0	0	86	30	7.8	7.8	7.6
0	0	53	32	7.7	7.8	7.6
0	0	60	34	7.8	7.8	7.6
0	0	51	36	7.6	7.8	7.6

Table 12.--Ammonium distribution and soil pH values in a fine sandy loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (2 inch depth, 40 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	5	23	36	7.7	7.5	8.1
0	9	0	34	7.6	7.5	8.0
4	0	19	32	7.6	7.5	7.9
0	29	30	30	7.7	7.7	8.0
4	40	25	28	7.6	7.9	8.2
6	88	8	26	7.5	7.9	8.2
0	159	0	24	7.5	8.1	8.2
6	375	42	22	7.5	8.9	8.4
83	487	166	20	7.9	9.1	9.1
4	1,646	137	18	7.6	9.3	8.6
0	112	6	16	7.6	8.1	8.2
0	6	0	14	7.6	7.4	8.1
0	0	0	12	7.7	7.4	8.0
0	0	0	10	7.8	7.3	8.0
0	0	0	8	7.6	7.4	8.1
0	0	0	6	7.7	7.4	8.1
0	0	0	4	7.8	7.4	8.1
0	0	0	2	7.6	7.4	8.0
0	0	0	0	7.6	7.5	8.0
0	0	0	2	7.5	7.5	8.1
0	0	0	4	7.5	7.4	8.0
0	0	0	6	7.6	7.4	8.0
0	0	0	8	7.7	7.4	8.0
0	0	0	10	7.5	7.4	8.0
0	0	0	12	7.7	7.6	8.2
0	228	110	14	7.6	8.2	8.6
8	1,077	430	16	7.6	9.3	9.4
0	795	327	18	7.6	9.1	9.3
41	459	9	20	8.0	9.1	8.2
0	444	21	22	7.7	8.1	8.1
0	115	25	24	7.7	7.9	8.1
0	22	28	26	7.6	7.7	8.3
0	23	25	28	7.6	7.6	8.4
0	21	35	30	7.5	7.5	8.2
0	8	15	32	7.6	7.5	8.4
0	0	67	34	7.5	7.5	8.4
0	0	10	36	7.4	7.5	8.4

Table 13.--Ammonium distribution and soil pH values in a fine sandy loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (4 inch depth, 40 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
0	29	0	36	8.0	8.4	7.9
0	33	0	34	8.0	8.4	7.9
0	13	0	32	8.2	8.4	7.8
0	47	0	30	8.0	8.4	8.0
0	63	0	28	8.0	8.5	8.0
4	45	0	26	8.2	8.6	7.9
4	190	0	24	8.8	8.8	8.0
0	168	0	22	8.5	9.4	8.0
0	592	7	20	8.8	10.2	7.9
0	1,016	11	18	9.4	10.2	8.7
18	662	90	16	9.0	9.9	8.8
0	18	2	14	8.8	8.8	8.5
0	32	8	12	8.5	8.3	8.4
0	6	7	10	8.2	8.4	8.4
0	4	5	8	8.3	8.4	7.6
0	6	0	6	8.3	8.4	8.0
0	0	0	4	8.2	8.3	8.2
0	0	0	2	8.2	8.0	8.0
0	0	0	0	8.2	8.2	8.2
0	0	0	2	8.2	8.4	7.9
0	0	0	4	8.2	8.2	8.1
0	0	0	6	8.2	8.2	8.0
0	0	0	8	8.3	8.1	8.0
0	5	0	10	8.3	8.2	8.2
0	4	0	12	8.4	8.6	8.5
0	4	0	14	8.5	8.6	8.4
10	70	8	16	8.8	9.0	8.7
9	1,618	730	18	9.8	9.6	9.1
0	480	547	20	9.6	9.5	8.9
0	57	5	22	9.0	8.8	8.9
0	28	0	24	8.4	8.6	8.8
0	79	0	26	8.2	8.2	8.5
0	93	0	28	8.3	8.5	8.4
0	61	0	30	8.3	8.6	8.3
0	36	0	32	8.1	8.3	8.2
0	0	0	34	8.1	8.2	8.2
0	0	0	36	8.1	8.1	8.0

Table 14.--Ammonium distribution on soil pH values in a fine sandy loam soil following the application of 100 pounds of nitrogen as anhydrous ammonia per acre with an undercutting blade (4 inch depth, 6 inch spacing between points of release).

ppm NH_4-N Depth of samples (inches)			Distance from center of the blade (in.)	pH values Depth of samples (inches)		
4-6	2-4	0-2		4-6	2-4	0-2
346	243	0	36	8.2	8.4	8.1
54	160	0	34	7.8	8.4	8.1
54	213	0	32	7.8	8.4	8.1
0	52	0	30	7.7	8.2	8.1
54	53	0	28	8.0	8.3	8.1
0	261	0	26	7.8	8.4	8.2
267	353	0	24	8.2	8.5	7.9
168	264	0	22	8.1	8.4	8.1
133	160	0	20	8.2	8.3	7.9
221	238	0	18	8.1	8.5	7.9
27	78	0	16	7.8	8.3	8.0
80	0	0	14	8.0	8.4	7.9
298	0	0	12	8.3	8.2	7.8
163	78	0	10	8.1	8.2	7.9
163	0	0	8	8.1	8.2	8.0
427	52	0	6	8.3	8.2	8.1
161	79	0	4	8.1	8.2	8.2
347	105	0	2	8.3	8.4	8.1
53	403	0	0	8.0	8.5	8.2
0	132	0	2	7.8	8.3	8.0
273	211	0	4	8.3	8.4	8.0
162	106	0	6	8.2	8.3	8.0
194	351	0	8	8.3	8.4	8.1
0	107	0	10	8.0	8.2	8.0
27	159	0	12	8.0	8.4	8.1
55	215	0	14	8.0	8.4	8.0
0	107	0	16	8.0	8.3	8.0
55	322	0	18	8.0	8.4	8.1
189	401	0	20	8.2	8.5	8.1
55	185	0	22	8.0	8.3	8.1
374	483	0	24	8.4	8.6	8.1
138	320	0	26	8.0	8.4	8.1
27	156	0	28	8.1	8.2	8.1
107	135	0	30	8.0	8.3	8.0
27	158	0	32	8.1	8.4	8.1
26	105	0	34	8.1	8.4	8.0
0	184	0	36	7.9	8.2	8.1

Table 15.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Stafford County; 0 lb N/A, 0 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	18	20	25	11	26	18	16	29	23	20	14	23	15	15	25	*	*
Plant		3.24		3.16		2.72		2.88		3.06		3.04		2.98		*	*
REP II																	
Soil	50	15	14	22	17	22	18	13	18	16	13	20	18	13	18	*	*
Plant		2.60		2.44		2.62		2.18		2.40		2.40		2.36		*	*
REP III																	
Soil	18	18	10	10	14	14	10	10	18	10	13	10	21	15	16	*	*
Plant		2.18		2.36		2.48		2.52		2.38		2.64		2.86		*	*

*No sample taken

Table 16.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Stafford County; 50 lb N/A, 6 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	55	59	15	21	21	16	21	23	34	24	25	21	22	17	18	*	*
Plant		5.14		3.62		3.04		3.72		3.42		3.62		3.42		*	*
REP II																	
Soil	23	14	22	19	39	11	20	18	15	20	18	16	18	11	10	*	*
Plant		2.38		2.68		2.72		2.90		2.34		2.38		2.76		*	*
REP III																	
Soil	15	22	20	11	23	8	16	13	21	17	17	18	15	10	15	*	*
Plant		2.28		2.68		3.12		3.20		2.52		3.12		2.28		*	*

*No sample taken

Table 17.--Nitrogen concentrations in soil ans wheat plant tissues across the path of an undercutting blade 7 months after N application. (Stafford County; 50 lb N/A, 20 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	27	26	32	20	26	21	14	19	25	18	18	20	23	24	32	*	*
Plant		2.72		2.80		2.62		2.68		2.66		3.00		2.86		*	*
REP II																	
Soil	36	14	20	12	16	13	22	15	18	12	19	34	19	21	27	*	*
Plant		3.24		3.02		2.80		3.00		3.04		3.02		2.86		*	*
REP III																	
Soil	32	22	21	20	19	16	25	21	18	17	16	22	14	17	15	*	*
Plant		2.12		2.86		2.74		2.80		2.60		2.80		3.00		*	*

*No sample taken

Table 18.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Stafford County; 50 lb N/A, 40 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<u>REP I</u>																	
Soil	26	23	16	17	18	17	14	14	14	18	28	16	17	14	22	*	*
Plant		3.38		3.92		4.00		3.44		3.44		3.18		3.04		*	*
<u>REP II</u>																	
Soil	14	21	29	18	17	15	11	17	11	21	39	14	14	21	17	*	*
Plant		3.38		3.04		2.64		3.20		3.08		2.70		2.20		*	*
<u>REP III</u>																	
Soil	18	16	19	17	27	18	27	17	22	14	11	16	22	13	15	*	*
Plant		2.46		2.54		2.78		2.94		2.98		2.98		3.14		*	*

*No sample taken

Table 19.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Stafford County; 100 lb N/A, 40 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	23	18	29	37	36	20	21	23	24	12	34	31	19	19	21	*	*
Plant		3.46		5.10		4.48		2.70		3.20		3.96		3.00		*	*
REP II																	
Soil	22	27	25	39	19	14	8	13	21	53	23	36	14	14	32	*	*
Plant		2.92		3.28		3.52		2.88		3.12		3.18		2.96		*	*
REP III																	
Soil	19	15	33	14	54	21	13	13	13	16	41	22	29	12	18	*	*
Plant		2.48		3.38		3.12		2.80		3.32		3.48		3.24		*	*

*No sample taken

Table 20.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Kiowa County; 0 lb N/A, 0 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	11	9	9	9	9	9	8	9	8	8	9	9	10	11	9	9	9
Plant		3.34		3.04		2.96		2.78		3.22		3.18		2.98		3.22	
REP II																	
Soil	10	8	9	10	9	7	8	10	10	8	11	12	8	9	11	10	9
Plant		2.60		2.78		2.92		2.90		2.80		2.98		2.60		2.96	
REP III																	
Soil	12	7	15	16	10	9	6	10	5	6	7	6	6	5	8	6	10
Plant		3.22		3.16		2.80		3.44		2.96		3.26		2.68		3.54	

Table 21.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Kiowa County; 50 lb N/A, 6 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	11	9	11	11	12	16	14	18	14	13	9	12	10	10	9	9	9
Plant		3.08		3.16		3.18		3.56		3.20		3.12		3.04		3.20	
REP II																	
Soil	7	8	10	34	16	13	13	13	25	25	28	15	20	12	9	10	11
Plant		3.28		3.64		3.84		3.36		4.00		3.58		3.38		3.10	
REP III																	
Soil	10	12	30	8	8	8	11	7	8	11	8	9	12	9	6	11	8
Plant		3.22		3.58		3.40		3.34		3.40		3.60		2.78		2.68	

Table 22.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Kiowa County, 50 lb N/A, 20 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	10	10	16	28	37	10	10	10	11	10	14	14	10	10	11	11	9
Plant		3.24		3.88		3.50		3.48		3.76		3.88		3.12		3.68	
REP II																	
Soil	8	7	8	13	14	9	18	15	17	10	17	14	17	12	12	15	14
Plant		3.30		3.28		3.54		3.44		3.06		3.80		3.66		3.14	
REP III																	
Soil	11	8	13	40	21	8	11	9	8	8	19	9	12	10	9	8	8
Plant		3.94		3.62		3.48		3.56		3.74		3.50		3.22		3.04	

Table 23.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Kiowa County; 50 lb N/A, 40 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	9	10	9	11	11	12	18	11	9	9	11	11	11	10	12	10	13
Plant		3.22		3.04		3.44		3.68		3.68		3.24		3.08		3.52	
REP II																	
Soil	10	11	14	12	152	17	9	9	9	11	10	11	12	11	11	10	11
Plant		3.30		3.58		3.36		3.60		3.02		3.24		3.18		3.22	
REP III																	
Soil	12	8	13	37	26	10	10	12	9	15	10	11	10	8	12	12	11
Plant		2.96		3.06		3.12		2.94		2.92		3.60		3.14		3.20	

Table 24.--Nitrogen concentrations in soil and wheat plant tissues across the path of an undercutting blade 7 months after N application. (Kiowa County; 100 lb N/A, 40 inches between points of NH_3 release). Read vertically to compare plant and soil nitrogen concentrations.

Sample number across blade width	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REP I																	
Soil	8	9	11	9	10	30	46	8	10	11	9	9	12	68	29	10	10
Plant		3.26		3.30		3.68		3.72		3.44		4.08		3.76		3.24	
REP II																	
Soil	9	10	108	14	11	9	9	8	10	133	27	12	10	12	9	11	11
Plant		3.14		3.62		3.48		3.58		3.76		3.50		2.82		3.40	
REP III																	
Soil	8	7	15	28	37	5	5	5	9	9	9	54	12	5	8	7	7
Plant		3.34		3.64		3.62		3.24		4.00		3.72		3.68		3.32	

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RETENTION PATTERNS AND LOSS OF ANHYDROUS AMMONIA APPLIED WITH AN UNDERCUTTING BLADE

by

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The retention of and distribution of anhydrous ammonia applied with an undercutting blade was investigated on a Cass fine sandy loam (CEC=4 meq) and on a Geary silt loam (CEC=15 meq). Combinations of rates (50, 100, and 200 lb N/A), spacing between release points (6, 16, and 40 inches), application depths (2 and 4 inches), and orifice sizes (2/32 and 3/32 inch) were selected for study.

Soil texture and application depth did not markedly affect distribution patterns, but did affect the retention of anhydrous ammonia in the soil. Excellent retention of ammonia was attained in the Geary silt loam even using adverse application practices. Ammonia losses were detected, however, from the sandy soil when applied at a 2 inch depth. Applications 4 inches below the soil surface continued to produce ammonia loss while using the 40-inch spacing between release points. When the ammonia was dispersed uniformly across the blade path by using the 6-inch spacing, losses were reduced to less than one percent.

The distribution patterns were determined by ammonium nitrogen analysis of a vertical cross-section of soil samples taken from the blade path. Distribution patterns across the blade path were unique to the spacing used. The distribution patterns were commonly oval-shaped around each release point. The lateral movement was directly proportional to the rate of application while initial vertical movement was limited to 2 inches. A 2/32-inch orifice was preferred in order to maintain pressure in the distribution line which caused uniform dispersion of ammonia across the blade path.

The second phase of the study was to make field applications of ammonia preplant to wheat in order to determine the effects of N rate and spacing between release points on plant nitrogen absorption, wheat yields, test weight and protein content of the grain at five Kansas locations.

Plant nitrogen content was statistically correlated with soil inorganic nitrogen concentrations, which were dependent upon N rate and spacing, when collected seven months after ammonia applications. Wheat yield differences were statistically significant at two locations. The 6- and 16-inch spacing commonly produced higher yields than the 40-inch spacing, however, statistical values were not significant for spacing effects only. Nitrogen rate and spacing had no consistent effect on test weight or protein percentage of wheat grain.