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Evaluation of Cogranulated Urea-urea Phosphate  
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**EVALUATION OF COGRANULATED UREA-UREA PHOSPHATE AS A  
NITROGEN SOURCE FOR CROP PRODUCTION**

**By**

**Richard Malcolm Johnson**

**A THESIS**

**Submitted to**

**Michigan State University**

**in partial fulfillment of the requirements**

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## ABSTRACT

### EVALUATION OF COGRANULATED UREA-UREA PHOSPHATE AS A NITROGEN SOURCE FOR CROP PRODUCTION

By

Richard Malcolm Johnson

Field, greenhouse and laboratory experiments were conducted to evaluate the relative N use efficiency of cogranulated urea-urea phosphate (UUP) as compared to urea (U) and  $\text{NH}_4\text{NO}_3$  (AN). Performance was evaluated in conventional and reduced tillage systems. Estimates were made of the soil's urea hydrolysis rate and of  $\text{NH}_3$  volatilization. Field experiments indicated a possible advantage to delaying N application 6-8 weeks after planting. Incorporation of UUP and U benefited crop yields. Greenhouse experiments showed that initial soil moisture content, residue level, N rate and N source all may influence  $\text{NH}_3$  loss. No difference in urease activity was recorded due to treatment. Results from the field  $\text{NH}_3$  loss experiment suggested an advantage to UUP over U. The tentative ranking of N sources in terms of relative N use efficiency would be :  $\text{AN} > \text{UUP} > \text{U}$ .

## DEDICATION

This thesis is dedicated to my grandparents Dorothy M. Johnson and Armand F. Joly. Their love and help throughout the years has been a constant source of inspiration.

Also, to my parents Robert and Carolyn Johnson. Their encouragement and love has given me the determination to finish and succeed.

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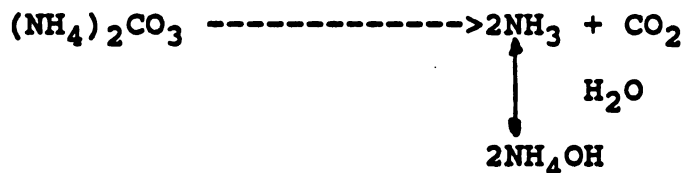
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## INTRODUCTION

In 1984, over 11 million tons of N fertilizer were applied in the United States. Urea  $[\text{CO}(\text{NH}_2)_2]$ , accounted for almost 25 % of this total, with an application of 2.7 million tons. The amount of urea applied in the United States has increased steadily since 1955 (Hargett and Berry, 1984). Several properties of this material have promoted its increased popularity. Urea contains 45-46 % N, the highest percentage of N currently available in any solid material. It is also less expensive to manufacture than many other N fertilizers. Finally, urea is easy to handle and safe to store in both the solid or solution form.

The principal drawback of urea is the possible loss of N due to  $\text{NH}_3$  volatilization. Although it is not an  $\text{NH}_4$  fertilizer in its applied form, urea is rapidly hydrolyzed by soil urease to  $(\text{NH}_4)_2\text{CO}_3$ . This compound is unstable and rapidly decomposes. Several investigators have proposed the following reaction mechanisms for this process (Fenn and Miyamoto, 1979; Terman and Hunt, 1964 and Chin and Kroontje, 1963):



It is apparent from examining the previous reactions that many physical, chemical and biological factors can affect the quantity of  $\text{NH}_3$  volatilized. Soil pH, soil moisture content, CEC, soil texture, soil urease levels, soil temperature, organic carbon and soil N all influence the amount of  $\text{NH}_3$  lost. In addition, atmospheric properties can give significant effects. The major factors include atmospheric  $\text{NH}_3$  concentration and relative humidity.

Most of the properties just mentioned are difficult if not impossible to control in the field. However, some degree of control may be achieved through cultural practices. Nitrogen rate, N source, timing of application and incorporation of N fertilizers are all good management practices which can increase efficient use of N and reduce losses due to  $\text{NH}_3$  volatilization. Although these practices are effective in many cases, they are complicated even further when urea or urea-based materials are applied in reduced tillage systems. The principle drawback, with respect to  $\text{NH}_3$  volatilization, is associated with the layer of crop residue left on the

surface in most reduced tillage systems. The residue can decrease the rate of fertilizer dissolution by preventing contact of the fertilizer with the soil. Also, urease activity is heightened in this residue layer. This would promote a rapid conversion of urea to  $(\text{NH}_4)_2\text{CO}_3$ , thus increasing the volatilization potential.

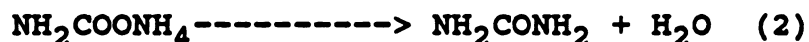
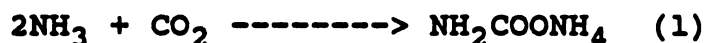
The objectives of this study were : 1) To investigate several methods in which N use efficiency may be increased in reduced tillage systems. These included variations in; N source, N application rate, method of application and timing of application; 2) To evaluate volatile  $\text{NH}_3$  loss from urea and urea-urea phosphate in the field as influenced by N application rate, and 3) To estimate the soil's urea hydrolysis rate as influenced by N application rate, N application method, initial moisture content, tillage system and soil texture.

## Literature Review

### CHEMISTRY OF UREA

Since the year 1773 when urea  $[\text{CO}(\text{NH}_2)_2]$  was first isolated from urine by Rouelle, scientists have studied its properties and benefits. However, it was not until 1920, when the availability of inexpensive raw materials made the manufacture of urea economically feasible, that it gained popularity as a N fertilizer. This source of raw materials came as a direct result of the implementation of the Haber process for the synthesis of  $\text{NH}_3$  (Hardesty, 1955).

Urea is produced by reacting  $\text{NH}_3$  and  $\text{CO}_2$  gas under high pressure and temperature (19.2-27.3 MPa , 180-195 C), in the presence of a suitable catalyst. Most often the catalyst is an iron-potassium aluminate mixture (Pesik, Stanford and Case, 1971). The  $\text{NH}_3$  and  $\text{CO}_2$  react to form ammonium carbamate, which is then decomposed to yield urea and water. The following reactions illustrate this process:



(Tisdale and Nelson, 1975)

Urea, or carbamide, is the amide of carbonic acid. It is a nonionic nitrogen material used not only as a fertilizer, but also as a protein supplement in ruminant nutrition and in the manufacture of plastics. Urea is a white crystalline solid containing 45-46 % N in the most common fertilizer grade. It is very soluble in water, at 30 C , 100 ml of H<sub>2</sub>O dissolve 133 g of urea. This is compared with 242 g for ammonium nitrate and 78 g for ammonium sulfate. If urea is mixed with NH<sub>4</sub>NO<sub>3</sub> the solubilities of both compounds are enhanced; 719 grams of urea and 845 grams of NH<sub>4</sub>NO<sub>3</sub> will dissolve in 100 ml of water to yield 1,206 ml of solution (Gasser, 1964). These solubility characteristics of urea have helped to increase its popularity, especially for use in N solutions.

Urea, in its crystalline form, is less hygroscopic than NH<sub>4</sub>NO<sub>3</sub>, Ca(NO<sub>3</sub>)<sub>2</sub> and NaNO<sub>3</sub>; but more hygroscopic than most other N fertilizers. Thus the material is likely to cake or deliquesce if stored in humid conditions. This is especially true if urea is mixed with other N. It is apparent that crystalline urea is more useful in making urea solutions, where granular or

prilled urea, which is less hygroscopic, is of greater use as a solid fertilizer. This decrease in the hygroscopic behavior of urea may be due to a clay film that is generally present in the prilled or granulated products.

Urea has numerous advantages for use as a N fertilizer. It has the highest percent N of any solid material and is easy and safe to handle and store. The high solubility of urea also make it ideal for solution application, alone or in combinations with other fertilizers or pesticides.

There are also several disadvantages of application of urea as a fertilizer. Biuret [ $\text{NH}_2\text{-CO-NH-CO-NH}_2$ ] , may be formed in the synthesis or subsequent processing of urea. If present in sufficient quantities, the compound may exhibit toxic effects to crops. Free  $\text{NH}_3$ , formed from the decomposition of urea, may damage the germination and early growth of crops. Finally,  $\text{NH}_3$  may be lost to the atmosphere upon the decomposition of surface applied fertilizer. This process is known as  $\text{NH}_3$  volatilization (Tisdale, Nelson and Beaton, 1985).

Fertilizer manufacturers have developed many new N materials in an effort to decrease volatile losses of N from urea or urea-based fertilizers. Most try to combine the benefit of the high N analysis of urea with some technique to control the hydrolysis of urea or

subsequent volatilization of  $\text{NH}_3$ . Techniques to minimize losses include (1) reduction of pH (2) coating of urea granule surfaces, or (3) reduction of  $\text{NH}_3$ -loss through the precipitation of Ca and Mg carbonates (Terman, 1979).

Urea forms addition products with many acids and salts. Examples would include urea nitrate (UN)  $[\text{CO}(\text{NH}_2)_2 \cdot \text{HNO}_3]$  and urea phosphate (UP)  $[\text{CO}(\text{NH}_2)_2 \cdot \text{H}_3\text{PO}_4]$ . Both of these materials possess a low solution pH and theoretically the reduction of pH would decrease volatile loss of  $\text{NH}_3$ . Gasser and Penny (1967) confirmed this theory and found UN and UP both to be efficient fertilizers. However, UN was found to result in injury to plant growth, where UP did not result in injury. Bremner and Douglas (1971) investigated UP further and found that it also reduced  $\text{NH}_3$  loss. The phosphoric acid formed in the decomposition of UP effectively retarded urease activity, thus reducing losses.

Tennessee Valley Authority (TVA) has conducted considerable research using urea phosphates for N and P sources. Recently, they released several new experimental urea phosphate materials. These materials are generally cogranulated products of urea and urea phosphate. They are formed by adding supplemental urea during the production of urea phosphate. Urea-urea phosphate (UUP), has a flexible nutrient content and N: $\text{P}_2\text{O}_5$  ratios of 1-1-0, 2-1-0 or 3-1-0 are possible. UUP represents an attempt

at combining the high N analysis of urea with a compound that reduces  $\text{NH}_3$  loss. Other research has been conducted to further investigate the agronomic effectiveness of this material (Yerokun, 1984).

Another property of urea fertilizers that may affect  $\text{NH}_3$  volatilization losses is granule size. Watkins et al. (1972) reported that varying urea granule size from 0.1 cm to 0.5 cm had no affect on  $\text{NH}_3$  losses. Nommik (1973a,b) found that the  $\text{NH}_3$  volatilization rate was retarded when the urea granule was increased from 0.003 g to 2.06 g. Mahli and Nyborg (1979) observed a significant decrease in the rate of urea hydrolysis by increasing urea granule size from 0.01 g to 2.26 g. They also noted that losses were even further suppressed by the inclusion of an urease inhibitor.

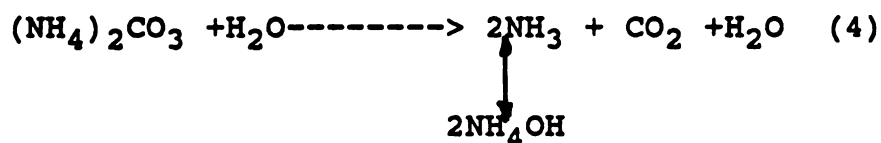
Nommik (1973a,b) offered the following explanation for the inhibition of  $\text{NH}_3$  volatilization by increased urea granule size. He indicated that the rate of solute diffusion would be increased by increasing granule size. This was due to an increase in the concentration gradient. The urea or  $\text{NH}_4$  would thus diffuse to a greater depth in the soil and would be protected against further volatilization losses. Utilizing large granules would also decrease the rate of urea hydrolysis This is due to an uneven distribution of large granule urea, coupled with a limited supply of urease present directly on the

soil surface. He also noted that further decreases in loss could be achieved if an urease inhibitor was added along with large granule urea.

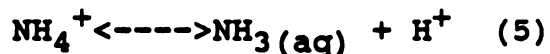
#### CHEMISTRY OF $\text{NH}_3$ LOSS: NON-CALCAREOUS SOILS

When urea is applied to the soil surface, it is quickly hydrolyzed to  $(\text{NH}_4)_2\text{CO}_3$ . This reaction is catalyzed by the enzyme urease. Urease is found universally in soils. Bacteria, fungi and actinomycetes all produce urease and thus decompose urea (Tisdale, Nelson and Beaton, 1985). Certain soil properties will encourage an increase in the level of the enzyme. Increases in the soil microbe population will usually be associated with increased urease activity. Other properties related to heightened urease activity would include an increase in; organic carbon, soil nitrogen, clay content and CEC (Zantua et al., 1977; Dalal, 1975; McGarity and Meyers, 1967 and Reynolds, Wolf and Armbruster, 1985).

Ammonium carbonate is unstable in the soil and rapidly decomposes to  $\text{NH}_3$  and  $\text{CO}_2$  gas. The following equations illustrate this process:



Upon the decomposition of  $(\text{NH}_4)_2\text{CO}_3$ , the following equilibrium situation may govern the  $\text{NH}_3\text{-N}$  loss:



In non-calcareous soils,  $\text{NH}_3$  volatilization occurs as the result of the dissociation of  $\text{NH}_4^+$  to  $\text{NH}_3(\text{aq})$  and  $\text{H}^+$ . The following relationships describe this phenomenon.

$$\frac{[\text{NH}_3(\text{aq})][\text{H}]}{[\text{NH}_4^+]} = K_d = 10^{-9.5} \quad (6)$$

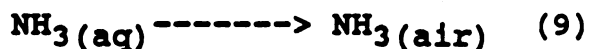
$$\log \frac{[\text{NH}_3(\text{aq})]}{[\text{NH}_4^+]} = -9.5 + \text{pH} \quad (7)$$

$\text{NH}_3(\text{aq})$  is the concentration of  $\text{NH}_3$  in the soil solution. This concentration will increase with increasing pH. For example, at pH values of 5, 7, and 9 the concentration of  $\text{NH}_3(\text{aq})$  will be 0.0032, 0.32 and 32 % of the total ammonical N in the soil solution (Nelson, 1982). The amount of  $\text{NH}_3$  lost from the soil solution will be a function of the partial pressure of  $\text{NH}_3$  over the solution. Henry's law states that the amount of a gas dissolved in a liquid at constant temperature is directly proportional to the partial pressure of the gas above the solution. Thus, at equilibrium:

$$[\text{NH}_3(\text{aq})] = K_H P_{\text{NH}_3} \quad (8)$$

If the concentration of  $\text{NH}_3(\text{aq})$  is changed, by addition of  $\text{NH}_4^+$  or by increasing the pH, the equilibrium between  $\text{NH}_3(\text{aq})$  and  $P_{\text{NH}_3}$  will be changed. The net result

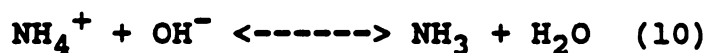
of this change in equilibrium will be a loss of  $\text{NH}_3$  to the atmosphere.



This  $\text{NH}_3$  loss, or volatilization, will continue until limited by  $\text{NH}_4^+$  concentration or by pH. As previously stated,  $\text{NH}_4^+$  upon dissociation will liberate a  $\text{H}^+$  ion. Thus in an unbuffered system,  $\text{NH}_3$  volatilization would lead to an acidification of the medium and cease after a short time. Avnimelech and Laher (1977) found that the buffering capacity of the system against an increase in pH is extremely important in determining the quantity of  $\text{NH}_3$  volatilized. If the system is well buffered, volatilization may proceed for long periods even though large quantities of  $\text{H}^+$  ion are released. This conclusion was verified by Vlek and Stumpe (1978), who found that in an aqueous system the buffering capacity frequently determined the amount of  $\text{NH}_3$  lost. Ferguson et al. (1984) stated "the potential for  $\text{NH}_3$  volatilization is decreased with increased  $\text{H}^+$  ion buffering capacity." These findings imply that the amount of  $\text{NH}_3$  volatilized by a soil may also depend on that soil's ability to supply  $\text{H}^+$  ions and thus resist an increase in pH.

#### CHEMISTRY OF $\text{NH}_3$ LOSS: CALCAREOUS SOILS

Jewitt (1942) postulated that the loss of ammonia in alkaline soils occurred by the following mechanism:



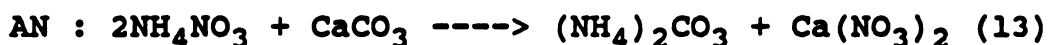
At high pH values, the activity of the  $\text{OH}^-$  ion would be increased, thus driving the reaction to the right and promoting increased loss of  $\text{NH}_3$ . Increasing the concentration of  $\text{NH}_4^+$  would have the same effect. This equilibrium was also suggested by several later investigators (Duplessis and Kroontje, 1964; Wahhab et al., 1957 and Ernst and Massey, 1960).

Ernst and Massey (1960) were among the first to suggest that calcium compounds play an important role in  $\text{NH}_3$  volatilization. They suggested that an increase in the degree of Ca-saturation of the soil exchange complex would occur with an increase in pH. This would lead to a decreased adsorption of  $\text{NH}_4^+$  and increase the probability of volatilization losses.

Larsen and Gunary (1962) investigated several ammonium fertilizers in an attempt to identify the mechanism of  $\text{NH}_3$  volatilization. They postulated that the different rates of  $\text{NH}_3$ -loss could be explained by examining the solubilities of the reaction products of different  $\text{NH}_4^+$ -N sources with Ca compounds in the soil. They investigated  $\text{NH}_4\text{NO}_3$ ,  $(\text{NH}_4)_2\text{SO}_4$  and several ammonium phosphates. Although they did not achieve conclusive results, it was apparent from their work that several factors other than pH were effecting  $\text{NH}_3$  volatilization.

Foremost of these was the formation of low solubility Ca salts when  $\text{NH}_4^+$ -N sources reacted with  $\text{CaCO}_3$  in the soil.

Terman and Hunt (1964) conducted a more complete investigation of this phenomenon. They concluded that  $\text{NH}_3$ -volatilization losses increased with decreasing solubility of reaction products. They suggested that the following reactions occur in calcareous soils:

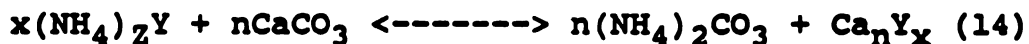


As previously discussed, the  $(\text{NH}_4)_2\text{CO}_3$  formed is unstable and will decompose yielding  $\text{NH}_3$  and  $\text{CO}_2$  gas. Both DAP and AS react with  $\text{CaCO}_3$  to form Ca-salts of low solubility. AN forms a soluble compound. If the reaction products are of low solubility, a more complete formation of  $(\text{NH}_4)_2\text{CO}_3$  will occur. This will allow greater volatilization of  $\text{NH}_3$ . Conversely, if the reaction products are soluble and stable, less  $(\text{NH}_4)_2\text{CO}_3$  will form and losses will be decreased.

It should be noted that the hydrolysis of urea is not dependant on reaction with calcium compounds. It only requires  $\text{H}_2\text{O}$  and urease.

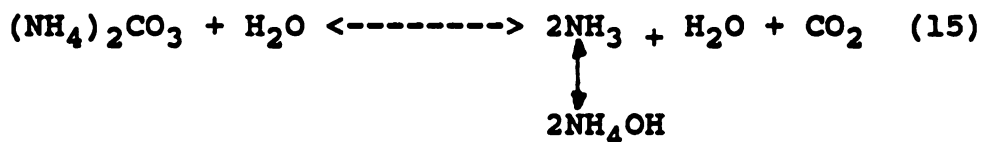
Fenn and Kissel (1973) described a series of reactions which they suggested represented the mechanism

of  $\text{NH}_3$  volatilization in calcareous soils. When  $\text{NH}_4$  compounds are applied to the soil surface they react with  $\text{CaCO}_3$  to form Ca-salts of varying solubilities:



(where Y represents the anion associated with the  $\text{NH}_4^+$  cation)

$(\text{NH}_4)_2\text{CO}_3$  is unstable and decomposes as follows:



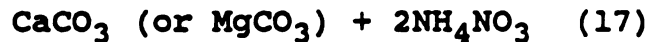
If  $\text{Ca}_n\text{Y}_x$  is insoluble, more  $(\text{NH}_4)_2\text{CO}_3$  will be formed. If  $\text{Ca}_n\text{Y}_x$  is soluble and does not form a precipitate  $(\text{NH}_4)_2\text{CO}_3$  formation will be minimized. The anions investigated that form insoluble precipitates with calcium were; Ca ( $\text{F}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HPO}_4^{2-}$ ). The other salts investigated formed soluble reaction products, Ca ( $\text{NO}_3$ ,  $\text{Cl}$ ,  $\text{I}$ ) and gave low  $\text{NH}_3$  losses.

As  $(\text{NH}_4)_2\text{CO}_3$  decomposes according to this reaction  $\text{CO}_2$  is lost from solution at a greater rate than  $\text{NH}_3$ . This allows for the production of additional  $\text{OH}^-$  and leads to greater  $\text{NH}_3$  loss by the following reaction:



This equilibrium is pH dependant with lower pH's favoring the  $\text{NH}_4^+$  forms.

Although this mechanism described loss of  $\text{NH}_3$  for  $\text{NH}_4^+$ -N compounds, it offered little insight as to how the loss of  $\text{NH}_3$  from urea might be controlled. This problem was addressed by Fenn et al. (1979). Their technique involved the application of Ca and Mg nitrates or chlorides with surface applied solutions of urea. They discovered that the  $\text{NH}_3$  was dramatically reduced when this procedure was used. They described the process with the following equation:



As the soil pH increases from the hydrolysis of urea to AC,  $\text{CaCO}_3$  and  $\text{MgCO}_3$  were precipitated. This reduced the AC concentration and decreased  $\text{NH}_3$  loss.

### Tillage System

Many reduced tillage practices have significant effects on the soil environment. Changes can occur in soil physical, chemical and biological properties (Baeumer and Bakermans, 1973; Griffith et al., 1977 and Phillips et al., 1980 ). These changes have necessitated a re-evaluation of many agricultural practices. For generations, agriculture has relied on the moldboard plow as the principle form of primary tillage. Prior to its adoption, economic control of weeds was not possible. It was not until the development of plant growth regulators

in the 1940's that reduced tillage systems became feasible ( Phillips et al., 1980 ). Herbicides allowed the farmer to reap the benefits of reduced tillage agriculture, while avoiding the problems caused by weed competition.

In 1985, 31 % of the cropland in the United States was planted in some form of conservation tillage system (Cons. Till. Inf. Cen., 1986 ). This represents an increase of almost 2 % over 1984 and from all indications this trend will continue. Because of this increase in popularity, an increased percentage of agricultural research has addressed problems associated with reduced tillage systems.

Reduced tillage systems leave a layer of crop residue on the soil surface. This may lead to an increase in soil moisture content and a decrease in soil temperature ( Moody et al., 1963; Thomas et al., 1973; Van Doren and Triplett, 1973; Van Wijk et al., 1959). The increase in soil moisture is most likely due to reduced evaporation and increased infiltration of rainfall. The decrease in temperature is related to the insulating effect of the residue and a change in surface albedo, which reflect radiation rather than adsorb it (Thomas and Frye, 1984) as well as the increased moisture content.

A reduced tillage system is generally a cooler, wetter environment. Nitrogen mineralization will tend to be slower in these systems. This is because the soil is undisturbed and the organic residues are left on the surface where decomposition is slower. Denitrification is also a greater concern in reduced tillage systems. Rice and Smith (1982) found that the rate of denitrification is directly related to the soil moisture content. Reduced tillage systems should therefore, exhibit a greater rate of denitrification because they possess a higher soil moisture content. Nitrate leaching losses tend to be higher in these systems. This is due to several factors. Evaporation is negligible in tillage systems that leave significant quantities of residue on the surface. Therefore, the upward movement of water and salts is practically stopped. This is coupled with decreased rainfall infiltration. The result is downward movement of rain and  $\text{NO}_3$ . Also, there exists a greater percentage of large pores in an undisturbed soil. The main flow of water will be through these large pores and not through the bulk of the soil. This will yield a deeper penetration of both water and  $\text{NO}_3$  (Thomas et al., 1973 and Thomas and Frye, 1984)

Finally,  $\text{NH}_3$  volatilization losses can be very high in reduced tillage systems (Bandel et al., 1980; Fox and

Hoffman, 1981 and Mengel et al., 1982). This is especially true if urea or other  $\text{NH}_4^+$ -N sources are surface broadcast. Touchton and Hargrove (1982) reported that both yield and N uptake were significantly reduced when a UAN solution was applied as a surface broadcast application. This treatment was notably less efficient than surface broadcast solid urea. Thomas and Frye (1984) explained the increased loss of  $\text{NH}_3$  from UAN solutions by noting that contact with plant residues (and urease) is more likely in this form. Torello and Wehner (1983) found that urease activity in bluegrass clippings was 18 to 25 times greater than in the underlying soil. Klein and Kothe (1980) showed that the urease activity was significantly higher in a no-till corn production system as compared to a conventionally tilled system. It is thus apparent that considerable caution must be exercised when applying urea as a surface broadcast application in a reduced tillage system.

Several researchers have tried incorporating urea fertilizers into the soil (Touchton and Hargrove, 1982; Mengel et al., 1982 and Grove et al., 1983). It was postulated that this practice would decrease  $\text{NH}_3$  volatilization losses. Ernst and Massey (1960), in a laboratory experiment, found a decrease in  $\text{NH}_3$  loss with an increase in depth of incorporation. Preliminary results indicate that an increase in efficiency is achieved by incorporating urea fertilizers. Reductions in

nitrogen immobilization may also be observed when nitrogen materials are incorporated and placed away from the concentration of residues at the surface (Mengel et al., 1982). Finally, incorporation of fertilizers will allow for a more rapid and complete dissolution of the material. A surface residue may impede this process and thus increase  $\text{NH}_3$  loss.

#### FACTORS AFFECTING UREA HYDROLYSIS

##### Temperature

It is generally accepted that urease activity increases with increasing temperature (Conrad, 1940; Fisher and Parks, 1958; Broadbent et al., 1958 and Simpson and Melsted, 1963). More recently several investigators have reported that an optimum temperature range exists. Further increases in temperature above this level will result in deactivation of the enzyme and thus a decrease in activity. The temperature range generally accepted as an optimum is 10 to 70 C (Bremner and Mulvaney, 1978; Petit et al., 1976; Chin and Kroontje, 1963 and Gould et al., 1973).

Several investigators have studied the persistence of urease in soils at subzero temperatures. It was found that temperatures of -10 to -33 C did not destroy soil urease (Bremner and Zantua, 1975; Speir and Ross, 1975 and Zantua and Bremner, 1975). Furthermore, it was

reported that urease activity was detected in soils at -10 to -20 C (Bremner and Zantua, 1975). This activity was postulated to have resulted from enzyme-substrate interactions in unfrozen water at the surfaces of soil particles. This conclusion was evidenced by experiments showing that urea hydrolysis did not occur in autoclaved soils or in the absence of clay minerals.

### Moisture

Several investigators have suggested that the soil moisture content had no effect on soil urease activity (Gould et al., 1973 and Zantua and Bremner, 1979). These reports are contrasted by other workers who have found that urease activity is increased (Stojanovic, 1959 and Vasilenko, 1962) or decreased (Simpson and Melsted, 1963) by increasing soil moisture content. It is likely that the effects of soil moisture on urease activity are generally small, as compared to soil temperature. Hydrolysis rates are probably highest at soil moisture contents in the readily available range to plants.

### Substrate Concentration

Many researchers have reported increases in urease activity with an increase in substrate (urea) concentration (Fisher and Parks, 1958; Simpson and Melsted, 1963; Overrein and Moe, 1967 and Gould et al., 1973). Other investigators have observed no response in

urease activity to urea applications (Zantua and Bremner, 1976 and Lloyd and Sheaffe, 1973). An explanation to this controversy was offered by Bremner and Mulvaney (1978). The rate of hydrolysis by urease increases with increasing urea concentration until the enzyme becomes saturated with the substrate. Further additions of urea over this level of saturation will give no increase in activity. Earlier work reporting an increase in urease activity with an increase in urea concentration was conducted in systems in which the substrate was limiting. More recent experiments have demonstrated that if urea is not limiting, an increase in activity will not be observed.

#### SOIL REACTION

Several investigators have attempted to determine the effect that pH has on urease activity (Vasilenko, 1962; Simpson and Melsted, 1963 and Petit et al., 1976). Much of this work utilized different buffer solutions and urea concentrations so comparisons between studies are difficult to make. Also, results are variable. Some workers have reported an optimum pH range of 6.5 to 7.0 (Vasilenko, 1962 and Petit et al., 1976) while others have reported a range of 8.8 to 9.0 (Tabatabai and Bremner, 1972).

### Organic Carbon, % Clay, CEC

Numerous researchers have determined that soil urease activity is highly correlated with organic carbon in soils (Gibson, 1930; Conrad, 1940; Chin and Kroontje, 1963; McGarity and Meyers, 1967; Moe, 1967; Lloyd and Sheaffe, 1973; Zantua and Bremner, 1976; Zantua et al., 1977 and Reynolds et al., 1985). These studies also found that additions of organic compounds to a soil may temporarily lead to an increase in urease activity. The increased levels may persist for several weeks, but eventually they will become identical to that of unamended soil. These findings suggest that the soil constituents protect urease against microbial degradation and inactivation. Each soil seems to have a stable level of urease activity, depending on its soil constituents (Zantua and Bremner, 1976). Paulson and Kurtz (1969) attempted to determine the locus of urease in soils. They were curious as to the percentage of activity that arose from urease directly associated with microorganisms and that from urease adsorbed to soil colloids. They determined that 79-89 % of the urease activity was due to urease adsorbed on soil colloids. Burns et al. (1972) obtained similar results and postulated that most urease activity was associated with the organo-mineral complex. This would give urease a degree of resistance against the activities of proteolytic enzymes and help to account for the persistence and stability of urease in the soil. A

carbon addition would yield a temporary burst in activity, but when the source was depleted the excess, free urease would be degraded or inactivated. The activity would then return to its stable level.

Urease activity is also highly correlated with clay content and soil CEC (Zantua et al., 1977 and Reynolds et al., 1985). These findings would be explained by the aforementioned mechanisms. A high soil CEC or clay content would also be reflected by an increase in the quantity of urease adsorbed by the soil colloids.

Boyd and Mortland (1985a,b, 1986) found that urease or other enzymes adsorbed by hydrophobic bonding to smectite-organic complexes exhibited varying degrees of activity depending on the nature of the adsorbed organic species and the nature of the enzyme. The immobilized enzymes tended to exhibit a decreased thermal stability and were more susceptible to degradation by proteolytic enzymes. This was explained by noting that both urease and protease bind to the surface of the clay. The close proximity of these enzymes would increase proteolysis over the level observed in a homogeneous solution. It was also stated that this mechanism may play a minor role in soils due to the scarcity of hydrophobic bonding sites.

## Cultivation

Gibson (1930) was perhaps the first to demonstrate that cultural practices may have significant effects on soil urease activity. In a survey of soils of Scotland he reported greater activity in soils from pastures than in cultivated land. He also noted that forest soils were generally more active than cultivated soils. He attributed this increase in activity to the greater content of organic matter present in these soils. Speir et al. (1980) compared urease in pots activity under a perennial ryegrass sod and in pots left fallow. Activity was initially similar in both treatments. However, the activity in the fallow pots was found to decrease steadily. This was attributed to a decrease in the microbial population and a temperature dependent denaturation of the enzyme. Reynolds et al. (1985) reported higher urease activities in pasture samples as compared to cultivated samples of the same soil type. They noted that pasture samples generally possessed higher organic carbon, CEC and microbial numbers. This may have accounted for the increased activity. Klein and Kothe (1980) found greater activity in no-tillage corn plots as compared to conventional tillage plots. It is possible that the increased surface residue present in no-tillage plots could have accounted for this increase in activity.

## FACTORS AFFECTING AMMONIA VOLATILIZATION

## Temperature

Most investigators have reported increased loss of  $\text{NH}_3$  with increasing temperatures (Martin and Chapman, 1951; Volk, 1959; Ernst and Massey, 1960; Wahhab et al., 1960; Watkins et al., 1972 and Harper et al., 1983). This increase in  $\text{NH}_3$  loss could result from an increase in evaporation. This would occur as the temperature was increased and could have served as a driving force to  $\text{NH}_3$  volatilization. Also, an increase in the equilibrium constant ( $K$  in EQ 6) would occur with increasing temperature. This results in a higher proportion of the ammonical N present as  $\text{NH}_3(\text{aq})$ . Increases in temperature would also increase diffusion of  $\text{NH}_3$  from the soil and allow a more rapid conversion of  $\text{NH}_3(\text{aq})$  to  $\text{NH}_3(\text{air})$ , thus increasing the volatilization potential (Vlek and Stumpe, 1978 and Nelson, 1982).

Meyer et al. (1961) reported a decrease in  $\text{NH}_3$  loss with increasing temperature. They explained this by noting the decrease in nitrification that would occur at lower temperatures. They also pointed out that urease is active at low temperatures. This would lead to a rapid increase in the soil  $\text{NH}_4$  concentration. The soil exchange complex could not adsorb this surge of additional  $\text{NH}_4$  and it would be available for loss. Gasser (1964) in a similar experiment, reported a temperature response that

was closely associated with soil CEC. If the soil CEC was low results similar to Meyer et al. would occur. This was because the  $\text{NH}_4$  present was in excess of the soil's ability to adsorb it. However, if the soil CEC was high, the  $\text{NH}_4$  could be adsorbed and the increased loss at low temperature might not be observed.

Fenn and Kissel (1974) conducted a thorough investigation on the effect of temperature on  $\text{NH}_3$  loss from applied  $\text{NH}_4^+$ -N fertilizers. They concluded that the effect of temperature on  $\text{NH}_3$  loss depends on the presence of  $\text{CaCO}_3$  in the soil and on the type of  $\text{NH}_4^+$ -N compound. If the compound reacts with  $\text{CaCO}_3$  to form an insoluble precipitate, the effect of temperature was slight. They observed that a high temperature would yield a high initial loss, but would decrease with time. A low initial temperature would give a low initial loss, but increase with time.

If the  $\text{NH}_4^+$ -N compound formed a soluble reaction product with  $\text{CaCO}_3$ , the temperature response was notably different. No response was observed to  $\text{NH}_4^+$  rates, but an increase in total loss and the rate of  $\text{NH}_3$  loss was reported with an increase in temperature.

#### Soil Moisture Content

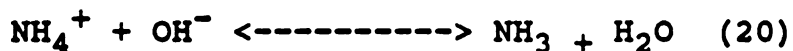
Many researchers report that  $\text{NH}_3$  loss will increase with increasing soil moisture content up to field

capacity (Volk, 1959; Ernst and Massey, 1960; Wahhab et al., 1960; Kresge and Satchell, 1960; Baligar and Patil, 1968 and Harper et al., 1983). This will allow for maximum rates of hydrolysis and still permit rapid soil drying. A low soil moisture content will cause a decrease in hydrolysis and allow less drying to occur. Other researchers have suggested that  $\text{NH}_3\text{-N}$  losses decrease with increasing soil moisture content (Martin and Chapman, 1951; Wahhab et al., 1957; Fenn and Escarzaga, 1976 and Yerokun, 1984). It is possible that when the soil moisture content is increased over the level needed to solubilize added fertilizer, an inhibition of  $(\text{NH}_4)_2\text{CO}_3$  formation occurs.

It should be noted that the majority of this research was conducted at soil moisture levels at or approaching field capacity. This work was also conducted in closed dynamic systems in which relative humidity could have effected the results. Ernst and Massey (1960) reported a decrease in  $\text{NH}_3$  loss with increases in relative humidity. Hargrove et al. (1977) in a field experiment, observed a diurnal fluctuation of  $\text{NH}_3$  loss. They explained this behavior by noting a similar diurnal fluctuation in atmospheric relative humidity. The major effect of an increase in relative humidity would be a decrease in the rate of soil drying. However, Brown and Bartholomew (1963) reported that there existed a competition between  $\text{NH}_3$  and aqueous vapor for sorption

sites on clays. All moist clays tended to adsorb less  $\text{NH}_3$  than dry clays in the range of  $\text{NH}_3$  pressures from 1 to 60 mm Hg. An increase in adsorption did occur with increases in  $p\text{NH}_3$  greater than 60 mm Hg.

Jewitt (1942) suggested a mechanism for  $\text{NH}_3$  loss that was closely associated with the concentration of  $\text{NH}_4$  salt in the soil and the loss of moisture from the soil. The initial soil moisture content had a relatively small effect. The following equilibrium was considered:



In this situation, both  $\text{NH}_3$  and  $\text{H}_2\text{O}$  would have their own partial pressures and would evaporate at a rate proportional to their respective molar concentrations. The soil is buffered somewhat with respect to  $\text{OH}^-$  concentration. The soil solution is also buffered for changes in  $\text{NH}_4^+$  concentration. This is due to the reversible reaction of free  $\text{NH}_3$  with the soil exchange complex. The result is that the equilibrium between  $\text{NH}_3$ ,  $\text{NH}_4^+$  and  $\text{OH}^-$  is maintained as a constant. Thus the ratio of  $\text{NH}_3$  loss to  $\text{H}_2\text{O}$  loss should be a constant. However, the ratio falls off slowly indicating a depletion of  $\text{NH}_4$  ion from the soil exchange complex. Wahhab et al. (1957) reported similar results a constant ratio of  $\text{NH}_3$  loss to  $\text{H}_2\text{O}$  loss, limited by the  $\text{NH}_4$  ion in the exchange complex.

Chao and Kroontje (1964) conducted a more complete investigation of this relationship. They discovered that  $\text{NH}_3$  loss and  $\text{H}_2\text{O}$  loss are not linearly related. They occur at different rates and may be described by different functions. The rate of  $\text{NH}_3$  loss decreased with time, while the rate of  $\text{H}_2\text{O}$  loss remained constant to near air-dry conditions.

Several other researchers have also looked at the relationship between moisture loss and  $\text{NH}_3$  loss (Martin and Chapman, 1951; Kresge and Satchell, 1960; Lauer et al., 1976 and Ferguson and Kissel, 1986). In most of these experiments evaporation was thought to act as the driving force behind  $\text{NH}_3$  volatilization. Experiments utilizing urea have revealed that the rate of drying frequently determines the quantity of  $\text{NH}_3$  lost. The rates of loss are generally not related directly and are not constant. If conditions of rapid drying exist,  $\text{NH}_3$  loss may be at a minimum. This is because the soil may have approached air-dry before the hydrolysis of urea was complete. Maximum losses have occurred under conditions of gradual drying, in which sufficient moisture is present to allow complete hydrolysis of urea (Ernst and Massey, 1960; Volk, 1959; Fenn and Escarzaga, 1976 and McInnes et al., 1985).

Several workers have showed a decreased loss of  $\text{NH}_3$  if sufficient rainfall or irrigation is present to move

the fertilizer into the soil (Meyer et al., 1961; Oberle and Bundy, 1984 and Bouwmeester et al., 1985 ). Fox and Hoffman (1981) have suggested the following guidelines for application of unincorporated urea in no-till corn:

(1) If at least 10 mm of rain falls within 2 days of application of urea, no  $\text{NH}_3$  loss will occur.

(2) If 10 mm or more rain falls 3 days after the urea is applied,  $\text{NH}_3$  losses will be slight ( < 10 % ).

(3) If 3-5 mm of rain falls within 5 days or 7-9 mm within 9 days  $\text{NH}_3$  will be moderate ( 10 to 30 % ).

(4) If no rain falls within 6 days, the  $\text{NH}_3$  loss can be substantial ( > 30 % ).

Increased  $\text{H}_2\text{O}$  applications reduce  $\text{NH}_3$  loss due to the fact that undissociated urea moves into the soil. Fenn and Miyamoto (1979) have demonstrated this effect. They suggest that urea moves slightly behind the wetting front. This explains the high  $\text{NH}_3$  loss normally observed in conditions of high evaporation. If the wetting front moves the urea below the depth of possible capillary movement losses will be greatly reduced.

## Nitrogen Rate

Many researchers have investigated the effect of an increased application rate of  $\text{NH}_4^+$ -N or urea fertilizers on  $\text{NH}_3$  volatilization losses. Most researchers have found that the total quantity of  $\text{NH}_3$  volatilized increases with increasing application rate. This would be predicted by Eq's [3] and [4]. An increase in  $\text{NH}_4^+$  would shift the equilibrium to the right and a greater quantity of  $\text{NH}_3$  would be available to be volatilized.

The principle point of disagreement in this area of research concerns the rate of  $\text{NH}_3$  volatilization. Some workers have found that the rate of  $\text{NH}_3$  loss increases with increasing rate of application (Wahhab et al., 1957 and Baligar and Patil, 1968b). Other investigators have reported that the rate of  $\text{NH}_3$  loss is constant (Jewitt, 1942; Martin and Chapman, 1951; DuPlessis and Kroontje, 1964 and Hargrove et al., 1977 ). Fenn and Kissel (1976) found that the rate of  $\text{NH}_3$  loss may also depend on the  $\text{NH}_4^+$ -N source. Using  $(\text{NH}_4)_2\text{SO}_4$ , they observed an increase in percentage loss of  $\text{NH}_3$  with increasing application rate. With  $\text{NH}_4\text{NO}_3$  they reported a decrease in percentage loss. They attributed the decrease in percentage loss with  $\text{NH}_4\text{NO}_3$  to a decrease in pH. They noted that  $(\text{NH}_4)_2\text{SO}_4$  should produce a greater decrease in pH, but this was not the case in a calcareous soil. The percentage loss with  $(\text{NH}_4)_2\text{SO}_4$  was also found to rapidly

decrease with decreasing application rate. This could be explained by a greater degree of adsorption of  $\text{NH}_4^+$  on the soil exchange complex.

#### Method of Application

Surface application of urea or other  $\text{NH}_4^+$ -N fertilizers results in an increased  $\text{NH}_3$  volatilization potential (Ernst and Massey, 1960; Meyer et al., 1961 and Gasser, 1964). This loss potential is generally increased if the soil surface is moist (Fenn and Kissel, 1976 and Fenn and Escarzaga, 1976). With urea this increased loss is due primarily to an increase in urease activity in moist soils. The applied urea fertilizer will be rapidly hydrolyzed and there is a greater likelihood that the material will volatilize before it can be moved into the soil by rainfall. With other  $\text{NH}_4^+$ -N sources, the primary problem is a more rapid dissolution of the fertilizer when applied to a moist soil (Fenn and Escarzaga, 1976). This will allow for a greater period of time in which volatilization can occur.

One strategy used to decrease these losses is incorporating the fertilizer into the soil. Several researchers have demonstrated that this practice can significantly reduce volatilization losses. Jackson and Burton (1962) reported that urea and  $\text{NH}_4\text{NO}_3$  resulted in equal yields when incorporated 15 cm below the soil surface. Steinberg (1944) reported that the  $\text{NH}_3$  loss from

$(\text{NH}_4)_2\text{SO}_4$  could be reduced to 0 when the fertilizer was covered with 6 cm of soil. Ernst and Massey (1960) applied urea to the soil surface and then covered it with soil layers of; 0.6, 1.3 and 3.8 cm. Although the differences among treatments were not large, there was a trend of decreasing  $\text{NH}_3$  loss with increasing depth of incorporation. Fenn and Kissel (1976) observed that a dry soil cover was more effective than a moist soil cover. They postulated that a dry soil cover would stop evaporation of water from the soil. This would account for the decreased losses of  $\text{NH}_4^+$ -N fertilizers that they observed. A dry soil cover would also decrease the rate of urease activity, this would account for the decreased losses of urea and urea-based fertilizers.

Another technique that is frequently used in an attempt to decrease volatilization losses is timing of fertilizer application. Mills et al. (1974) reported that rapidly growing corn seedlings were effective in diminishing  $\text{NH}_3$  volatilization losses. They attributed these reductions to a rapid crop uptake of  $\text{NH}_4^+$ . Also, they noted that acidification of the soil, especially in the rhizosphere, after  $\text{NH}_4^+$  adsorption may aid in its retention by the soil. It is important that the application rate not exceed the needs of the plant. In this case plants may exhibit  $\text{NH}_3$  toxicity symptoms. Meyer et al. (1961) also observed an increase in N use efficiency when they applied urea as a summer sidedress.

They cited a more efficient uptake by an actively growing crop as the reason for decreased  $\text{NH}_3$  losses.

#### Rate of Air-Flow & Atmospheric $\text{NH}_3$

Several investigators have reported an increase in  $\text{NH}_3$  losses with an increase in the rate of air-flow over the soil. In a field experiment this would mean an increase in wind speed. In a laboratory experiment this would be an increase in the rate air exchange (Chao and Kroontje, 1964; Overrein and Moe, 1967; Watkins et al., 1972; Kissel et al., 1977 and Lauer et al., 1977 ). The rate of  $\text{NH}_3$  loss increases until an air-exchange rate of 15-20 volumes per minute is achieved (Kissel et al., 1977). This rate of air-exchange is equivalent to a wind velocity of approximately 0.26 km/hr. Wind velocities of this magnitude are almost always present at the soil surface. However, in a crop canopy this velocity may be significantly reduced. Many laboratory experiments have utilized an exchange rate of 10 volumes per minute or less. In this range,  $\text{NH}_3$  loss increases linearly with increases in the air-exchange rate. Not only are these experiments under-estimating the  $\text{NH}_3$  loss, they are also increasing variability. Fenn and Kissel (1973) reduced loss variability to 10 % or less, with an air-exchange rate of 14-16 volumes per minute.

A rapid flow of air across the soil surface will decrease the partial pressure of  $\text{NH}_3$  in the immediate

vicinity. This will permit rapid diffusion of  $\text{NH}_3$  from the soil, due to a large partial pressure gradient (Nelson, 1982). Avnimelech and Laher (1977) stressed the importance of this factor and stated that: " One can easily demonstrate that if no  $\text{NH}_3$  is present in the air, all the  $\text{NH}_3$  in the soil will eventually disappear." They also commented that this factor is highly variable and is affected by industrial and urban fumes, as well as by the neighboring fertilized fields. A number of researchers have investigated atmospheric  $\text{NH}_3$  concentrations (Leubs et al., 1974; Denmead et al., 1974; Denmead et al., 1976 and Denmead et al, 1978).

Another consequence of rapid air flow across the soil surface is an increase in the soil moisture loss. This is especially true if the air is of low relative humidity. As previously stated, the rate of soil drying can have significant effects on the quantity of  $\text{NH}_3$  lost from a soil.

#### Texture, Organic Matter & CEC

Several researchers have demonstrated that soil texture may be an important factor in determining the quantity of  $\text{NH}_3$  lost from a soil. Wahhab et al. (1957) observed significantly higher losses in a sandy soil, as compared to a sandy-loam soil. This trend was also demonstrated by Chao and Kroontje (1964). Greater losses were recorded on a coarse textured soil. Ryan and Keeney

(1975) reported similar results with surface applications of a wastewater sludge. A decrease in  $\text{NH}_3$  loss was observed with an increase in clay content of the soil.

It is generally accepted that soils covered with surface residues or a grass sod will lose more N due to  $\text{NH}_3$  volatilization than bare soils. Volk (1959, 1961) reported a  $\text{NH}_3$  loss of 25 % for a bare soil, 29 % for an unlimed turf and 39 % for a limed turf. Meyer et al. (1961) observed increased  $\text{NH}_3$  loss when a straw residue covered the soil surface. A similar increase in volatilization losses was also observed in forest soils.  $\text{NH}_3$  loss ranged from 6-30 % when urea was applied to a bare soil and from 27-46 % when the surface was covered with a forest litter (Watkins et al., 1972). Rashid (1977) showed an increase in  $\text{NH}_3$  volatilization losses when organic residues having a high C/N ratio were present. He explained these losses by noting that a decrease in nitrification would occur at high C/N ratios. This would leave a larger concentration of  $\text{NH}_4^+$ -N to be potentially volatilized. Immobilization of nitrogen was not considered.

Increased  $\text{NH}_3$  losses due to surface residues are generally explained by one of two mechanisms. Urease activity is consistently higher in organic residues. Torello and Wehner (1983) observed urease activity 18 to 25 times higher in turfgrass clippings as compared to the

underlying soil. Increased urease activity would lead to a greater degree of urea hydrolysis and possibly, increased volatilization losses. Also, residues possess a limited CEC. This would permit them to retain less  $\text{NH}_4^+$  on exchange sites and more  $\text{NH}_3$  could be lost. The greater volatilization potential of coarse textured soils could also be explained by a limited CEC.

A number of researchers have investigated the effect that the soil exchange complex can have on  $\text{NH}_3$  volatilization. Conrad and Adams (1940) reported that the soil adsorbed both urea and the  $\text{NH}_4^+$  produced in the hydrolysis of urea. Urea was generally retained to a lesser extent than the  $\text{NH}_4^+$ . The positively charged  $\text{NH}_4^+$  ion would be attracted to the net negative charge of the clay lattice. Urea is an uncharged molecule and would thus move with the soil water. Adsorption of  $\text{NH}_4^+$  would decrease volatilization losses. Several other workers have also arrived at this conclusion. An increase in CEC should result in a decrease in  $\text{NH}_3$  losses (Martin and Chapman, 1951; Ernst and Massey, 1960 and Baligar and Patil, 1968). Gasser (1964) indicated that a soil's base exchange capacity (BEC) was the most important factor in determining the quantity of  $\text{NH}_3$  lost from applied  $(\text{NH}_4)_2\text{SO}_4$ . Soils with a BEC of less than 10 me/100 g were found to volatilize 20 % or more of the added fertilizer. Losses decreased to less than 10 % when the BEC increased to 20 me/100 g. Fenn and Kissel (1976) confirmed earlier

opinion by finding that, in general,  $\text{NH}_3$  loss decreased as CEC increased. They also noticed that the percentage decrease in  $\text{NH}_3$  loss, from an increase in CEC, was greater for an application rate of 110 kg/ha than at 550 kg/ha. They explained this occurrence by postulating that a greater percentage of the  $\text{NH}_4^+$  would be adsorbed at a lower application rate.

## MATERIALS AND METHODS

The objectives of this research were discussed in the previous section. This section will describe the experimental procedures. Field experiments were conducted in 1984 and 1985. They were conducted at two different locations to evaluate the effect of soil texture on relative nitrogen-use efficiency. One site was located at the Saginaw Valley Bean and Sugar Beet Research Farm. The soil type was a Charity clay. The other site was located in East Lansing on a Conover loam. At both locations a conventional tillage system was compared with a conservation tillage system. Fertilizer performance was also evaluated as determined by yield, N uptake and % N content at silking. A greenhouse experiment was conducted in the winter of 1985 to determine crop response under controlled conditions.

In the summer of 1985 a field experiment was initiated to determine quantitatively, the amount of  $\text{NH}_3$  lost by volatilization. This experiment was conducted at the field site in East Lansing.

In 1985, the urease activity was determined at both field sites and in greenhouse soils. Factors including

tillage system, soil texture, nitrogen application rate and method of application were evaluated.

#### GENERAL DESCRIPTION of SOILS

Field experiments were conducted on both the Charity clay and the Conover loam. In the greenhouse and ammonia loss experiment only the Conover loam was utilized. The soils are described below.

##### Charity Clay

This soil is classified as Aeric, Haplaquept, fine, illitic, mesic with 80 g kg<sup>-1</sup> sand, 280 g kg<sup>-1</sup> silt and 640 g kg<sup>-1</sup> clay.

The cation exchange capacity was estimated to be 270 to 290 mmol (p<sup>+</sup>) kg<sup>-1</sup> soil (Zielke, 1983 and Yerokun, 1984).

##### Conover Loam

This soil is classified as Udollic, Ochraqualf, fine, loamy, mixed, mesic with 380 g kg<sup>-1</sup> sand, 450 g kg<sup>-1</sup> silt and 170 g kg<sup>-1</sup> clay.

The cation exchange capacity was estimated to be 105 mmol (p<sup>+</sup>) kg<sup>-1</sup> soil (Yerokun, 1984).

Soil test values are presented in Table 1.

Table 1. Soil test values for field experiments.

Soil Type	pH	Bray P1	Exchangeable		
		P	K	Ca	Mg
		----- mg kg <sup>-1</sup> ----			
Charity	7.2	63	354	7215	1281
Conover	7.4	60	150	2122	363

#### Field Experiments

In this study two tillage systems were established in each location (Table 2). A conventional tillage program consisted of fall disking and fall moldboard plowing and a conservation tillage program of fall disking and fall chisel plowing in Saginaw and no-till in East Lansing. In the conventional tillage programs and in the conservation tillage plots in Saginaw in 1984, the spring seedbed was prepared with a single pass of a spring and spike-tooth harrow. The remaining conservation tillage plots received no spring tillage.

Table 2. Tillage systems for experiments 1984 and 1985.

Location	Year	Tillage System <sup>+</sup>	
		Conventional	Conservation
Saginaw	1984	FD-FMP-SC-P	FD-FCP-SC-P
	1985	"	FD-FCP-P
E. Lansing	1984	FD-FMP-SC-P	P
	1985	"	P

+ FD-fall disk, FMP-fall moldboard plow, FCP-fall chisel plow, SC-spring cultivation, P-plant.

The quantity of residue present on the soil surface was measured after spring tillage but before planting. In both years, two procedures were used. The photographic method of Hartwig and Laflen (1978) was used to obtain an estimate of percent cover. Also, a quantitative measurement of the actual amount of residue present was made using the procedure of Whitfield et al. (1962). In 1985, the line transect method of Laflen et al. (1981) was used to obtain an additional estimate of percent cover.

The nitrogen treatments consisted of three sources [urea (U), urea-urea phosphate (UUP) and ammonium nitrate (AN)] three rates (0, 134, 179 kg N ha<sup>-1</sup>), two placements (surface broadcast and banded 5 cm deep below the soil surface between rows between rows) and two application

dates. In Saginaw the application dates were; May 9 and June 26 in 1984 and May 11 and June 11 in 1985. In East Lansing, the dates were May 11 and June 12 in 1984 and May 2 and June 7 in 1985. Treatments were arranged in a split plot design with four replications. Tillage was the main plot and nitrogen treatment the sub-plot.

In Saginaw, P fertilizer was applied at rates of 106 kg  $P_2O_5$  ha<sup>-1</sup> in 1984 and 157 kg  $P_2O_5$  ha<sup>-1</sup> in 1985. In East Lansing, P and K were applied at 27 kg  $P_2O_5$  ha<sup>-1</sup> and 107 kg  $K_2O$  ha<sup>-1</sup>, respectively. Weeds were controlled by preemergence application of 1.96 kg ha<sup>-1</sup> Cyanazine and 2.8 kg ha<sup>-1</sup> Alachlor. Preplant control of quackgrass (Agropyron repens L.) was accomplished with 1.68 kg ha<sup>-1</sup> of Glyphosate and post emergence control of Canada thistle (Cirsium arvense L.) was accomplished with 0.84 kg ha<sup>-1</sup> of Bentazon. Corn (Zea mays L.) was planted with a John Deere no-till planter, at 54,000 seeds ha<sup>-1</sup> in 76 cm rows.

Ear leaf samples were collected at silking by removing ten leaves per plot. In addition, whole plant samples were collected at maturity. This was done by harvesting ten plants (less roots) per plot. The ears were removed from the stalks. Weights of stover and ears were determined. Subsamples of both grain and stover were collected for moisture determination. Nitrogen

determinations were made on grain and stover so that N uptake could be calculated.

Yields were determined by hand harvesting two 7.01 m rows. All yields were corrected to 15.5 % moisture. Planting dates, harvest dates and plant tissue sampling dates are presented in Table 3.

Table 3. Planting, harvesting and plant sampling dates for field experiments conducted in 1984 and 1985.

Location	Year	Planting Date	Harvest Date	Ear Leaf	Whole Plant
Saginaw	1984	5/9	10/2	7/27	9/20
	1985	5/7	10/1	8/2	9/17
E.Lansing	1984	5/11	10/6	7/16	9/13
	1985	5/2	9/24	7/22	9/22

#### Greenhouse Experiment

A greenhouse experiment was conducted in the winter of 1985 using Conover loam soil to measure crop response to N fertilizers. Soil test levels are given in Table 4. Treatment combinations included three N sources (U,UUP and AN), three N rates (0,75 and 150 mg N kg<sup>-1</sup> soil), two

levels of surface applied corn residue (0 and 336 g m<sup>-2</sup>) and two moisture regimes (surface moistened and surface dry) arranged in a randomized complete block with four replications.

Table 4. Soil test values for greenhouse and NH<sub>3</sub> experiment.

Soil Type CEC <sup>+</sup>	pH	Bray P1	Exchangeable			Zn
		P	K	Ca	Mg	
			---- kg ha <sup>-1</sup>		--- mg kg <sup>-1</sup>	
Conover loam 105	7.2	164	314	4267	591	5
+ cmmol (p <sup>+</sup> ) kg <sup>-1</sup> soil						

The soil taken from the field was air dried, mixed and screened to pass a 4.75 mm sieve. One thousand eight hundred eighty g of soil was then placed in tared pots lined with plastic. Each pot received 50 mg P kg<sup>-1</sup> soil and as KH<sub>2</sub>PO<sub>4</sub>, K levels were adjusted to 100 mg K kg<sup>-1</sup> soil with KCl. In addition 20 mg Zn kg<sup>-1</sup> soil was applied before planting the second crop. The moisture content was then adjusted to 0.15 kg H<sub>2</sub>O kg<sup>-1</sup> soil and ten corn seeds were planted to a depth of 2.54 cm. These were later thinned to three plants per pot. Residue treatments were applied after planting. Fertilizer was applied

immediately after planting for those pots receiving the high initial moisture treatment. These pots then received three 0.025 L moisture applications as a spray treatment over the next ten days. This is equivalent to a 1.3 mm rainfall event. The surface of the pots receiving the low initial moisture treatment was permitted to dry for a period of three days before fertilizer was applied. These pots received no additional moisture for seven days. After this period 0.100 L of water was applied to the surface to leach the fertilizer into the soil. After the initial ten day period, all pots were put on a regular watering schedule and maintained at  $0.15 \text{ kg H}_2\text{O kg}^{-1} \text{ soil}$ .

Three consecutive crops of corn (Zea mays var. Pioneer 3901) were grown for a period of five weeks each. Daytime temperature ranged from 20 to 29 C. Night temperature was controlled at 20 C. Supplemental irradiation of  $20 \text{ umol m}^{-2} \text{ s}^{-1}$  was provided for a period of  $16 \text{ hr day}^{-1}$ . Moisture was adjusted daily to 80 % of field capacity ( $0.15 \text{ kg H}_2\text{O kg}^{-1} \text{ soil}$ ) by gravimetric means.

At the end of five weeks plants were harvested by clipping the above ground portion at the soil surface. Soil from the no residue treatments was sieved to pass a

4.75 mm screen, repotted and replanted. Where residue was applied seeds were "punch" planted to a depth of 2.54 cm.

At the end of the experiment soil samples were taken from each pot for laboratory analysis.

### Field Ammonia Volatilization Experiments

Field measurements of  $\text{NH}_3$  volatilization were made in East Lansing on a Conover loam soil. The objective of this experiment was to quantify the  $\text{NH}_3$  lost from applied urea and urea based fertilizers with a minimum disturbance to the soil field environment. This was done by constructing a vacuum driven aeration apparatus similar to that of Kissel et al. (1977). A diagram of the basic apparatus is given in (Figure 1). The experimental variables consisted of; N source (U, UUP) and N rate (0, 84, 168, 252 kg N ha<sup>-1</sup>). These treatments were replicated three times, with two samples per replication.

Metal containers with a diameter of 15.5 cm were driven into the soil. When covered, the air volume enclosed above the soil surface was 1 liter. The containers were connected to boric acid (20 g L<sup>-1</sup>) traps and to the vacuum pump with tygon tubing. The air flow rate was adjusted to 0.083 L s<sup>-1</sup>. This air exchange rate is equivalent to a wind velocity of 0.05 km h<sup>-1</sup>. The

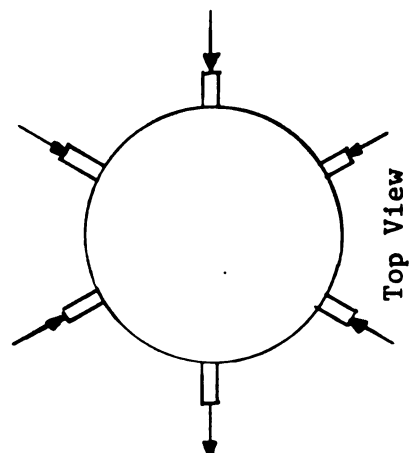
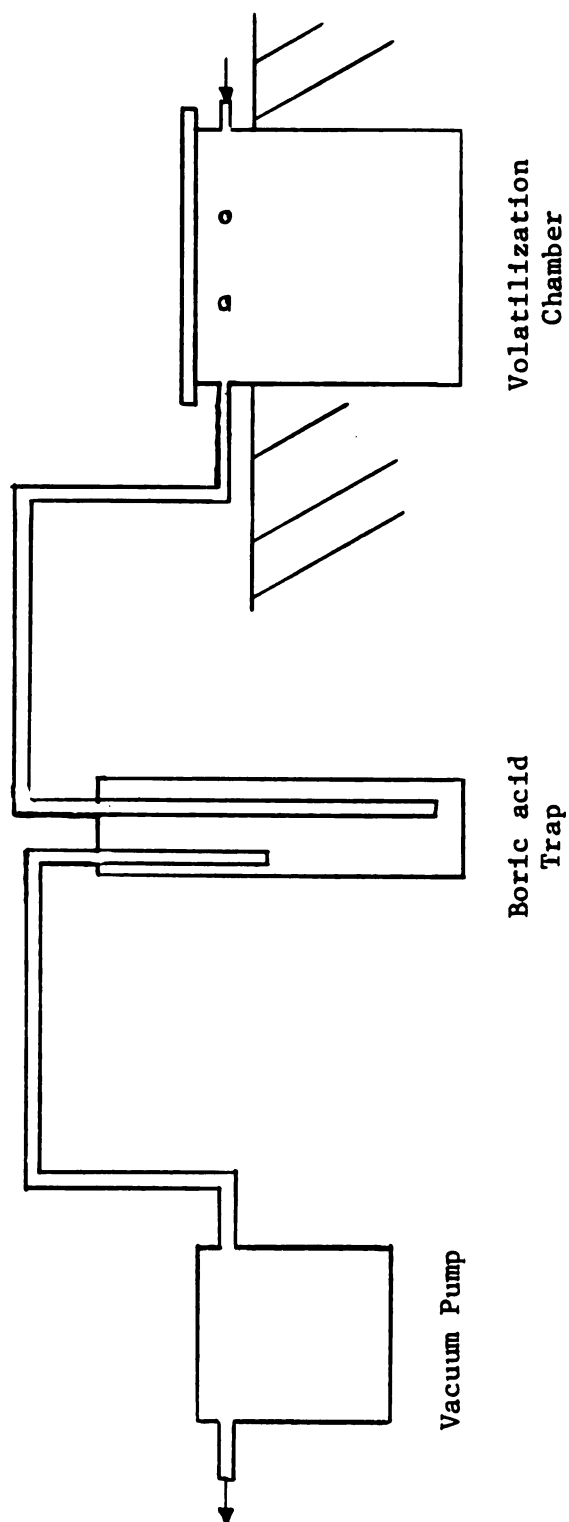


Figure 1. The Basic Volatilization Field Sampler used in the ammonia loss experiment, East Lansing, 1985.

volatilization chambers were covered only when measuring  $\text{NH}_3$  loss to minimize disturbance to the soil environment.  $\text{NH}_3$  loss was measured for a period of 1800 seconds on alternate days for an eight day period. Trapped  $\text{NH}_3$  was measured by titration with standard  $\text{H}_2\text{SO}_4$ . In addition to  $\text{NH}_3$  measurements,  $\text{CO}_2$  and soil and air temperature measurements were made inside the volatilization chambers. A  $\text{CO}_2$  sampling port was installed in the system after the volatilization chamber and preceding the chemical trap (Figure 1). Two 0.003 L samples were taken from each chamber during  $\text{NH}_3$  measurement. These samples were stored in a cooler and analyzed the same day using an infrared gas analyzer system as described by Schumacher and Smucker (1983). Soil and air temperatures were recorded during  $\text{NH}_3$  measurement and for 600 seconds prior to this time. A system of copper constantan thermocouples was installed and temperature readings were recorded once per 60 s using a computerized data collection system. Environmental data including relative humidity, air temperature and rainfall were collected every day prior to  $\text{NH}_3$  measurements. It should be noted that the chambers were covered during rainfall events, but uncovered immediately after.

At the termination of the experiment, soil samples were collected from each of the chambers and saved for  $\text{NO}_3$  and  $\text{NH}_4$  analysis.

### Urea Hydrolysis Experiment

In the summer of 1985 selected soil samples were collected from the field experiments in Saginaw and East Lansing. Soils were sampled to a depth of 2.54 cm and 20 probes per plot were taken. These samples were sealed in plastic bags and immediately placed in a cold room at 4 C until urea hydrolysis measurements could be performed.

The urea treatments evaluated from the field experiments included; nitrogen rate (0, 134, 179 kg N ha<sup>-1</sup>), method of placement (surface broadcast or sidedress) and tillage system (conventional or conservation). In addition, selected urea treatments from the greenhouse were evaluated. They included; nitrogen rate (0, 75, 150 mg N kg<sup>-1</sup> soil), and residue level (0, 3.36 mg kg<sup>-1</sup> soil). Treatments were arranged in a randomized complete block design with four replications.

Before urea hydrolysis rates were determined, background urea levels in the soil was measured. No detectable urea was found.

Urea hydrolysis was determined using the buffer method of Zantua and Bremner (1975). This consisted of incubating 5 g of soil with 0.010 L of a urea solution containing 5,000 ug urea-N. Incubations were conducted in

stoppered 0.125 L Erlenmyer flasks on a rotary shaker at 50 rpm. Incubations were carried out at  $25 \pm 1$  C for 5 hours. Soils were then extracted with 0.040 L of 2M KCl containing  $50 \text{ mg L}^{-1}$  phenylmercuric acetate at 200 rpm on a rotary shaker. After extraction, an aliquot of the extract was analyzed for urea-N by the procedure described by Douglas and Bremner (1970).

Urea hydrolysis was calculated by subtracting urea remaining from the initial urea added. Rates were reported as  $\text{ug urea hydrolyzed g soil}^{-1} \text{ h}^{-1}$ .

### Laboratory Analyses

#### Plant Sample Treatment

All plant samples from the field and greenhouse studies were dried at 60 C for 48 hours. Dry weights were then obtained. Samples were thereafter ground to pass a 0.425 mm sieve and total Kjeldahl N content was determined.

### $\text{NH}_4$ and $\text{NO}_3$ Extractions

Soil samples were placed in plastic bags immediately after sampling and then stored in a cold room at 4 C until analyses could be performed. Extractions for  $\text{NO}_3^-$  and  $\text{NH}_4^+$ -N were performed by using a 10:1 w/v ratio of 2M KCl.

### Total Nitrogen Determinations

Total N on plant tissue was determined by the micro Kjeldahl method similar to that described by Bremner (1965). Two hundred milligrams of plant tissue were digested in 0.100 L Kjeldahl flasks, using .003 L 72 M  $\text{H}_2\text{SO}_4$  and 1.3 g catalyst mixture (100:10:1 mixture of  $\text{K}_2\text{SO}_4$ : $\text{CuSO}_4$ :Se). The samples were digested for 1.5 hours. After cooling, 0.10 L of distilled water was added to each sample. Ammonia was liberated by alkaline steam distillation into boric acid and was determined by titration with standard  $\text{H}_2\text{SO}_4$ . All determinations were made in duplicate and are reported as % N in oven dry plant tissue.

### Soil Nitrate and Ammonium Determinations

Nitrate and  $\text{NH}_4$  in the soil was determined by automated colorimetric procedures. Nitrate was determined by the Cd reduction method (Technicon, 1973a) and ammonium by the alkaline phenate method (Technicon,

1973b). Nitrate and  $\text{NH}_4$  in the extracts was determined individually using a Technicon Autoanalyzer System II. Values obtained are reported as ppm  $\text{NO}_3^-$ -N and  $\text{NH}_4^+$ -N in air dry soil.

### Statistical Analyses

Statistical methods described by Steel and Torrie (1980) and Little and Hill (1983) were used for pertinent statistical analyses.

## RESULTS AND DISCUSSION

### Residue Measurements

After the tillage treatments were applied and prior to planting, the levels of residue present on the experimental plots were determined. This was done because the amount of residue present on the surface of the soil was thought to play a major role in the tillage fertilizer interaction. In 1984 and 1985, two different methods of estimating residue were used. The first method was a quantitative measurement in which the residue present in a 4 m<sup>2</sup> area was collected, washed free of soil, oven dried and weighed. In addition, two estimates of percent cover were made. The photographic procedure of Hartwig and Laflen (1978) was used in both 1984 and 1985. A second estimate of percent cover was made in 1985. This was the line-intercept method of Laflen et al. (1981). These data are presented in Table 5.

In both locations and years the reduced tillage systems left an appreciably greater amount of residue on the surface. The no tillage systems tended to possess a greater level of residue than the chisel plowed

**Table 5. Residue cover as affected by tillage and measurement method at East Lansing and Saginaw, 1984 and 1985.**

Method	East Lansing				Saginaw			
	No-till		Plow		Chisel		Plow	
	1984	1985	1984	1985	1984	1985	1984	1985
Line transect (%)	-	75	-	6	-	45	-	14
Photo-graphic (%)	84	85	45	13	63	73	21	18
Residue Dry Wt. (Mg ha <sup>-1</sup> )	3.01	2.92	0.27	0.16	3.16	2.14	0.97	0.58

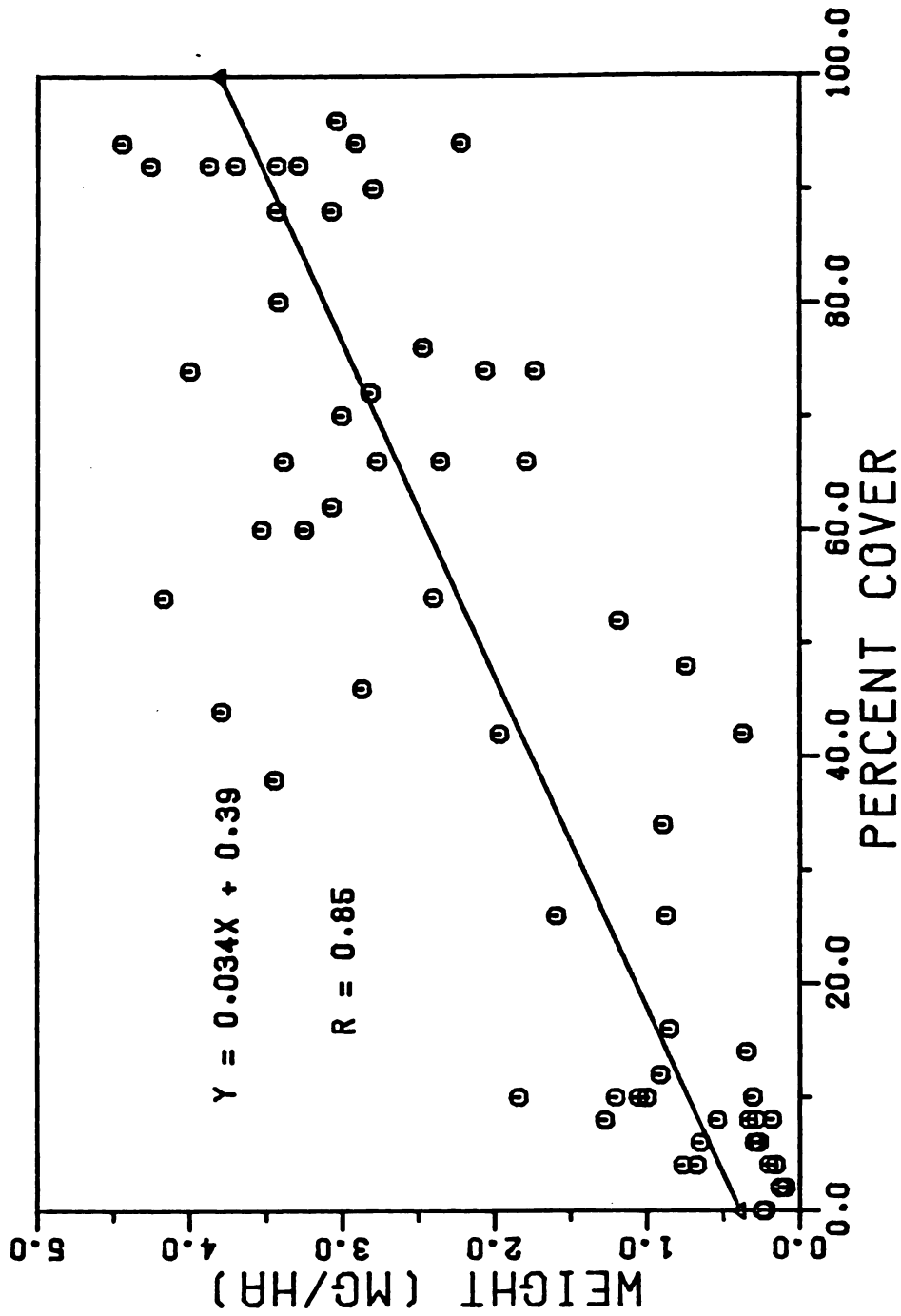


Figure 2. Relationship between percent cover as determined by the photographic method and residue dry weight, 1984.

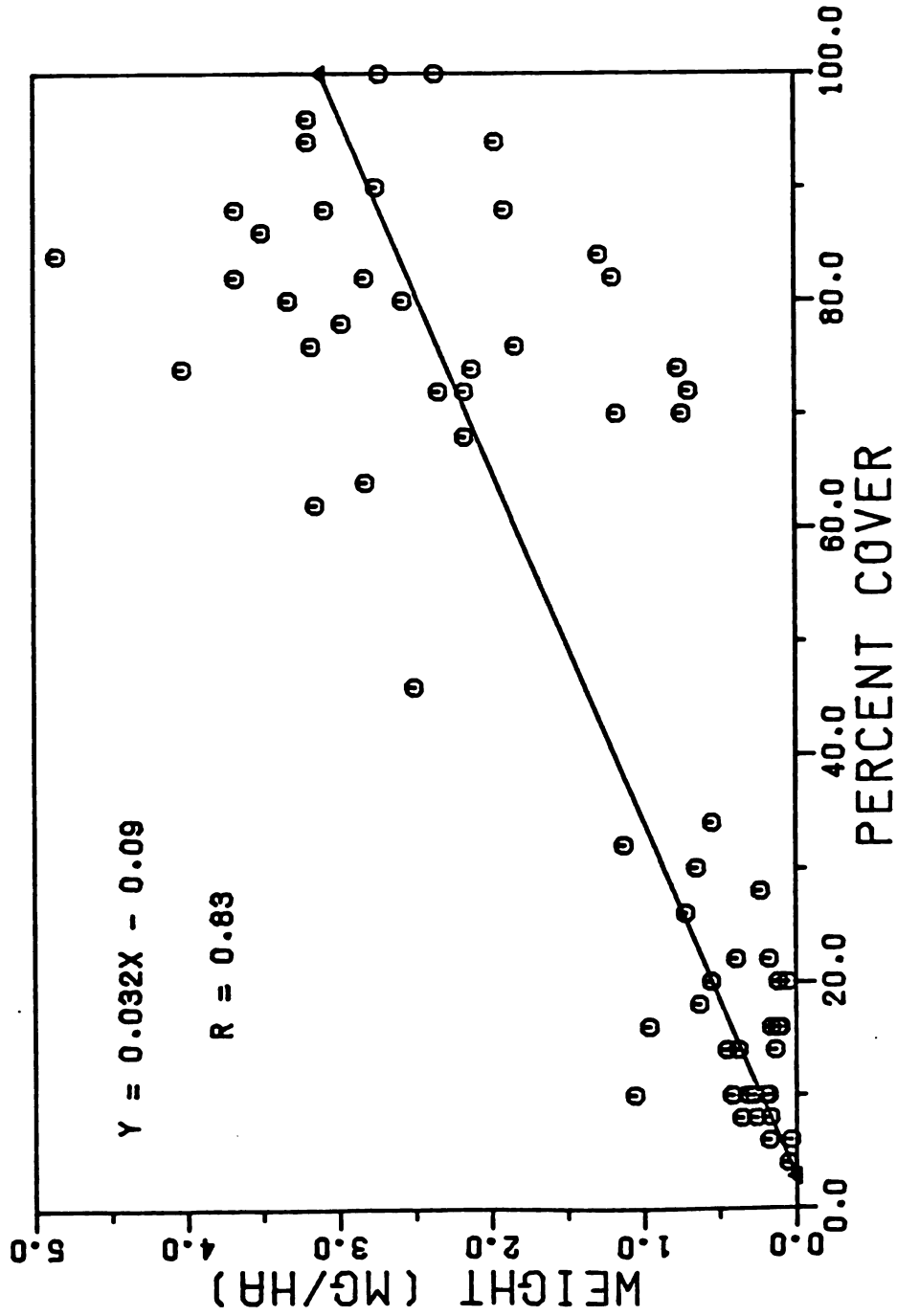


Figure 3. Relationship between percent cover as determined by the photographic method and residue dry weight, 1985.

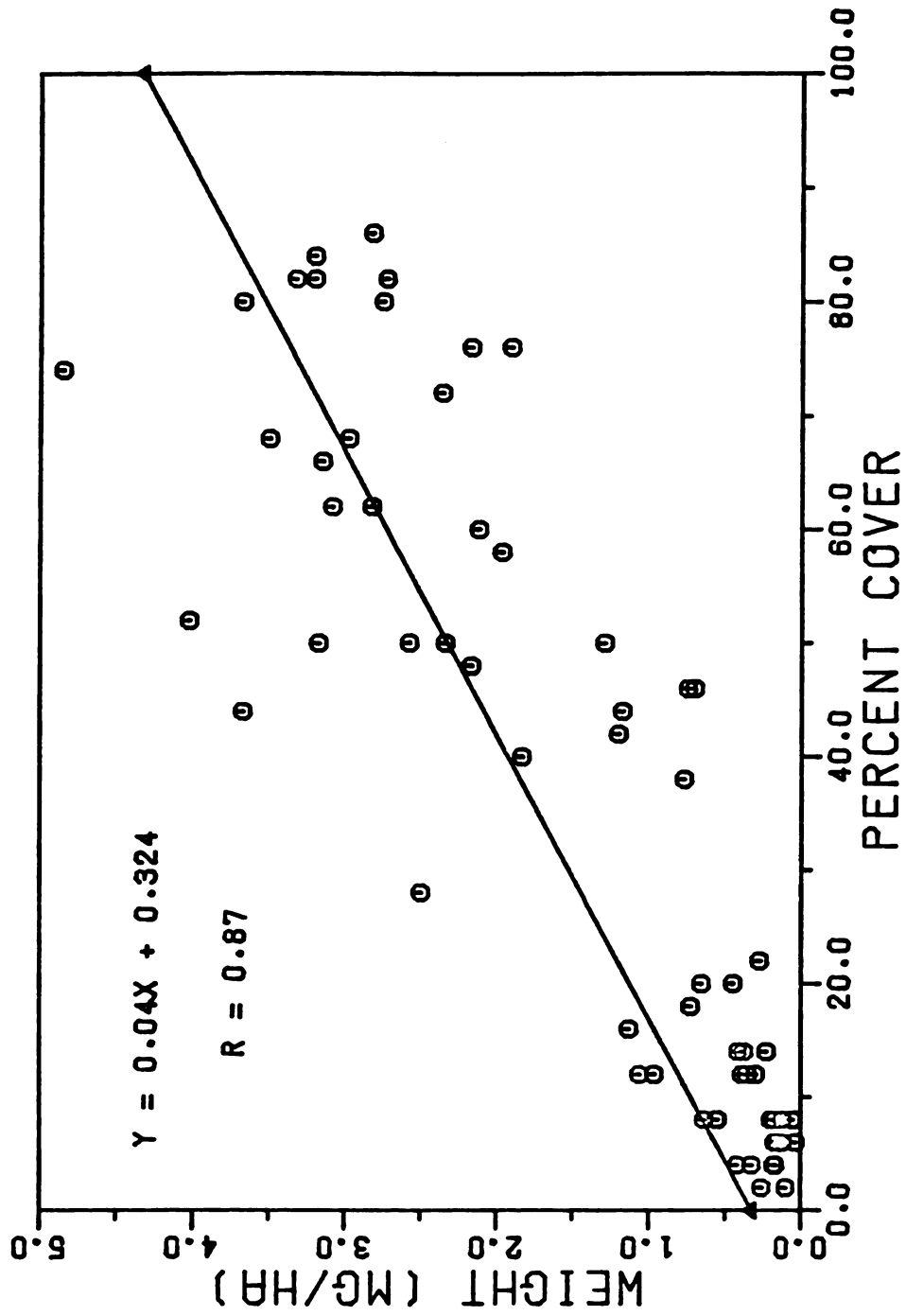


Figure 4. Relationship between percent cover as determined by the line intercept method and residue dry weight, 1985.

treatments. The moldboard plowed treatments exhibited similar results for both years and locations.

Linear regressions were performed to investigate the relationship between residue dry weight and percent cover. The correlation coefficient ( $r$ ) for the photographic method was 0.85 in 1984 (Figure 2) and 0.83 in 1985 (Figure 3). For the line intercept method, the correlation coefficient was 0.87 (Figure 4).

These statistics indicate that there is a good positive correlation residue dry weight and percent cover. They also indicate that there exists little difference in the methods used to determine percent cover. The final choice of a method may be based on the labor input and not on the accuracy of the determination. For this reason the line intercept may be favored. Measurements can be collected in a short period of time and the results are immediately available. This procedure would seem to be very useful for growers and extension scientists who may require information quickly in the field. The photographic procedure is also very useful, however this method requires a longer period of time before data can be evaluated.

### Field Studies

The field experiments were conducted at Saginaw and East Lansing in 1984 and 1985. The experiments were not combined because the variances were found to be nonhomogeneous. This was determined by Bartlett's test (Little and Hills, 1978). Consequently, the experiments will be discussed separately.

Significant effects due to tillage were not found and the interaction between tillage system and N treatment was also not significant. Therefore all the field data was averaged across tillage systems. Therefore, under the conditions of this experiment tillage system did not influence the relative N use efficiency. Several researchers have reported a decrease in both yield and N uptake with reduced tillage systems (Fox and Hoffman, 1981; Bandel et al., 1980 and Mengel et al., 1982). A similar response was not observed in these field experiments. It is possible that temperature differences may account for these discrepancies in results. Ammonia loss increases with increasing temperature (Ernst and Massey, 1960). The results which reported an increase in  $\text{NH}_3$  loss with reduced tillage systems were conducted in Pennsylvania, Maryland and Indiana, respectively. These areas may possess a higher average temperature at the time of fertilizer application. Also, the experiments were in production for

a longer period of time than those presented here. Both of these occurrences would help to explain the differences in results.

### East Lansing

In 1984 and 1985 the experiment consisted of three N fertilizer sources, three N application rates, two methods of application and two times of application. In 1984, there was not a consistent response in crop yield to the N treatments (Table 6). There was an increase in yield with the early application date at the 134 kg ha<sup>-1</sup> rate. This response could possibly be explained by climatic data. There was a rainfall of 1.42 cm two days after the early N treatment was applied. After the late application date only trace rainfall occurred in the two weeks following fertilizer application. Fox and Hoffman (1981) suggested that if 10 mm of rain falls within two days of fertilizer application, no NH<sub>3</sub> will be lost. This amount of moisture will be sufficient to move the fertilizer into the soil where NH<sub>3</sub> loss will be less likely. The apparent reduction in yield at the 179 kg rate is not explained.

There was a trend for increasing yields with increasing N rate for all sources at the late application, but the response was not significant. Any

Table 6. Effect of nitrogen source, nitrogen rate, method of application and time of application on yield of corn (averaged across two tillage systems) East Lansing, 1984 and 1985.

<u>Fertilizer</u> <u>Source</u> <u>Rate</u>		<u>1984</u>		<u>S'ds</u> <sup>#</sup>	<u>1985</u>		<u>S'ds</u> <sup>#</sup>
		<u>Broadcast</u>			<u>Broadcast</u>		
		5/11	6/12	6/12	5/2	6/7	6/7
<hr/>							
kg N ha <sup>-1</sup> ----- Mg ha <sup>-1</sup> -----							
0 ----- 6.68 ----- ----- 6.96 -----							
AN <sup>##</sup>	134	-	7.60	-	-	10.8	-
	179	-	7.74	7.07	-	10.8	10.9
U	134	8.05	7.26	7.50	10.7	10.8	10.4
	179	7.81	7.79	7.65	10.5	10.8	10.6
UUP	134	9.21	6.93	7.07	10.6	10.4	10.0
	179	7.23	7.41	7.54	11.2	10.5	10.5
LSD (5%)			1.31			0.81	

<sup>#</sup> placed 5 cm below the soil surface in a band between rows.

<sup>##</sup> AN=ammonium nitrate, U=urea, UUP=urea-urea phosphate.

loss of N from the broadcast application at this date was not apparent in the yields obtained since the sidedressed treatments yield the same as the broadcast treatments.

In 1985, there was a significant yield response to applied N regardless of source, time or method of application (Table 6). While there tended to be an increase in yield at the 179 kg rate over the 134 kg rate, the differences were not significant. Again, there was no advantage to the sidedressed treatment.

It is apparent that the residual N level in this soil prevented a yield response to applied N in 1984. In 1985, there was a response to applied N, but the 134 kg rate was sufficient. Yield levels in 1985 were sufficiently high so that a yield response at the 179 kg rate would have been expected had the residual level not produced such a high yield level. The control in both years yielded nearly twice the expected yield of 3 to 4 Mg ha<sup>-1</sup>.

In 1984 the ear leaf N concentrations reflect the lack of yield response in that these levels do not increase with N rate (Table 7). The level of N in the control was not significantly less than any of the N treatments. The levels of N present in all samples were determined to be in the "low" to "very low" range of sufficiency. This would indicate that a possible stress

Table 7. Effect of nitrogen source, nitrogen rate, method of application and time of application on ear leaf nitrogen concentration at tasseling (averaged across two tillage systems) East Lansing, 1984 and 1985.

<u>Fertilizer</u> Source Rate		<u>1984</u>		<u>S'ds</u>	<u>1985</u>		<u>S'ds</u> <sup>#</sup>
		<u>Broadcast</u>			<u>Broadcast</u>		
		5/11	6/12	6/12	5/2	6/7	6/7
kg N ha <sup>-1</sup> -----				% N -----			
	0	-----	2.16	-----	-----	1.82	-----
AN <sup>##</sup>	134	-	2.11	-	-	2.22	-
	179	-	2.00	2.04	-	2.26	2.21
U	134	2.09	2.36	2.10	2.18	2.13	2.09
	179	2.15	2.17	2.29	2.24	2.25	1.94
UUP	134	2.11	2.25	2.04	2.11	2.13	2.15
	179	2.21	2.20	2.19	2.28	2.29	2.14
LSD (5%)		NS			0.19		

<sup>#</sup> placed 5 cm below the soil surface in a band between rows.

<sup>##</sup> AN=ammonium nitrate, U=urea, UUP=urea-urea phosphate.

to the plants may have existed, however, this effect was not reflected in the yield or uptake data.

In 1985, the ear leaf N concentrations reflect the yield response observed (Table 7). There was also a trend indicating an increase in % N with increasing N application rate. This effect was observed in the broadcast treatments at both application dates. There was no apparent effect of N source, method or timing of application. The N levels in these samples were also in the "low" to "very low" range.

The N uptake data for 1984 and 1985 closely reflected the yield data (Table 8). In 1984 there was a significant response to the early application date at the 134 kg N ha<sup>-1</sup> rate. At the 179 kg N ha<sup>-1</sup> rate, a response was suggested, but it was not significant. There was also a trend suggesting that an increase in N uptake occurred with increasing N rate. This effect was only noted at the late application date. In 1985 there was a significant response due to increased N rate in the early broadcast UUP and in the late broadcast AN. This response was also suggested with the late broadcast U and UUP and the sidedressed UUP. There were no apparent advantages to N source, timing or method of application.

**Table 8. Effect of nitrogen source, nitrogen rate, method of application and time of application on total nitrogen uptake (averaged across two tillage systems) East Lansing, 1984 and 1985.**

<u>Fertilizer</u> Source Rate		<u>1984</u>			<u>1985</u>		
		<u>Broadcast</u>		<u>S'ds</u> <sup>#</sup>	<u>Broadcast</u>		<u>S'ds</u> <sup>#</sup>
		5/11	6/12	6/12	5/2	6/7	6/7
		kg N ha <sup>-1</sup> ----- g/10 plants -----					
0		-----	24.5	-----	-----	22.2	-----
AN <sup>##</sup>	134	-	33.9	-	-	47.0	-
	179	-	35.6	34.8	-	53.3	50.0
U	134	42.6	34.0	35.2	48.2	47.9	48.1
	179	41.7	37.7	31.9	46.8	48.2	47.8
UUP	134	39.4	32.3	30.8	44.5	46.9	46.7
	179	41.6	36.7	35.0	51.3	49.0	49.2
LSD (5%)		5.73			5.42		

<sup>#</sup> placed 5 cm below the soil surface in a band between rows.

<sup>##</sup> AN=ammonium nitrate, U=urea, UUP=urea-urea phosphate.

## Saginaw

In 1984 the experiment conducted in Saginaw was identical to the experiment run in East Lansing in 1984 and 1985. In 1985 three additional factorial combinations of treatment variables were added.

The yield data from 1984 demonstrated a significant response due to N fertilization (Table 9). This was indicated by a significant difference in yield between the control and treated plots. All N sources performed similarly. Time of application had an apparent effect in 1984. Although the differences were not significant, yields were generally lower for the early application date. These differences could not be explained by environmental conditions. It is suggested that the rapidly growing corn plants present at the later application date were effectively absorbing N thus decreasing the N available for loss. There is also an apparent benefit from sidedressing the fertilizer. There was a general increase in yield from the 134 kg rate at the early application date and from the sidedressed treatment, but none of the differences were significant.

Yields of the treated plots in 1985 were significantly greater than the control (Table 9). The extremely low values for the 0 N treatment suggest that the levels of residual N in this soil is very low. This is in sharp contrast with the soils in East Lansing.

Table 9. Effect of nitrogen source, nitrogen rate, method of application and time of application on yield of corn (averaged across two tillage systems) Saginaw, 1984 and 1985.

<u>Fertilizer</u> Source Rate		<u>1984</u>		<u>S'ids</u> <sup>#</sup>	<u>1985</u>		<u>S'ids</u> <sup>#</sup>
		<u>Broadcast</u>			<u>Broadcast</u>		
		5/11	6/12	6/12	5/2	6/7	6/7
		kg N ha <sup>-1</sup> -----			Mg ha <sup>-1</sup> -----		
	0	-----	4.01	-----	-----	3.05	-----
AN <sup>##</sup>	134	-	8.62	-	9.38	7.79	7.81
	179	-	9.06	10.5	10.0	8.61	8.70
U	134	7.30	9.24	9.43	8.41	8.53	8.07
	179	8.50	9.19	10.7	9.52	8.68	8.83
UUP	134	8.50	9.02	8.71	8.88	7.89	8.07
	179	9.50	8.59	9.23	9.68	8.86	8.51
LSD (5%)			1.70			1.01	

<sup>#</sup> placed 5 cm below the soil surface in a band between rows.

<sup>##</sup> AN=ammonium nitrate, U=urea, UUP=urea-urea phosphate.

There was no response to N source or method of application, however, there was a uniform if not significant response to increasing N rate. Also there was an apparent benefit to the early application date. This effect cannot be conveniently explained by environmental data. Sufficient moisture occurred after both application dates to leach the fertilizer into the soil. The differences observed were, most probably, a consequence of the severe N depletion of the soil. At the time of the second N application the plants were under severe stress. All plants that had not received N applications were chlorotic and severely stunted. The yield depression observed at the late application date was most likely a result of this stress. Plants that received the early N application did not exhibit stress symptoms.

In 1984 there was a significant increase in ear leaf N concentration due to N fertilization (Table 10). At the  $179 \text{ kg N ha}^{-1}$  rate, on the late application date,  $\text{NH}_4\text{NO}_3$  performed better than the U broadcast treatment and better than the U and UUP sidedressed treatments. This was the expected response of  $\text{NH}_4\text{NO}_3$ . Ammonium nitrate forms a soluble reaction product when applied to calcareous soils, thus decreasing  $\text{NH}_3$  loss (Fenn and Kissel, 1973). There was a positive response to the N rate at the early application date. Finally, sidedressing the fertilizer also increased the ear leaf N concentration. These results reflected the responses

Table 10. Effect of nitrogen source, nitrogen rate, method of application and time of application on ear leaf nitrogen concentration at tasseling (averaged across two tillage systems) Saginaw, 1984 and 1985.

<u>Fertilizer</u> Source Rate		<u>1984</u>		<u>S'ids</u> <sup>#</sup>	<u>1985</u>		<u>S'ids</u> <sup>#</sup>
		<u>Broadcast</u>			<u>Broadcast</u>		
		5/11	6/12	6/12	5/2	6/7	6/7
kg N ha <sup>-1</sup> -----		-----			-----		
		-----			-----		
0		-----	0.95	-----	-----	1.31	-----
AN <sup>##</sup>	134	-	2.46	-	2.11	1.86	1.89
	179	-	2.62	2.85	2.22	1.99	2.18
U	134	1.90	2.37	2.59	2.12	1.75	1.94
	179	2.10	2.44	2.62	2.06	1.99	2.07
UUP	134	1.84	2.39	2.58	2.22	1.98	2.04
	179	2.21	2.54	2.63	2.08	1.97	1.95
LSD (5%)		0.17			0.32		

<sup>#</sup> placed 5 cm below the soil surface in a band between rows.  
<sup>##</sup> AN=ammonium nitrate, U=urea, UUP=urea-urea phosphate.

noted in the yield data. The principle advantage to the late application date was considered to be a more efficient uptake of N by the rapidly growing plants present at that time. The increases due to sidedressing were probably a result of increased contact of fertilizer with the soil, thus increasing the probability of  $\text{NH}_4$  becoming adsorbed on the exchange complex.

Results from 1985 showed a significant benefit from N fertilization, but no advantage to a specific N treatment as determined by N uptake (Table 11). There was, however an apparent advantage to early application of N. This response was significant at the  $134 \text{ kg N ha}^{-1}$  rate of U. This effect was probably a result of the severe N depletion of the soil. Plants receiving the early N application did not exhibit signs of N deficiencies. There was also a trend indicating a benefit to sidedressing.

There were no differences due to N source in 1984 as determined by N uptake (Table 11). There were differences due to N application rate, method and timing of application. There was a uniform trend throughout the data indicating a benefit due to increased N rate. This response was significant for the late broadcast of UUP and the sidedressed U and UUP. There was also an indication in the data that there was a benefit to the sidedressed treatments, however this was significant only

Table 11. Effect of nitrogen source, nitrogen rate, method of application and time of application on total nitrogen uptake (averaged across two tillage systems) Saginaw, 1984 and 1985.

<u>Fertilizer</u> Source Rate		<u>1984</u>		<u>S'ids</u> <sup>#</sup>	<u>1985</u>		<u>S'ids</u> <sup>#</sup>
		<u>Broadcast</u>			<u>Broadcast</u>		
		5/11	6/12	6/12	5/2	6/7	6/7
		kg N ha <sup>-1</sup> -----			g/10 plants -----		
	0	-----	15.8	-----	-----	15.1	-----
AN <sup>##</sup>	134	-	34.6	-	28.7	25.7	28.1
	179	-	38.0	42.8	29.7	25.9	29.4
U	134	23.5	31.2	32.9	29.6	22.7	33.0
	179	27.1	34.1	39.3	30.2	31.4	27.8
UUP	134	24.2	30.8	34.6	32.4	26.6	30.9
	179	26.3	38.3	39.5	31.4	29.1	32.0
LSD (5%)			4.75			7.10	

<sup>#</sup> placed 5 cm below the soil surface in a band between rows.

<sup>##</sup> AN=ammonium nitrate, U=urea, UUP=urea-urea phosphate.

for the 179 kg N ha<sup>-1</sup> rate of U and AN. There was also a uniform significant response to time of application. The early application date yielded a lower N uptake. This data would confirm the hypothesis that at the later application date, the plants more efficiently utilized the applied N.

The N uptake data for 1985 reflected the ear leaf N concentration data and the yield data (Table 11). There is an apparent advantage due to early application of N and increased N rate. Sidedressing of N also resulted in apparent yield increases, this was significant for the 134 kg N ha<sup>-1</sup> rate of U. There was no benefit due to N source.

It is apparent from the experimental results that environmental effects can play a significant role in fertilizer performance. Results were affected by the environment in both years in East Lansing and in 1985 in Saginaw. In 1984 in Saginaw, environmental factors contributed only slightly. Experimental results demonstrated a positive effect to a later fertilizer application date. This was attributed to a more efficient uptake of N by the rapidly growing plants present at the later date. In addition, benefits were suggested due to increased N rate and sidedressing of N. Both of these factors would serve to effectively increase the

concentration of  $\text{NH}_4$  on the exchange surface. No effects were observed due to N source.

### Greenhouse Cropping Study

The treatments in this experiment consisted of three N rates, three N sources, two rates of corn residue and two initial moisture regimes. Factorial combinations of these treatment were arranged in a randomized complete block design with four replications. Three crops of corn were grown. Yield and total Kjeldahl N were determined so N uptake could be calculated. Relative N use efficiency will be estimated from these data.

Approximate significance of the F statistic for the various factors and interactions is presented in Table 12.

### Crop Yield

The yield of the first crop was affected only by the rate of corn residue applied to the surface . Yield of the 0 residue was 2.65 g/pot compared to 2.84 where residues were applied [LSD (5%)= 0.12]. This was not the

**Table 12. Approximate probability of significance of the F statistic for various sources of variance for three crops of corn in the greenhouse experiment, 1985.**

<b>Source of Variance</b>	<b>Yld1#</b>	<b>Yld2</b>	<b>Yld3</b>	<b>Upt1##</b>	<b>Upt2</b>	<b>Upt3</b>	<b>UptT</b>
<b>Source (S)</b>	-	**	**	**	**	**	**
<b>Residue(R)</b>	**	**	**	-	**	**	**
<b>Rate (Rt)</b>	-	**	**	**	**	**	**
<b>Moisture (M)</b>	-	*	-	-	**	-	**
<b>M*R</b>	-	-	-	-	-	-	-
<b>M*S</b>	-	-	-	-	**	-	**
<b>M*Rt</b>	-	-	-	-	-	-	-
<b>R*S</b>	-	**	-	-	**	-	*
<b>R*Rt</b>	-	**	*	**	**	**	-
<b>S*Rt</b>	-	-	**	-	**	**	**
<b>M*R*S</b>	-	-	-	-	-	-	-
<b>R*S*Rt</b>	-	**	-	-	**	-	**
<b>M*R*RT</b>	-	-	-	-	-	-	-
<b>M*S*Rt</b>	-	-	-	-	-	-	-
<b>M*R*S*Rt</b>	-	-	-	-	-	-	-

\* significance at 0.05.

\*\* significance at 0.01.

# Crop Yield 1,2 and 3.

## N uptake 1,2,3 and total.

effect of the residue that was expected. It was postulated that the residue would cause an increase in  $\text{NH}_3$  loss and thus a depression in yield and N concentration in the plant tissue. The residue should prevent the fertilizer from moving into the soil where it could become adsorbed on the soil exchange complex. Residues possess a limited exchange capacity, thus adsorption is unlikely. In addition, residues generally possess a higher urease activity (Torrello and Wehner, 1983). which should also increase  $\text{NH}_3$  loss. Because the residue did not cause a decrease in yield or in N concentration, a different explanation must be offered. The observed effect is perhaps a result of moisture stress. The residue present on the surface of the soil would tend to decrease evapotranspiration, thus maintaining a higher moisture content in the soil. This should normally not be a concern in the greenhouse. However, it could have occurred as a result of the initial moisture treatments investigated in this study. During the initial treatment period, the crops receiving the low moisture treatment were subjected to a ten day moisture stress period. This was an unavoidable consequence of the experiment and may have influenced yields.

In the second crop the simple effect of moisture was significant. In addition, the interaction of N rate, N source and residue level was also significant.

An increase in yield was observed for those pots receiving the low initial moisture treatment. The yield for the low moisture treatment was 1.95 compared to 1.83 g/pot for the high moisture treatment [LSD (5%) = 0.11]. A low surface moisture content would effectively limit the hydrolysis of urea, thus decreasing  $\text{NH}_3$  loss. The high moisture treatment, in which several wetting and drying cycles were simulated, would tend to increase urea hydrolysis, evaporation and thus  $\text{NH}_3$  loss. The net effect of the high moisture treatment should be a decrease in N use efficiency and yield. This was observed in the second cropping.

The three way interaction of N rate, N source and residue level was significant (Table 13) for the second crop. When residues were present on the surface of the soil there was a significant yield response to all N rates for all three sources. However, in the absence of residue yields were affected by increasing N rates only for U and UUP. In addition, the only N source differences noted were between the  $75 \text{ mg N kg}^{-1}$  soil rates of U and AN. It appears that the effect of the residues is to increase the  $\text{NH}_3$  loss to the extent that the differences due to N rate and N source are increased. When residue is not present, these factors contribute less to the total  $\text{NH}_3$  loss. Further evidence of this effect is presented in the section on N uptake.

**Table 13. The effect of fertilizer source, fertilizer rate and corn residue on crop yield in the greenhouse experiment, 1985.**

<u>Fertilizer</u>		<u>0 Residue</u>			<u>+ Residue<sup>#</sup></u>		
<u>Source</u>	<u>Rate</u>	<u>Yld1</u>	<u>Yld2</u>	<u>Yld3</u>	<u>Yld1</u>	<u>Yld2</u>	<u>Yld3</u>
mg N kg <sup>-1</sup> soil		-----g pot <sup>-1</sup> -----					
	0	2.03	1.36	2.37	1.84	0.86	1.90
U	75	2.73	1.72	2.41	2.75	1.24	2.49
	150	2.69	2.06	3.16	2.97	1.79	2.77
UUP	75	2.61	1.79	2.64	2.78	1.28	2.50
	150	2.51	2.15	3.39	2.72	2.34	3.14
AN	75	2.71	2.01	2.72	2.80	1.60	2.65
	150	2.64	2.03	3.93	3.05	2.67	4.09
LSD (5%)		NS	0.27	NS	NS	0.27	NS
# 336 g m <sup>-2</sup>							

In the third crop, the two way interactions of N rate by residue and N source by residue were significant (Table 12). Yields were generally higher for the third crop than would be expected. A decrease should be observed due to N depletion of the soil. The higher than expected yield level might be explained by a one week longer growing period. Also this crop was grown later in the year, so photosynthesis was probably higher due to increased light levels.

There was a significant increase in yield for crop three with increased N rate at both levels of residue (Table 14). There was also a significant depression in yield in the high residue treatment. The lower yields for the high residue treatment could be a result of increased  $\text{NH}_3$  loss, due to a heightened urease activity in the residues. The limited CEC of the residue would also permit a greater loss of  $\text{NH}_3$ .

There were no significant differences between N sources at the  $75 \text{ mg kg}^{-1}$  soil rate (Table 15). There was a response to N source at the  $150 \text{ mg kg}^{-1}$  soil rate. Ammonium nitrate performed better than both of the urea fertilizers. This may be a reflection of the lower volatilization potential of AN. There was also a difference between the urea fertilizers, UUP performed better than U. This may be a result of a decrease in urease activity and  $\text{NH}_3$  loss due to the decrease in pH

Table 14. The effect of N rate and residue level on crop yield in the greenhouse experiment, 1985.

Fertilizer Rate	0 Residue			+ Residue <sup>#</sup>		
	Yld1 <sup>##</sup>	Yld2	Yld3	Yld1	Yld2	Yld3
mg N kg <sup>-1</sup> soil	----- g pot <sup>-1</sup> -----					
0	2.03	1.36	2.37	1.84	0.86	1.90
75	2.68	1.84	2.87	2.77	1.37	2.27
150	2.61	2.08	3.86	2.91	2.27	2.96
LSD (5%)	NS	###	0.19	NS	###	0.19

<sup>#</sup> 336 g m<sup>-2</sup>  
<sup>##</sup> crop yield 1,2 and 3.  
<sup>###</sup> Source\*rate\*residue interaction significant, see Table 13.

**Table 15. The effect of N source and N rate on crop yield in the greenhouse experiment, 1985.**

<u>Fertilizer</u>		Yld1 <sup>#</sup>	Yld2	Yld3
Source	Rate			
mg N kg <sup>-1</sup> soil		----- g pot <sup>-1</sup> -----		
	0	1.94	1.11	2.14
U	75	2.74	1.48	2.45
	150	2.83	1.92	2.97
UUP	75	2.70	1.53	2.57
	150	2.62	2.25	3.27
AN	75	2.75	1.80	2.69
	150	2.85	2.35	4.01
LSD (5%)		NS	NS	0.23
# Crop yield 1,2 and 3.				

usually associated with UUP. The crop yields for all sources at the  $75 \text{ mg kg}^{-1}$  soil rate were approaching that of the ON control. This would indicate that the N is becoming depleted in the soil. It is suggested that three crops were sufficient to remove the N from the soil, in the  $75 \text{ mg kg}^{-1}$  soil rate treatment to background levels.

### Nitrogen Uptake

The N uptake data generally reflected that of the yield data, with the exception that a moisture by source interaction became important for the uptake of crop two and the total uptake.

The simple effect of N source was significant for uptake one. The N uptake values were 78.1, 75.0 and 82.8 mg N/pot for U, UUP and AN respectively [LSD (5%) = 3.72]. There was a difference between AN and the urea materials, but not between the urea fertilizers themselves.

There was also a significant residue by N rate interaction for the N uptake of crop one (Table 16). There was a significant difference in N uptake between the control and the  $75 \text{ mg kg}^{-1}$  soil rate for both levels of residue, however, only the residue treated pots showed a difference between the  $75 \text{ mg kg}^{-1}$  soil and the  $150 \text{ mg kg}^{-1}$  soil rates. In addition, the N uptake was lower in the residue treated pots for the 0 N and the  $75 \text{ mg kg}^{-1}$

Table 16. The effect of N rate and residue level on nitrogen uptake by three crops in the greenhouse, 1985.

	0 Residue				+ Residue <sup>##</sup>			
Fertilizer Rate	Upt1 <sup>#</sup>	Upt2	Upt3	Tot	Upt1	Upt2	Upt3	Tot
mg N kg <sup>-1</sup> soil	-----				mg N pot <sup>-1</sup>	-----		
0	35.4	18.0	16.2	69.6	26.8	12.9	13.8	53.6
75	78.1	37.9	22.8	139	69.2	21.2	17.3	107
150	82.0	60.0	43.1	185	85.3	52.2	24.1	162
LSD (5%)	4.30	###	4.71	NS	4.30	###	4.71	NS

<sup>#</sup> N uptake 1,2,3 and total.

<sup>##</sup> 336 g m<sup>-2</sup>.

<sup>###</sup> Source\*rate\*residue interaction significant, see Table 18.

soil rates. This difference was not significant for the 150 mg kg<sup>-1</sup> soil rate.

In crop two there were significant moisture by N source and residue by N source by N rate interactions. In the moisture by N source interaction two trends became apparent (Table 17). There is a decrease in N uptake for U and UUP, but not for AN. This would further serve to substantiate the premise that the decreased efficiency of the urea fertilizers is due to an increase in NH<sub>3</sub> volatilization losses. There was also a trend indicating that there was a benefit to UUP over U. This was significant with the high initial moisture treatment.

In the three way interaction significant effects due to N rate, N source and residue level were all recorded (Table 18). There was a uniform increase in N uptake with increased N rate. Also, there was a significant decrease in N uptake with the high residue rate. This trend was observed for all treatments except the 150 mg kg<sup>-1</sup> soil rate of AN. Differences between U and UUP were noted for the 150 mg kg<sup>-1</sup> soil rate, but not for the 75 mg kg<sup>-1</sup> soil rate. The N uptake for AN was significantly greater than U in all cases, however, it was significantly greater than UUP only at the 150 mg kg<sup>-1</sup> soil rate of the residue treated pots. This effect may be suggesting a benefit to UUP over U.

Table 17. The effect of initial moisture content and fertilizer source on nitrogen uptake by 3 crops in the greenhouse, 1985.

Fertilizer Source	<u>Crop 1</u>		<u>Crop 2</u>		<u>Crop 3</u>		<u>Total</u>	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
----- mg N/pot -----								
Urea	75.5	80.7	29.6	41.0	20.4	25.1	125	146
Urea-urea phosphate	74.1	76.0	38.6	45.2	24.3	25.0	136	146
Ammonium nitrate	81.9	83.7	51.7	50.8	32.9	33.3	166	167
LSD (5%)	NS		4.6		NS		6.6	

Table 18. The effect of N source, N rate and residue level on nitrogen uptake by three crops of corn in the greenhouse, 1985.

Fertilizer		0 Residue				+ Residue			
Source	Rate	Upt1 <sup>#</sup>	Upt2	Upt3	Tot	Upt1	Upt2	Upt3	Tot
mg N kg <sup>-1</sup> soil		-----				-----			
	0	35.4	18.0	16.2	69.6	26.8	12.9	13.8	53.6
U###	75	78.2	34.1	20.4	132	64.7	18.0	17.3	100
	150	83.2	53.6	34.8	172	86.1	35.4	18.4	140
UUP	75	75.3	36.7	25.3	137	68.4	20.1	16.7	105
	150	78.8	62.3	34.5	176	77.6	48.5	22.1	148
AN	75	80.8	42.8	22.6	146	74.5	25.6	17.9	118
	150	83.9	64.0	60.0	208	92.1	72.6	31.9	197
LSD(5%)			6.5		9.3		6.5		9.3

<sup>#</sup> N uptake for crop 1,2,3 and total.

<sup>##</sup> 336 g m<sup>-2</sup>

<sup>###</sup> U=urea, UUP=urea-urea phosphate, AN=ammonium nitrate.

In the third cropping there were two significant interactions noted, a residue by N rate interaction and a N source by N rate interaction. There was a positive response in N uptake to increased N rate (Table 16). This was significant in all cases except the  $75 \text{ mg kg}^{-1}$  soil rate of the residue treated pots. The lack of response in this case probably indicates that N in the soil is becoming depleted. There was also a response showing a decrease in uptake when residues were present. This effect was significant for the  $75 \text{ mg kg}^{-1}$  soil and  $150 \text{ mg kg}^{-1}$  soil rates, but not for the 0 N control.

The N rate by N source interaction for the third crop (Table 19) shows an increase in N uptake with increased N rate for all sources. However, at the  $75 \text{ mg kg}^{-1}$  soil rate there was not a significant difference due to N source. In addition only UUP was significantly different from the control. This is further evidence that three crops was sufficient to remove the N from the soil. At the  $150 \text{ mg kg}^{-1}$  soil rate AN possessed a significantly greater N uptake than both of the urea fertilizers. There was not a significant difference between U and UUP.

In the data for total N uptake there were significant interactions of moisture by N source and residue by N rate by N source. The trends exhibited in crop two continued to hold in the moisture by N source interaction (Table 17). There was evidence of N loss from

Table 19. The effect of N source and N rate on nitrogen uptake by three crops in the greenhouse, 1985.

<u>Fertilizer</u>		Upt1 <sup>#</sup>	Upt2	Upt3	Total
Source	Rate				
mg N kg <sup>-1</sup> soil		----- mg N pot <sup>-1</sup> -----			
	0	31.1	15.5	15.0	61.6
U	75	71.5	26.1	18.9	116
	150	84.7	44.5	26.6	155
UUP	75	71.8	28.4	21.0	121
	150	78.2	55.4	28.3	161
AN	75	77.6	34.2	20.2	132
	150	83.6	68.3	46.0	202
LSD (5%)		NS	##	5.76	##

<sup>#</sup> N uptake for crop 1,2,3 and total.

## Source\*rate\*residue interaction significant, see Table 18.

the urea fertilizers applied to moist soils. This is probably a result of an increase in the rate of urea hydrolysis. Several researchers have reported an increase in  $\text{NH}_3$  loss with an increase in initial moisture content (Martin and Chapman, 1951 and Ferguson and Kissel, 1986). Moist soils are also more prone to evaporative losses. This is an important factor in this experiment, because the high moisture treatment also included several wetting and drying cycles. When urea is applied to a dry surface hydrolysis is inhibited and  $\text{NH}_3$  loss is decreased. The N uptake for U and UUP was similar when applied to a dry soil, however, when applied to a moist soil UUP performed better than U. This would indicate a possible increase in N use efficiency due to UUP. As previously mentioned, this effect is most likely a result of a decrease in the rate of urea hydrolysis. This effect was also reported by Bremner and Douglas (1971). The N uptake for AN was significantly greater than the urea fertilizers. Also AN showed no response to the moisture treatments. This would suggest that the increased losses due to the high moisture treatment with the urea fertilizers was probably due to  $\text{NH}_3$  volatilization.

Nitrogen uptake generally decreased with each successive crop until at the third cropping the N uptake from treated pots was not appreciably greater than that of the ON control (Table 18). When residue was present on the soil surface, N uptake decreased. This effect was

significant for all treatments for total N uptake. In addition there was a significant increase in total N uptake due to an increase in N rate. There was not a significant difference in total N uptake between U and UUP, although a benefit was suggested from UUP. Both U and UUP had a significantly lower total N uptake than AN.

Soil samples collected at the end of the study showed 7.0 mg kg<sup>-1</sup> mineral N (NO<sub>3</sub> + NH<sub>4</sub>) for the N treated soils and 6.7 mg for the control, suggesting that the applied N was depleted.

#### Urea Hydrolysis Measurements

The urease activity of selected field and greenhouse soils was determined to evaluate the relative rate of urea hydrolysis in response to several factors. In the field samples variables included; N application rate, method of application soil type and tillage system. In the greenhouse samples the variables included; N rate and residue rate. Only treatments that received urea applications were evaluated.

### Field Samples

There were no significant differences in the field samples due to treatment, however, there were two interesting trends in the data (Table 20). The most distinctive one was an apparent higher urease activity in the Charity clay soil as compared to the Conover loam. Several researchers have reported an increase in urease activity with increasing clay content of the soil (Zantua et al., 1977 and Reynolds et al., 1985). This has been attributed to an increased adsorption of urease to the soil colloids.

There was also an indication of a decreased urease activity in reduced tillage systems. This effect cannot be easily explained. Some workers have reported increases in urease activity in reduced tillage systems (Kleins and Koth, 1980). Other investigators have shown a decrease in urease activity in ground left fallow (Speir et al., 1980). The reduced tillage systems investigated in this research were in production for only two growing seasons. This is probably an insufficient period of time for microbial levels to build up in the soil to a level where they might affect urease activity. The plots evaluated by Kleins and Koth (1980) were in no-till production for approximately ten years. It is possible that the response observed in the present experiment was a result of a general decrease in enzyme activity. This might occur in

**Table 20. Effect of fertilizer rate, method of application, tillage system and soil type on urease activity in corn plots receiving urea fertilizer, 1985.**

Method of Application	Fertilizer Rate	Soil Type			
		Conover		Charity	
		Conv##	Red###	Conv.	Red.
	Kg N ha <sup>-1</sup>	ug urea hydrolyzed h <sup>-1</sup> g <sup>-1</sup> soil			
	0	388	366	411	410
Surface broadcast	134	381	297	416	403
	179	377	335	419	414
Sidedressed#	134	329	308	413	414
	179	389	341	416	411
LSD (5%)		NS	NS	NS	NS

# Placed in a band 5 cm below the soil surface between rows

## Fall moldboard plow plus spring cultivation, on both soils.

### No-till on Conover. Chisel plow plus spring cultivation on Charity.

a reduced tillage system because the enzymes and microbes are no longer mixed throughout the profile by tillage procedures. Speir et al. (1980) attributed similar decreases in urease activity to a decrease in microbial population and a temperature dependent denaturation of the enzyme. The effect due to tillage system was less pronounced for the clay soil. This was probably a result of an increased concentration of urease bound to the soil colloidal fraction of the clay soil.

There was no consistent effect due to N rate or method of application.

#### Greenhouse Samples

There were no significant effects due to treatment in the greenhouse (Table 21). There was apparent increase due to increased levels of residue and increased N rate, but these differences were slight.

Table 21. The effect of N rate and residue level on urease activity of greenhouse samples, 1985.

Fertilizer Rate	<u>0 Residue</u>	<u>+ Residue</u> <sup>#</sup>
mg N ha <sup>-1</sup> soil	ug urea hydrolyzed h <sup>-1</sup> g <sup>-1</sup> soil	
0	394	396
75	395	405
150	403	406
LSD(5%)	NS	
# 336 g m <sup>-2</sup>		

### Field $\text{NH}_3$ Loss Experiment

Field measurements of  $\text{NH}_3$  volatilization were made in the summer of 1985. This was done in an attempt to quantify the actual amount of  $\text{NH}_3$  lost from U and UUP in a field situation. The experimental variables included two N sources and four N rates. The experiment was conducted in East Lansing on the Conover loam soil.

The  $\text{NH}_3$  volatilized was measured five times over a seven day period. In addition  $\text{CO}_2$  and soil and air temperatures were made during  $\text{NH}_3$  loss measurements. Environmental data including relative humidity and air temperature readings were collected at the beginning of each day that  $\text{NH}_3$  measurements were made (Table 22). Soil samples were collected at the end of the experiment and  $\text{NO}_3$  and  $\text{NH}_4$  determined.

### Ammonia Loss

There were significant differences in  $\text{NH}_3$  loss due to day, N treatment and the interaction of day and N treatment (Table 23). The  $\text{NH}_3$  loss increased over time to a maximum value and then decreased to background levels. Losses on the first day of the experiment were not

**Table 22. Relative humidity (Rh), minimum and maximum temperature during selected 24 hour periods, temperature during measurement and CO<sub>2</sub> concentration during the field NH<sub>3</sub> loss experiment, East Lansing, 1985.**

Date	Rh	Temperature			CO <sub>2</sub>
		minimum	maximum	ambient	
	(%)	----- C -----			umole fraction
8/16/85	58	-	-	28	-
8/17/85	64	29	14	27	461
8/18/86	-	31	22	28	492
8/19/86	67	27	12	22	475
8/21/86	61	28	13	26	455
8/23/85	56	28	12	26	508

**Table 23. Effect of N fertilizer source, fertilizer rate and day of measurement on NH<sub>3</sub> evolved from the soil in a field experiment, East Lansing, 1985.**

Fertilizer			Date					
Sce	mg N/C <sup>#</sup>	Rate	8/17	8/18	8/19	8/21	8/23	Total
		Kg N ha <sup>-1</sup>	-----mg N <sup>##</sup> -----					###
	0	0	0	0	4.2	0	0	4.2
U	160	84	0	25	0	0	0	30
	320	168	0	63	100	6	3.2	171
	480	252	0	82	196	20	2.5	301
UUP	0	0	0	0	0	0	0	0
	160	84	0	0	19	0	0	19
	320	168	0	35	59	3.3	0	96
	480	252	0	0	82	12	31	126
LSD (5%)					43			78

# mg N applied to an individual chamber.  
 ## mg N volatilized in 9,000 s.  
 ### mg N volatilized in 1,800 s.

recorded. This was expected due to the time required for urea hydrolysis to occur. On the second and third day of measurement significant losses occurred in both U and UUP treated plots. Significant responses due to increased N rate were recorded on days two, three and in the total N volatilized. An increase in N rate would directly affect the equilibrium illustrated in Eq's [5] and [9] on pages 9 and 10. The net effect would be an increase in  $\text{NH}_3(\text{aq})$  and thus  $\text{NH}_3(\text{air})$ , which would increase the volatilization potential. This effect would be more pronounced in the loam soil, because the lower CEC will allow for less  $\text{NH}_4$  adsorption.

There was a trend throughout the data suggesting that a decrease in  $\text{NH}_3$  loss may occur if UUP is selected as the N source rather than U. This effect was highly significant at the  $252 \text{ kg N ha}^{-1}$  rate. There was also a delay in volatilization when UUP was the N source. Bremner and Douglas (1971) reported a decrease in urease activity with urea phosphate (UP). They postulated that the phosphoric acid formed in the decomposition of UP effectively retarded urease activity. This is the effect suggested by the experimental results.

### Soil $\text{NO}_3$ and $\text{NH}_4$

There was a significant difference in  $\text{NO}_3$  levels in the soil, but not in the levels of  $\text{NH}_4$  (Table 24). The quantity of  $\text{NO}_3$  increased with increasing N rate for both U and UUP, however, UUP tended to have higher  $\text{NO}_3$  levels than U. This would suggest that UUP resulted in lower  $\text{NH}_3$  losses. As previously mentioned, UUP is thought to decrease urease activity. A decrease in urease activity would allow for a greater period of time in which nitrification could occur. This trend is suggested by the higher levels of soil  $\text{NO}_3$  present in the UUP plots.

### $\text{CO}_2$ Levels

The end products of urea hydrolysis are  $\text{NH}_3$ ,  $\text{CO}_2$  and  $\text{H}_2\text{O}$ . This is illustrated in Eq's [3] and [4] on page 9. The levels of  $\text{CO}_2$  were determined in each volatilization chamber during  $\text{NH}_3$  measurements. It was postulated that this would be an estimate of the relative rate of urea hydrolysis. No effects were recorded due to N treatment. The  $\text{CO}_2$  levels in the treated chambers was not significantly greater than that of the 0 N controls. It is apparent that there exists a significant background

**Table 24. Effect of N fertilizer source and fertilizer rate on soil NO<sub>3</sub> and NH<sub>4</sub> levels in samples taken at the termination of the NH<sub>3</sub> loss field experiment, East Lansing, 1985.**

<u>Fertilizer</u>		NO <sub>3</sub>	NH <sub>4</sub>
Source	Rate		
	Kg N ha <sup>-1</sup>	---mg kg <sup>-1</sup> soil---	
Urea	0	34.9	0.80
	84	103.8	1.22
	168	210.5	0.83
	252	247.4	0.89
Urea-urea phosphate	0	29.1	0.68
	84	130.1	0.70
	168	209.3	0.83
	252	313.0	1.18
LSD (5%)		68.5	NS

CO<sub>2</sub> flux from the soil. This is most likely a reflection of soil microbial activity.

### Soil and Air Temperatures

Soil and air temperatures were recorded during NH<sub>3</sub> measurements (Figure 5). Insufficient equipment was available to take readings in each chamber, therefore statistical inferences could not be made. It is possible to make generalizations about the environment inside the volatilization chamber. It was hoped that the NH<sub>3</sub> sampling device would not seriously alter the soil environment. If large increases in temperature occurred during sampling, this may introduce a bias into the NH<sub>3</sub> loss readings.

On the third day of measurement maximum NH<sub>3</sub> loss occurred, the soil and air temperature readings for this day are presented in Figure 5. It is apparent from examining this figure that an initial increase in air temperature occurred. This is followed, with minor exceptions, by a gradual decrease in temperature. Soil temperature stayed relatively constant, although an slight decrease is apparent. A short period of time passed before the aeration apparatus was turned on, it is suggested that the initial increase in air temperature is

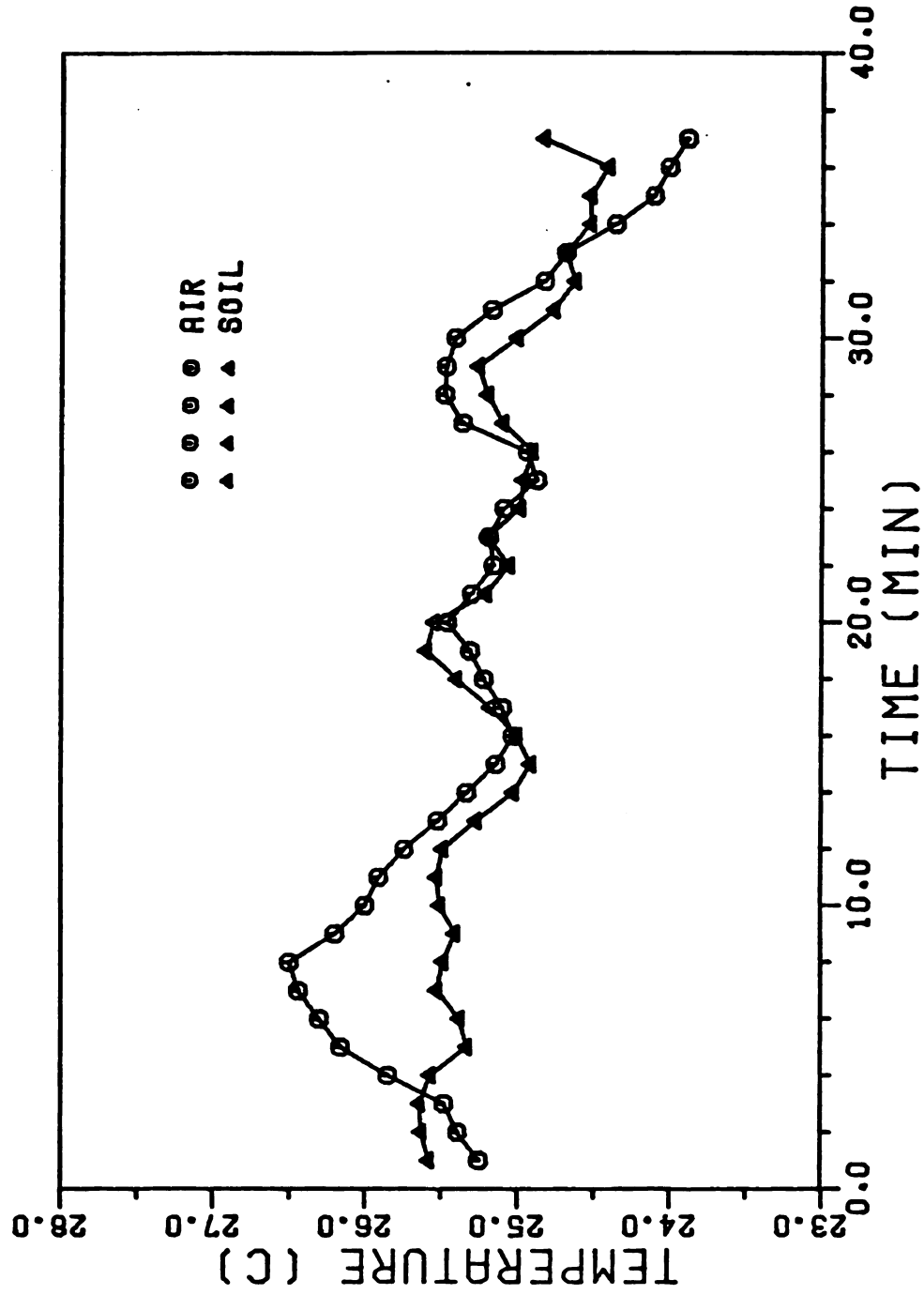


Figure 5. Soil and air temperatures during the  $\text{NH}_3$  loss experiment, East Lansing, 1985.

a result of this lag period. The following decrease is probably a result of increased evaporation of  $H_2O$  from the soil. This would be stimulated by the negative partial pressure of  $H_2O$  , created over the soil by the increased air flow. The effect of the temperature inside the volatilization chamber is probably minor. There was an overall decrease in temperature over the course of the experiment. This would most probably yield a decrease in  $NH_3$  loss.

## SUMMARY AND CONCLUSIONS

Field and greenhouse experiments were conducted to investigate several methods by which N use efficiency may be increased in reduced tillage systems. In the field, these included variations in; N source, N application rate, method of application and timing of application. In the greenhouse experiments were designed to evaluate the effects of N source, N application rate, corn residue levels and initial moisture content.

Results from the field experiments, although affected by environmental variability, indicate that there may be a positive effect on crop yield and N uptake from a delayed application of N fertilizer. This delay was 6 to 8 weeks in the reported experiments. This effect is probably due to a more efficient uptake of N by the rapidly growing crops present at the time of the late application date. There were indications that an increased N application rate and sidedressing of N fertilizer may result in benefits to crop yield and N uptake. Both of these factors would serve to increase the concentration of  $\text{NH}_4$  on the soil exchange complex. Adsorbed  $\text{NH}_4$  would have a lower volatilization potential.

There were no consistent effects observed due to N source.

In the greenhouse study there were indications that both initial moisture content and residue present on the surface of the soil could influence  $\text{NH}_3$  volatilization losses. A high initial soil moisture would promote a rapid, sustained urea hydrolysis rate. An increased level of residue on the soil surface could also result in increased urease activity. Heightened urease activity may result in higher  $\text{NH}_3$  losses. Crop yield and N uptake generally increased with N application rate. Significant differences were observed between AN and the urea based fertilizers. Ammonium nitrate has a lower volatilization potential due to the formation of a soluble reaction product in the soil. This would yield a decreased concentration of  $(\text{NH}_4)_2\text{CO}_3$  in the soil and thus decreased  $\text{NH}_3$  loss. Although not uniformly significant, there was a trend indicating that UUP would result in an increased N use efficiency as compared to U. This may be explained by a decrease in pH in the immediate vicinity of the fertilizer application, resulting in suppressed urease activity. A decreased  $\text{OH}^-$  ion activity also will tend to result in lower  $\text{NH}_3$  losses.

A laboratory experiment was conducted to evaluate the urease activity of soils in selected treatments. The non-buffer method of Zantua and Bremner (1975) was

utilized because it was reported to be a better index of urease activity under natural conditions than the buffer methods. Measurements were conducted in both conventional and reduced tillage systems. In addition, measurements were made of greenhouse samples. Experimental variables included; N application rate, N application method soil texture and residue level.

The results of this experiment indicated that urea hydrolysis was probably not limiting in any of the field or greenhouse experiments. There were no consistent significant effects due to treatment in the greenhouse or field samples. There were, however, indications that soil type and tillage system may influence urease activity in some situations. Higher urease activity was associated with the clay soil. This effect may be a result of increased adsorption of urease on the soil colloids which might decrease its denaturation by proteolytic enzymes. The reduced tillage systems were also associated with a decreased urease activity. This may be caused by a general decrease in microbial levels due to a fallowing effect.

Data from the  $\text{NH}_3$  loss experiment suggested that there may be an advantage to UUP as a N source as compared to U. This effect is more pronounced at higher application rates. The benefit of UUP is probably

associated with a delay and subsequent decrease in the urea hydrolysis rate.

In conclusion, an increase in N use efficiency may be gained if fertilizer application is delayed until the plants are at a stage of growth in which they could efficiently uptake the N. This would probably entail a 6 week delay in application. Sidedressing of N fertilizer decreased apparent  $\text{NH}_3$  loss in some instances, but this trend was not uniform throughout the data. Due to the increase in  $\text{NH}_3$  loss observed with a high initial moisture content, it would seem a good practice not to apply urea fertilizers to a moist soil. If the material is applied to a dry soil, urea hydrolysis may be delayed until sufficient rainfall occurs to leach the fertilizer into the soil. There is some indication from greenhouse and field experiments that there is an advantage to using UUP over U. This effect, however was not expressed uniformly throughout the data. Taking the data as a whole, the tentative ranking of N sources in terms of relative N use efficiency would be:  $\text{AN} > \text{UUP} > \text{U}$ .

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