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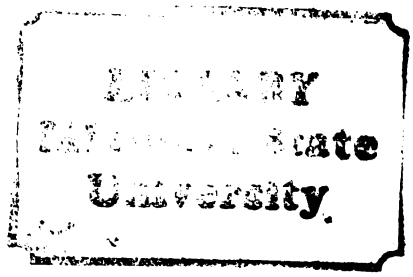

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AGRONOMIC EFFECTIVENESS OF SOME UREA PHOSPHATE FERTILIZERS AS DETERMINED BY AMMONIA VOLATILIZATION LOSSES AND CROP RESPONSE

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By

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ABSTRACT

AGRONOMIC EFFECTIVENESS OF SOME
UREA PHOSPHATE FERTILIZERS AS DETERMINED
BY AMMONIA VOLATILIZATION LOSSES AND CROP RESPONSE

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Laboratory aeration studies, greenhouse and field investigations were conducted to evaluate ammonia volatilization from and relative crop responses to fertilizer granules of cogranulated urea-urea phosphate, urea phosphate and urea.

Ammonia volatilization in the laboratory was significantly greater from urea-urea phosphate and urea than from urea phosphate and ammonium nitrate. The losses increased with the nitrogen rates (0, 60, 120 and 200 mg N/kg soil), however, at the end of fourteen days, residual nitrogen was proportional to the rates applied.

In the greenhouse, urea-urea phosphate was less effective than the other fertilizers. Of the two soils used, oats responded more on Charity clay than on Granby loamy sand. The nitrogen rates were 0, 60, 120 and 180 mg N/kg and there was response to nitrogen applications up

to 120 mg N/kg.

There was yearly variability in the three field studies. The first investigation which compared broadcast to incorporated fertilizer applications at 0, 67, 134 and 202 kg N/ha suggests that incorporating urea-urea phosphate and urea following application is advantageous. Corn responded to nitrogen rates up to 134 kg N/ha. The second study which compared fertilizers banded 5 cm below and 5 cm to the side of seeds indicates that there was no variability among fertilizers when banded. The third study which compared fertilizers when applied in contact with seeds at 0, 6, 11, 22 and 44 kg N/ha shows that increasing rates reduced stand counts and grain yields. Urea-urea phosphate and urea were more detrimental to corn.

DEDICATION

To my parentage,

Who gave me life, love and hope,

The aspiration to succeed and

Glorify the name Yerokun.

In honor of my dear Mother, Gertrude Gbadero

The essence of my joy and struggle.

In dear and loving memory of my Father, Simeon Alabi

The pillar of my determination and a

Monument of unageing intellect.

In solemn memory of my Grandmother, Alimotu Aduke.

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I am grateful to the many people who helped me in the course of my project, especially Calvin Bricker for technical and logistics support.

My gratitudes to Darlene Kriss and Jodie Schonfelder who assisted in the preparation of this manuscript.

I thank my Sisters and Brothers for their encouragement of my pursuits. Dellia, 'your love and support were the bare essence of my progress.'

Most of all, I give ceaseless praise and thanks to God Almighty who has made everything possible by the breath of life.

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INTRODUCTION

Ammonia volatilization from nitrogen fertilizers is becoming of increasing concern. There is a large use of nitrogen fertilizers to increase world food production and with cultural practices such as no-till and sodding, it is important that this factor be studied to determine the economic losses as well as the environmental ramifications. Leaching of nitrates and denitrification are major, recognized, and well studied nitrogen loss phenomena.

Numerous investigators have observed that ammonia loss is enhanced under certain conditions. Soil temperature, pH, moisture, cation exchange capacity, as well as application methods and species of ammonium salt all have a bearing on ammonia loss. Since factors such as soil type, temperature and urease activity cannot be controlled in the field, research has focused on factors such as release rate of nitrogen, soil moisture and cultural and liming practices. Nitrogen fertilizers vary in their efficiencies which may be determined by their mineralization pathway which is affected by factors already mentioned. Fertilizer industries have manufactured slow release fertilizers with a slow rate of dissolution which reduces ammonia loss. These are costly and perhaps only economical on high value crops. Acid compounds and ions such as H_2PO_4 and HNO_3 have also been bonded to nitrogen fertilizers to reduce the rate of dissolution and keep fertilizer band pH low. Recommendations are being made to band or incorporate fertilizers rather than broadcast.

Greater efficiency in energy conversion in the manufacture of

urea-based fertilizers adds to their increasing importance. Urea as a fertilizer has two limitations: 1) Ammonia loss and, 2) damage to seedlings and young plants.

There is a problem with the direct determination of ammonia volatilization in the field. As the soil is a continuum, diffusion can negate any results that may be obtained by direct determination from any part of the field. Therefore, closed system aeration studies have been employed in laboratory studies. It is not absolutely possible to duplicate or simulate field conditions, therefore, studies have to be focused on specific contributing factors while others are held constant. Results will thus be relative to the condition of study, however, data has been obtained that can be used in making recommendations.

Seedling damage and crop response have also been used as measures of fertilizer efficiency but at best this indirect approach can only give results relative to another fertilizer. There should be less seedling damage and greater crop response where ammonia volatilization is less. It is important to realize that there could be adequate nutrient supply from various sources at the critical stages of crop development which would in essence shield the difference among sources.

Many reports in the literature are based only upon either a direct or an indirect evaluation of nitrogen loss. In direct measurements only one author was found to use a constantly moist air in the system. The following study engages both the direct and indirect methods as well as a constantly moist air in the system. This approach is used in the belief that a comparison of the methods may show any differences due to cropping and or hydrolysis pathway; and that moist air will substantially reduce ammonia loss. If moisture is constant then it can

be determined if initial moisture content has an influence over ammonia volatilized. As loss is a consequence of hydrolysis, the speed and duration of this reaction will have an effect on the rate of and total ammonia loss.

The objectives of this study are: 1) To determine the ammonia volatilized directly from soils as a consequence of soil texture, initial moisture content, nitrogen source and application rate: and 2) To determine the relative efficiencies of urea, ammonium nitrate, urea phosphate and cogranulated urea-urea phosphate as nitrogen fertilizers.

LITERATURE REVIEW

Mechanism of Ammonia Volatilization

Initial investigations of ammonia volatilization were mainly qualitative and determined by plant response and seedling damage. In time various scientists developed quantitative methods of determining ammonia loss. There is a general agreement that factors such as soil temperature, CEC, moisture, pH, salts, application methods, rate, and source influence the magnitude of ammonia lost.

Terman and Hunt (1964) were perhaps the first to determine the mechanism of ammonia loss and this analysis will serve to elucidate how the factors mentioned can affect this phenomenon. Recently, Fenn and Kissel (1973) have done a more detailed analysis of this mechanism. They suggest that when an ammonium salt dissolves in calcareous soils ammonium carbonate and calcium salts of varying solubilities form. Ammonium carbonate subsequently decomposes losing carbon dioxide to the atmosphere at a faster rate than ammonia. This results in the formation of ammonium hydroxide and an increase in pH, which increases ammonia loss. They derived the following reactions to describe the mechanism:

$$x(NH_4)_2Y + nCaCO_3(s) \rightleftharpoons n(NH_4)_2CO_3 + Ca_nY_x \quad \ldots\ldots\ldots (1)$$

Ammonium carbonate is unstable and decomposes as follows:

$$(NH_4)_2CO_3 + 5H_2O \rightleftharpoons \underset{\downarrow\uparrow}{2NH_3} + 6H_2O + CO_2\uparrow \quad \ldots\ldots\ldots\ldots (2)$$
$$2NH_4\,OH$$

The amount of NH_4OH formed depends on Ca_nY_x solubility. If it is insoluble the reaction proceeds to the right forming more $(NH_4)_2CO_3$ and NH_4OH. If a soluble product is formed, no appreciable $(NH_4)_2CO_3$ is

formed. A faster loss of CO_2 and NH_3 would give more OH^-. NH_4^+ is thus balanced by OH^- which would favor NH_3 loss, thus:

$$NH_4^+ + OH^- \rightleftharpoons NH_4OH \rightleftharpoons NH_3 + H_2O \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Terman and Hunt (1964) suggest that in calcareous soils $CaCO_3$ reacts with ammonium sulfate and ammonium phosphate to form products of low solubility. The other product, ammonium carbonate is less stable dissociating into NH_3, CO_2 and H_2O. Less ammonia volatilization will occur with ammonium nitrate which forms no Ca precipitate. Fenn and Kissel (1973) observed that if the ultimate anion effect is to produce an insoluble product, NH_3 volatilization would be enhanced. They, therefore, conclude that the solubility of the potential reaction product is a major factor regulating ammonia volatilization from calcareous soils.

Nelson (1982) states that ammonium salts added to or formed in non-calcareous soils will undergo the following reactions:

$$NH_4^+ \rightleftharpoons NH_3(aq) + H^+ \quad \ldots\ldots\ldots\ldots\ldots (4)$$

the equilibrium product of this reaction-

$$\frac{[NH_3(aq)][H^+]}{[NH_4^+]} = K = 10^{-9.5} \quad \ldots (5)$$

The soil pH determines the ammonia concentration in the soil solution as indicated in the equation:

$$\text{Log}\frac{[NH_3(aq)]}{[NH_4^+]} = -9.5 + pH \quad \ldots (6)$$

The rate of ammonia loss is governed by the difference in partial pressure between $NH_3(aq)$ and NH_3 in the atmosphere (P_{NH_3}) above the solution. At equilibrium, the concentration of aqueous ammonia is related to P_{NH_3} in the atmosphere by the Henry constant

(K_H)

$$[NH_3(aq)] = K_H P_{NH_3}$$

Increasing the $[NH_3(aq)]$ or the pH will result in a change in equilibrium between P_{NH_3} and $NH_3(aq)$ with resultant loss of ammonia to the atmosphere.

Factors Affecting Ammonia Volatilization

If the reaction product between fertilizer and soil is insoluble, Ammonia volatilization may proceed. The duration and magnitude of this loss will be determined by the soil and human factors mentioned earlier. A number of studies have been conducted to isolate and determine the effect of each factor. Comprehensive studies have been carried out by Ernst and Massey (1960) and Fenn and Kissel (1976). A discussion of these factors follows.

Temperature

Cool temperatures which limit nitrification and high temperatures which aid evaporation will both enhance NH_3 loss. Water soluble nitrogen fertilizers will hydrolyze with subsequent ammonification and nitrification. Soil bacteria and enzymes play a dominant role in these processes and since their metabolic activities are temperature dependent so would hydrolysis. It is in common agreement that increasing temperature within a certain range will increase the rate of urea hydrolysis (Ernst and Massey, 1960; Gasser, 1964; Wagner and Smith, 1958). The optimum temperature for urea hydrolysis is 50C (Ernst and Massey, 1960). Incubation studies by the same authors showed increasing

and significant NH_3 volatilization at 7, 16, 28, and 32C. Gasser (1964) suggests that temperature increases up to about 30C will increase the rate of hydrolysis, thus nitrogen loss. Wagner and Smith (1958) compared losses at 10C and 25C. For the first two weeks there was more nitrogen loss at 25C, thereafter, there was more loss at 10C. In seven weeks 8.5% N of urea at 25C and 11% N at 10C were lost. They conclude that the higher cumulative loss at the lower temperature was due to bacterial and nitrification inhibition thus maintaining a higher NH_3 concentration over a longer period. The rate of loss was more rapid with higher concentrations of urea applied to the soil surface. Meyer et al (1961) working with a calcareous soil observed that there was greater ammonia loss at 4C than at 28C probably due to reduced microbial activity to convert ammonium to nitrate at 4C. Urea hydrolysis proceeds moderately rapidly at 4C and may have caused a build up of ammonium in excess of soil adsorption capacity. By increasing the temperature from 10 to 20 to 30C urea hydrolysis was increased. Except at 10C, the rate of ammonia loss appeared constant, and this may also be true for the rate of hydrolysis (Fisher and Parks, 1958).

In the studies done by Fenn and Kissel (1974) they noted that total ammonia loss from precipitate forming compounds such as ammonium sulfate was only slightly influenced by temperature. Higher temperatures promoted higher initial losses and this decreased in time. Lower temperatures gave lower initial losses which relatively increased in time. The same authors also showed nonprecipitate forming compounds, ammonium nitrate for instance, to be influenced by temperature and not the rate of application. Ammonia loss increased directly with temperature.

Moisture

Jewitt (1942), postulated that ammonia volatilization is based upon a drying process and not on the initial moisture content. However, Volk (1959) observed an increased loss from a soil at one third field capacity compared to an air dried soil. Initial moisture contents of 1% (air-dry), 5%, 21% (field capacity), and 37.5% gave increasing and significant ammonia losses (Ernst and Massey, 1960). The same authors also agree that ammonia loss follows moisture loss which was greatest at 37.5% in this study. They observed that urea hydrolysis was faster at moderate soil moisture than at field capacity.

Jewitt (1942), found a correlation between rate of water loss and that of ammonia. Moisture content itself seems to be of no consequence but rather the evaporation rate. At higher moisture levels, drying enhanced ammonia loss three to four times whereas it slowed losses at lower moisture levels, perhaps because the soils dried quickly below the point of supporting rapid hydrolysis of urea (Volk, 1959). Kresge and Satchell (1960) noticed that most of the ammonia appreared to be lost when soil was drying from a moisture content near field capacity. This allowed enough moisture for hydroloysis and fairly rapid drying. Practically no loss was observed at air-dry and maximum loss was at 25% field capacity. Further increase in soil moisture reduced NH_3 loss. Gasser (1964) and Wahhab et al (1957) found ammonia loss possible only when there was moisture loss.

In laboratory experiments, Martin and Chapman (1951) observed little or no loss of NH_3 when using moist air in the aeration apparatus: however, there was loss with dry air. Using soils at field capacity at

24C, Ernst and Massey (1960) observed that air with extreme humidities, 0% and 100%, passed over soil produced lower ammonia losses compared to intermediate humidities at 50-55% and 85-90%. Chao and Kroontje (1964) observed that when moisture saturated and unsaturated air were passed over soils the rate of ammonia loss decreased with time while the rate of water loss remained nearly constant until nearly air-dry conditions. In their investigation, they suggest that it is likely that when the equilibrium between soil and vapor phase is reached most of the applied NH_4OH is changed by soil to ammonium. The reverse shift from ion form on soil to NH_3 in vapor phase by the application of air flow is not at the same speed as water evaporation under this condition. This is the cause of low mobility of ammonia. Ammonia loss and moisture loss follow different functions under this condition hence no linear relationship. Jewitt (1942) further explains that the soil solution establishes an $NH_4^+ + OH^- \rightleftharpoons H_2O + NH_3$ equilibrium. The latter compounds have their own partial pressures and evaporate in proportions governed by their relative molar concentrations. The reversible reaction between the ion and base exchange complex tend to maintain the ammonium concentration constant. The soil solution is thus buffered against ammonium concentration change. When exchangeable ammonium is low the ratio may change. This may explain that as water evaporates the equilibrium shifts to the right which causes a build-up and consequent loss of ammonia.

Urea initially moves into the soil undissociated. Therefore, by increasing the amount of water applied after urea application, Fenn and Miyamoto (1981) were able to reduce the amount of ammonia lost. They also observed a suppression of ammonia loss from initially moist soils

by application of more water. Urea was shown to move largely with the wetting front. This implies that as evaporation proceeds urea is moved up with this front and if hydrolysis is favored NH_4^+ is produced which can be lost as NH_3 if not adsorbed by the soil exchange sites.

Ammonia loss from sandy soil at optimum moisture was greater than from silty or clayey soil (McDowell and Smith, 1958).

Soil Reactions

Broadbent et al (1958) observed that when soil pH becomes too acid or alkaline nitrification is inhibited. This may result in a build-up of ammonium and consequent loss of NH_3. Gasser (1964) and Jewitt (1942) have also shown that rather high pH will favor ammonia volatilization. Increasing soil pH increases NH_3 loss. A pH drop from 8.3 and 8.4 to 7.3 greatly reduced ammonia loss while further drop to 5.4 had no significant effect (Wahhab et al, 1957).

Urea hydrolysis was observed to increase soil pH (Gasser, 1964). As the soil pH increased, Volk (1959) noticed a decrease in the ammonium adsorption capacity of some Florida soils and this resulted in greater ammonia volatilization. Increased loss of NH_3 with increase in pH was great for alkaline soils with high clay content. With increasing pH the soil has increasing calcium saturation of the soil exchange complex, thereby, there is less adsorption of ammonium from hydrolysis. Also perhaps there is increased hydroxyl activity in the soil solution, leading to ammonia volatilization (Ernst and Massey, 1960). Presence of ammonium carbonate raises soil pH and this may precipitate the soluble and adsorbed Ca and Mg, therefore, volatilization would increase from displaced and unadsorbed ammonium (Fenn and Miyamoto, 1981). An

equilibrium will exist between adsorbed and solution ammonium ions and an $NH_4^+ + OH^- \rightleftharpoons H_2O + NH_3$ equilibrium also exists in solution Wahhab et al (1957). If soil pH is raised, NH_4^+ and OH^- activities are increased and the reaction driven to the right leading to ammonia loss. Ernst and Massey (1960) observed maximum losses first from higher pH soils and later from lower pH soils probably because hydrolysis may have been completed earlier in the higher pH soils.

It is postulated that due to the equilibrium $NH_4^+ + OH^- \rightleftharpoons NH_3 + H_2O$ ammonia may be volatilized even from acid soils, (DuPlessis and Kroontje, 1964). The effective OH^- concentration would be dependent on the pH. It is probably low OH^- activity in acid soils that retards ammonia loss. Even H-saturated soils lost NH_3 when NH_4OH was surface applied, due to the temporary alkalinity imparted by NH_4OH (Martin and Chapman, 1951). Ammonia formed during decomposition raises soil pH and may also cause volatilization in acid soils (Kresge and Satchell, 1960).

Cation Exchange Capacity

Conrad and Adams (1940) suggest that the exchange capacity of soils is very important in retarding ammonia loss especially if the colloidal humus fraction is very high. They report studies by Van Haneveld-Lake, who recovered 88% of applied urea in 1:2 soil:water extraction after 48 hours; 0.5-3% N of applied NH_4Cl and 96-100% N of applied $NaNO_3$ were also recovered. Clay lattices have a net negative charge and this would be instrumental in retaining the positively charged ammonium ions while the negatively charged nitrate ions are leached. These same authors also indicate that Grette observed a 1.90% adsorption on silica, 2.94% on alumina and 0.30% on iron oxide. This is

with little doubt a result of the exchange capacities of these substances. Considerable loss is expected from soils with less than 10% base exchange capacity (Gasser, 1964).

Fenn and Kissel (1976) observed lower ammonia losses when ammonium concentration was reduced at the same CEC. This could be due to a more complete adsorption on the exchange sites. When there is a saturation of the exchange sites, there is less adsorption of ammonium from hydrolysis and this will lead to a higher NH_3 loss ratio (Ernst and Massey, 1964).

A low soil CEC may allow for more ammonium carbonate formation thus increasing the pH and NH_3 loss (Fenn and Kissel, 1976).

As the soil CEC increases so does the soil water holding capacity, thus the question arises of which factor contributes more to ammonia loss. In an unpublished work, Fenn and Kissel observed NH_4^+-N volatilization from Houston Black clay to be nearly constant over a wide range of water contents from 0.15 to 0.30g/g soil. Thus it is felt that CEC exerted the major influence.

Textural differences contribute to NH_3 loss. Coarser soils lost more ammonia in studies conducted by Chao and Kroontje (1964) and Wahhab et al (1957). Ammonia fixation was seen to increase with increasing clay contents of soils (McDowell and Smith, 1958). When ammonium concentration was increased, DuPlessis and Kroontje (1964) observed a stimulation of NH_3 loss from fine textured soils, while Wahhab et al (1957) observed a more general increase in NH_3 loss. Leaching experiments by Broadbent et al (1958) showed urea retention to be mostly in the top 6 inches of clay columns, while it was more uniform for the sandy soils. Also, McDowell and Smith (1958) observed that when

injected into moist columns NH_3 movement was greater in sandy and silty soils than in clayey soils.

Aqueous vapor and gaseous NH_3 compete for adsorption sites on moist clay systems. Brown and Batholomew (1963) showed that dry clay was able to adsorb additional quantities of NH_3 gas applied while clay with water molecules on the exhange sites was incapable of retaining more than the initial NH_3 gas applied without an increase in partial pressure. Dry clay adsorbed more NH_3 between 1-60 mm Hg. Dilute NH_3 solutions were competitive with water for adsorption sites. Even in clay suspensions NH_3 was not strongly held. Increasing water tended to replace adsorbed NH_3.

Salt

The cation on soil exchange complex has a bearing on ammonia volatilization. Sodium and potassium were observed to contribute to higher losses of NH_3 than Ca and Mg apparently as a result of higher pH induced by the former (Martin and Chapman, 1951). Fenn and Kissel (1973) observed that neutral Mg-saturated soils lost twice as much NH_3 as Ca-saturated soils when ammonium sulfate was applied, however, there was no difference when ammonium hydroxide was applied. DuPlessis and Kroontje (1964) meanwhile observed more volatilization from Ca-clay than from Mg-clay treated with ammonium hydroxide. At a higher partial pressure of CO_2 in the soil atmosphere Mg-clay lost more NH_3 than Ca-clay due to greater precipitation of $CaCO_3$ than $MgCO_3$, which increased the pH of Mg-clay (Fenn and Kissel, 1973). With the precipitation of Ca as $CaCO_3$, CO_3 increases as does NH_3 retention. Calcium is thus eliminated from being a potential replacement ion for

NH_4 (Fenn et al, 1981a). Urea and NH_4OH precipitated Ca and Mg, the amount being inversely related to NH_3 loss. As divalent cations are precipitated room is made for ammonia adsorption thus reducing upward movement of ammonia and it's loss (Fenn and Miyamoto, 1981).

Fenn et al (1981a) suggest that Ca and Mg sulfates and chlorides suppress ammonia volatilization by two basic chemical reactions: 1) precipitation of carbonate by Ca thus preventing the permanent formation of $(NH_4)_2CO_3.H_2O$. 2) calcium depression of soil pH by depression of dissociation of the $CaCO_3$-$Ca(OH)_2$ buffer system.

Calcium did not significantly reduce soil pH but it did reduce ammonia loss giving the greatest loss at a Ca:N of 0.25. Fenn et al (1981b) observed a significant reduction in sand pH at Ca:N of 0.5. This subsequently reduced ammonia loss from 41% after 9 days to 8% of applied nitrogen at Ca:N of 0.25. In broadcast applications, higher rates of calcium were required to reduce ammonia loss from low than from high nitrogen applications. The same authors observed that at 550 kg N/ha application ammonia loss was slightly less than at 110 kg N/ha application, at a Ca:N of 0.25. Progressive increases in nitrogen application gradually decreased the ratio of Ca:N required to reduce ammonia loss to less than 10% of applied nitrogen. When Ca:N exceeded 0.25 there was a decrease in calcium precipitation.

Fenn and Kissel (1975) observed a rapid increase in ammonia loss up to 6.1% $CaCO_3$ when ammonium sulfate was applied. There was a slight increase in ammonia loss from 6.1% to 9.7% $CaCO_3$ and no appreciable increase beyond this value. Ammonium nitrate reached a maximum loss at 1.3% soil $CaCO_3$ and 110 kg N/ha, with lower losses at 6.1% soil $CaCO_3$ and 550 kg N/ha. As a result of fertilizers having residual acid effect

higher application rates caused less ammonia losses from low (0.5%) $CaCO_3$ soils. Ammonium sulfate losses increased with percent $CaCO_3$. Ammonium nitrate reacted differently showing least losses at high rates (Fenn and Kissel, 1975).

The effects of calcium appear to be three:

1) calcium precipitation at Ca:N of 0.25.

2) any extra calcium not precipitated depresses soil pH by depression of the $CaCO_3$-$Ca(OH)_2$ buffer system, and

3) calcium tends to reduce the rate of urea hydrolysis (Fenn et al, 1981b).

As calcium is associated with slower hydrolysis there may be the formation of a Ca-urea complex. Urea hydrolysis becomes slow enough that nitrification and it's acid production begins to convert NH_3 to soluble HNO_3 which reacts with $CaCO_3$ to form $Ca(NO_3)_2$.

Ammonium Source

Incubation studies by Bremner and Douglas (1971) showed a linear correlation between incubation time and urea nitrogen hydrolysis. This indicates that hydrolysis is a result of enzymatic activities. Gasser (1964) shows that urea is hydrolyzed by the enzyme urease as well as acids and alkalis. This process is faster in forest and grassland soils and slower in alkali and calcareous as well as sandy soils with little organic matter content. He also concludes that hydrolitic activities increase with microbiological activities. Bremner and Douglas (1971) ranked rate of hydrolysis as urea > urea oxalate > urea nitrate > urea phosphate; they observed a 4.6-6.1% N loss for urea and 0.1-1.1% N loss for urea phosphate, following 14 days of incubation.

The rather efficient energy conversion of urea based fertilizers adds to their increasing importance. The loss of NH_3 from urea, however, is a problem that plagues fertilizer development. Meyer et al (1961) and Kresge and Satchell (1960) are among authors who observed that urea lost more nitrogen than the other fertilizers in their studies. Kresge and Satchell couple this with an increase in pH above neutral at 320 kg N/ha application. This problem may be controlled by: 1) bonding of acid compounds to urea to lower the fertilizer band pH and reduce the dissolution and hydrolysis rate. Ortho and polyphosphates, nitrates and sulfates have been employed in this; or 2) coating of urea to reduce the dissolution rate. Sulfur and microbicides have been used for this. These will be discussed later.

Ernst and Massey (1960) did not see any difference in ammonia loss between application of crystalline or solution urea to the soil surface at field capacity. This was also true when the fertilizers were watered into the soil. Volk (1959) observed that crystalline urea lost more NH_3 than pellets, perhaps due to the pellets clinging to the turf or residue thereby missing areas of higher CEC in the soil.

Terman and Hunt present the following source specific mechanisms:

1). $(NH_4)_2SO_4 + CaCO_3 \xrightarrow{H_2O} CaSO_4.2H_2O + (NH_4)_2CO_3$

They observed an intermediate; $Ca\text{-}(NH_4)_2(SO_4)_2.H_2O$. Preferential formation of this phase which persisted under concentrated conditions, than gypsum, would prevent ammonia loss by less $(NH_4)_2CO_3$ formation.

2). $CO(NH_2)_2 + 2H_2O \xrightarrow{urease} (NH_4)_2CO_3$

This is not dependent on $CaCO_3$. Higher NH_3 losses with increasing pH could be due to lower adsorption capacity of soils.

3). $2NH_4NO_3 + CaCO_3 \longrightarrow Ca(NO_3)_2 + (NH_4)_2CO_3$

Calcium nitrate being soluble the reaction does not go to completion and little NH_3 is lost.

Less ammonia was lost from urea than ammonium sulfate due to it's strong reaction with $CaCO_3$ thus yielding soluble $CaSO_4$. The Ca is now able to act as a replacement ion for NH_4^+ (Fenn et al, 1981a). Ammonium sulfate gave more dry matter weight than urea nitrate on clayey and sandy soils with light or heavy dressing because urea nitrate caused damage to the plants. The nitrate in urea nitrate becomes free acid when water is added. The now rapidly decomposing urea contributes to crop damage. The nitrate is immediately available for crop uptake and the acid does not contribute to crop damage (Gasser and Penny, 1967). Using urea: ammonium nitrate mixtures, Kresge and Satchell (1960) observed greatest ammonia losses with urea only and a reduction in losses as the ratio decreased.

Mixing urea with acid materials such as superphosphate may reduce ammonia volatilization (Gasser, 1964). Polyphosphates are thought by Spratt (1973) to be even superior to orthophosphates. He observed that the hydrolysis of polyphosphates at 25C was rapid enough to not limit phosphorus uptake by plants. Bremner and Douglas (1971) observed that urea phosphate showed less ammonia loss than urea because of the phosphoric acid retarding hydrolysis by urease. Urea phosphate was as good or better than ammonium sulfate in studies. Where pH is less than 5.5, urea is not readily hydrolyzed. Hydrolysis occurred only when urea

diffused into portions with pH higher than 5.5. Diffusion thus increases the soil volume in which nitrogen becomes available. The acidified soil near free NH_3 can adsorb it thereby preventing damage to plants (Gasser and Penny, 1967). The same authors observed that urea polyphosphate increased yield but not phosphorus uptake, as compared with ammonium phosphate without a nitrification inhibitor (N-Serve)[1] With N-Serve, the urea polyphosphate gave no increase in yield, but all sources produced a general increase in phosphorus uptake.

Sulfur coated urea (SCU) applied with lime gave less than 0.2% nitrogen loss compared to 52% for urea top-dressed with lime. The self liming effect of urea contributes to an increase in pH, thus creating more conducive conditions for urea hydrolysis (Matocha, 1976). While mixing reduced ammonia volatilization from NH_4OH and urea it seemed to enhance losses from SCU-30 (30% sulfur), possibly because of a faster breakdown of the sulfur coating which in this case has more surface area contact with the soil (Matocha, 1976). The same author showed that nitrogen uptake from soils with lime was linear with rate of application. When mixed with the soil differences due to source were small. Uptake was greatest from $(NH_4)_2SO_4$ and lowest from SCU-30, perhaps as a result of slower dissolution of the latter. Ammonium sulfate and SCU-30 were more effective than SCU-19 and urea ammonium phosphate, when broadcast.

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[1] N-Serve is 2-chloro-6(tri-chloro-methyl) pyridine marketed by Dow Chemical.

Application Rate

The rate of fertilizer applied invariably influences NH_3 loss (Chao and Kroontje, 1964; Jewitt, 1942). Ammonia volatilization is of concern where large amounts of fertilizer are side-dressed. Accumulation of NH_3 before nitrification and diffusion is possible (Kresge and Satchell, 1960). Jones (1932) observed that for urea the rate of ammonification was faster than the rate of nitrification. More NH_3 will then accumulate with increasing rates of application. This is further verified by Broadbent et al (1958), who conclude that when urease is saturated by nitrogen concentration hydrolysis may not be complete.

Martin and Chapman (1951) observed that nitrogen loss increased with rate. Fenn and Kissel (1976) observed an increase in percentage loss with increasing rates of $(NH_4)_2SO_4$. They observed a rapid decrease of percent nitrogen loss with lower rates of application, as the CEC increased. This is perhaps the result of greater adsorption on the exchange sites.

Application Method

Generally, loss of NH_3 should be reduced with deeper application but there are exceptions. Urease activity is bound to decrease with soil depth and consequently urea hydrolysis and NH_3 loss. Jackson and Chang (1947) postulate the depth of application to be the most important factor in complete adsorption of anhydrous ammonia. They observed that a 67 kg N/ha application to soil with intermediate texture, moisture and pH gave little or no loss at a depth of 2.5 cm. At 5 cm depth air-dry soil lost less than 5%. Surface applications lost more comparatively.

Fenn and Kissel (1975) conclude that surface application of ammonium salts to limed soils will cause greater volatilization while mixing the limestone may reduce loss. Gasser (1964) and Meyer et al (1961) further state that crop residue on the soil surface tends to increase NH_3 volatilization from broadcast fertilizer because of the higher urease activity in the residue. Jackson and Chang (1947) observed that large amounts of $CaCO_3$ did not prevent ammonia retention when incorporated 5-10 cm; and retention was even greater on calcareous than on non-calcareous sandy soils. Gasser and Penny (1967) noted that mixing fertilizer with soil or acid fertilizers diminished nitrogen loss and seedling damage. In time, NH_3 losses from deep applications will decrease while surface applications may show an increase (Ernst and Massey, 1960). Yield studies by Terman and Hunt (1964) showed lower yields with surface application of urea and SCU-19 and intermediate yields with urea ammonium phosphate and SCU-31.

MATERIALS AND METHODS

General Overview

The objectives of this study have been stated. This section will proceed to discuss how these objectives were demonstrated and elucidated. In 1980, Tennessee Valley Authority (TVA) made available for research urea phosphate fertilizers in the ratios of 2:1 and 1:1 urea to phosphate. Initial laboratory investigations by them, using 3:1 ratio fertilizer had shown a five day delay in ammonia volatilization. This result, along with the results of some other agronomists prompted TVA to purport some hypothesis about the agronomic effectiveness of urea phosphates. If truely they are advantageous, it is reasonable to expect qualitative as well as quantitative yield superiority over most other fertilizers. Also there should be lower ammonia volatilization. Under TVA contract, field studies were undertaken at the Saginaw Valley Bean and Beet Research Farm.[2] Corn was used as the indicator crop. Results obtained over the first two years did not consistently support any of the hypothesis by TVA, and this warranted an indepth study of NH_3 loss from soils and of crop response to fertilizers under controlled conditions.

Beginning in the Spring of 1982, laboratory aeration studies were conducted. An investigation of the relationship between uptake of nitrogen in the greenhouse and ammonia loss was undertaken. Oats were

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[2] Dr. D.R. Christenson, Crops and Soils Department, Michigan State University - Project Coordinator.

used as the indicator crop because of general success with their cultivation under controlled conditions. Field studies were conducted from 1980 through 1983.

General Description of Soils

Three soils were used in these investigations and they are described below.

Charity Clay

This soil is classified as Aeric, Haplaquept, fine, illitic, mesic,[3] with 8% sand, 28% silt and 64% clay. Textural analysis was determined by the Hydrometer method (Bouyoucos, 1951).

The cation exchange capacity of the soil was estimated to be 260 cmol (p^+)/kg soil. This was determined by saturating 2 grams of soil with 1N NH_4OAc then washing and centrifuging three times to remove excess NH_4^+ in solution. Three alcohol washes and centrifugations followed, and acidified NaCl was added. Ammonium on the CEC was determined by alkaline steam distillation into H_3BO_3 and titration with standard H_2SO_4.[4] Soil pH as determined in a 1:1 soil: water suspension using a glass electrode was 7.9.

Conover Loam

This soil is classified as Udollic, Ochraqualf, fine loamy, mixed,

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[3] Personal communication, Dr. D. Mokma, Crop and Soil Sciences Department, Michigan State University.

[4] Unpublished mimeo, Dr. D.D. Warncke, Crop and Soil Sciences Department, Michigan State University.

mesic,[3] with 38% sand, 45% silt and 17% clay.

The cation exchange capacity was estimated to be 105 cmol (p^+)/kg soil. Soil pH was determined to be 7.1.

Granby Loamy Sand

This soil is classified as Typic Haplaquoll, sandy, mixed, mesic[3], with 73% sand, 12% silt and 15% clay.

The cation exchange capacity was estimated to be 80 cmol(p^+)/kg soil. Soil pH was determined to be 7.5.

FIELD EXPERIMENTS

Broadcast Fertilizer Sources

Field studies were conducted at the Saginaw Valley farm on a Charity clay soil (Table 1). The study was arranged as a randomized complete block design with four replications. Each experimental unit measured 10.06 by 2.84 meters. Cogranulated urea-urea phosphate (34-17-0), urea (46-0-0 + 0-46-0) and ammonium nitrate (34-0-0 + 0-46-0) were applied at 0. 67, 134, 202 kg N/ha. The sources were adjusted with 0-46-0 where required to give 50 kg P/ha. The fertilizers were each surface broadcast and broadcast with incorporation into the soil.

Tillage practices prior to planting consisted of mold board plow in the fall and a single pass of combination spring tooth-spike tooth harrow in the spring. All the fertilizers for designated incorporated

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[3] Personal communication, Dr. D. Mokma, Crop and Soil Sciences Department, Michigan State University.

Table 1. Soil test values and planting information for the field experiments. 1980-1983.

Experiment	Year	pH	P	K	Hybrid	Planting Date	Harvest Date
			-kg/ha-				
Broadcast (Charity Clay)	1980	7.9	95	403	Michigan 3102	5/9	9/26
	1981	7.8	123	582	Michigan 3102	5/19	10/7
	1983	7.9	101	549	Pioneer 3901	5/12	10/7
Band Applied (Charity Clay)	1980	7.9	89	421	Michigan 3102	5/23	10/23
	1981	7.8	166	470	McKenzie 409	5/20	10/4
	1982	7.8	166	470	Pioneer 3901	5/21	10/8
Fertilizer with Seed							
Conover Loam	1980	7.1	149	314	Michigan 3102	4/22	10/10
	1981	7.1	149	314	McKenzie 409	5/5	9/23
	1982	7.1	149	314	Pioneer 3901	4/28	9/23
	1983	7.1	157	291	Pioneer 3901	5/17	9/20
Charity Clay	1980	7.8	87	439	Michigan 3102	5/23	10/23
	1981	7.7	94	493	McKenzie 409	5/21	10/8
	1982	7.7	94	493	Pioneer 3901	5/20	10/11
	1983	7.7	95	526	Pioneer 3901	5/18	10/7

plots were hand spread then all the plots were harrowed on the same day. Thereafter, fertilizer for designated broadcast plots were hand spread. Corn was planted at a 71 cm row spacing. Weeds were controlled by pre-emergence application of 1.68 kg/ha Cynazine and 766 ml/ha Alachlor. These were active ingredients.

Ear leaf samples were obtained at tasseling by removing ten ear leaves per plot. Likewise ten whole plants (less roots) were harvested at maturity to determine stalk and ear percent nitrogen (uptake). The plots were hand harvested. Yields were calculated by weighing corn ear harvested from two 6.09m rows (1980, 1981) and two 7.89m rows (1983). Plant samples in 1980 and 1981 were digested in hydrogen peroxide-sulfuric acid and nitrogen determinations made on aliquots of the diluted digest. In 1983, the micro-Kjeldahl method was used.

Band Applied Study

Field studies were conducted at the Saginaw Valley farm on a Charity clay soil (Table 1). The study was arranged as a randomized complete block with four replications. Diammonium phosphate, monoammonium phosphate, ammonium nitrate, urea and urea phosphate were all applied in a band 5 cm to the side and 5 cm below the seed. The phosphate fertilizers were applied at 224 kg of material per hectare. Ammonium nitrate and urea were applied in combination with 0-46-0 to give the same nitrogen and phoshorus (38 kg N/ha and 44 kg N/ha) as urea phosphate. Additional nitrogen to give 168 kg N/ha was side-dressed in June. Corn was planted. Weeds were controlled by pre-emergence application of 1.68 kg/ha Cynazine and 766 ml/ha Alachlor.

Whole plant samples (less roots) at the four leaf stage and the

ear leaf samples at tasseling were taken for chemical analysis. All plant samples were digested in hydrogen peroxide-sulfuric acid. Nitrogen was determined on an aliquot of the diluted digest.

Fertilizer With The Seed

Field studies were conducted at the Saginaw Valley farm on a Charity clay soil and at the Michigan State University campus Soils Farm on a Conover loam (Table 1). The study was arranged as a randomized complete block design with four replications. Urea phosphate, cogranulated urea-urea phosphate, urea + 0-46-0 and ammonium nitrate + 0-46-0 were applied in contact with corn seeds at rates to give 0, 11, 22, 44 kg N/ha. Urea and ammonium nitrate were adjusted for phosphorus with 0-46-0 to give the same as from urea phosphate. No additional fertilizer was applied at planting and 168 kg N/ha was side dressed as anhydrous ammonia in June. Stand counts were made periodically after emergence. Weeds were controlled by pre-emergence application of 1.68 kg/ha Cynazine and 766 ml/ha Alachlor. Ear leaf samples were taken at tasseling for chemical analysis.

Greenhouse Experiment

A greenhouse investigation was conducted using Charity clay soil and Granby loamy sand soil (Table 2) to determine crop response to four nitrogen fertilizers, at four application rates. The experimental design was a 3-factor factorial arranged as a randomized complete block with four replications. Urea, urea phosphate, ammonium nitrate and urea-urea phosphate were mixed with the soil at 0, 60, 120, and 180 mg N/kg soil. An additional four treatments for each soil were established

where phosphate was applied to the soil surface at the rates used. These treatments were mixed with the soil between the first and second croppings. Three consecutive crops of Oats (var. Karwood) were each grown for a period of five weeks. Day time temperatures ranged from 21-27C. Night temperature was about 21C and the photoperiod was 12-16 hours per day. Moisture was daily adjusted to field capacity (29% w/w for clay, and 10% for loamy sand) by gravimetric means.

Air dried soil (1600g clay and 1900g loamy sand) was placed into pots lined with plastic. Each pot received an application of 50 and 10 mg/kg soil K and P, respectively, by addition of KCl and $Ca(H_2PO_4)_2.H_2O$. The nitrogen fertilizer treatments were applied and the moisture contents adjusted. The pots were allowed to equilibrate for six hours before planting. Additional P and K were applied to the second and third crops as aqueous solutions of $Ca(H_2PO_4)_2.H_2O$ and KCl while no further addition of nitrogen was made.

The oat seeds were planted at twenty seeds to a depth of 2.5cm and thinned to fifteen plants per pot after emergence. At the end of five weeks the above ground portions were cut at the soil surface. The soils were then screened and re-potted.

All plant samples were dried in an oven at 55C for 24 hours and dry weights taken. The samples were ground to pass a 40-mesh screen, and total N determined by the micro Kjeldahl method which is described in the Laboratory Analysis section.

Table 2. Soil test values for laboratory and greenhouse experiments.

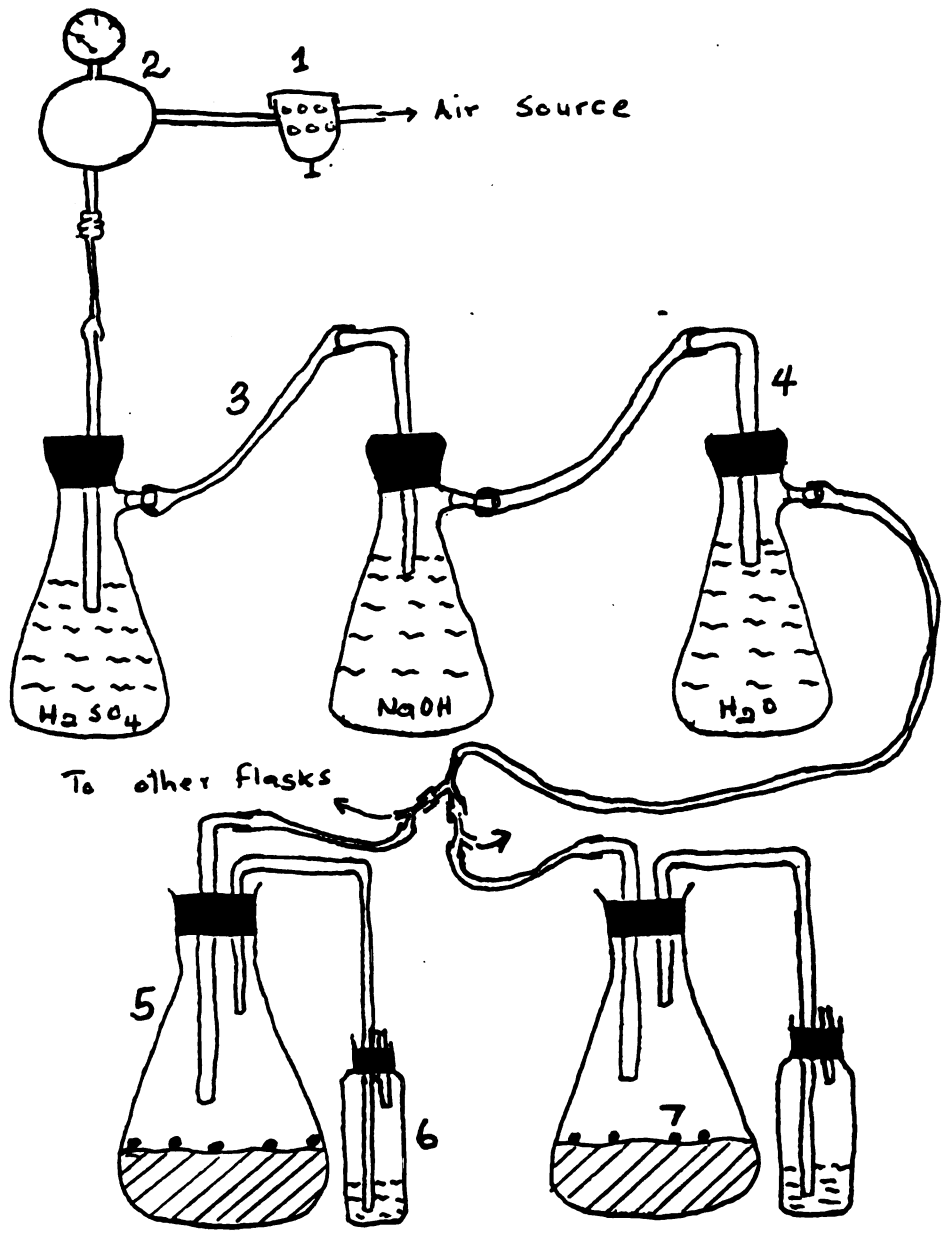
Soil	pH	P	K
		---kg/ha---	
Charity clay	7.7	335	482
Granby loamy sand	7.5	50	231

Laboratory Experiment

The soils used in the greenhouse section were also used in this study (Table 2). The objective was to make a direct determination of ammonia volatilized from nitrogen fertilizers applied to the soil surface. To do this, an aeration apparatus was constructed using Teflon and glass tubing (Figure 1). The four factors that were observed in this investigation were: 1) four nitrogen sources - urea, urea phosphate, urea-urea phosphate and ammonium nitrate; 2) four rates of application - 0, 60, 120, and 200 mg N/kg soil; 3) two moisture levels - field capacity and 25% field capacity; and 4) two soils - Charity clay and Granby loamy sand soils. Nitrogen loss was measured for 14 days and replicated 3 times. The temperature fluctuated between 25 and 28C.

Eight hundred grams of air-dried soil was placed in each one-liter Erlenmeyer flask and the desired moisture content achieved by gravimetric means. After 24 hours, nitrogen fertilizers were applied to the soil surface, and the Erlenmeyer flasks connected to 250 ml square bottles containing 25 ml of 2% - H_3BO_3. Moist air passed through H_2SO_4, NaOH and water was allowed to flow through the flasks. Air flow was visually maintained at about 5 psi. At 24 hour intervals the H_3BO_3,

Figure 1. Laboratory aeration apparatus.



1. Condenser
2. Compressor - gauge
3. Teflon tubing connection
4. Glass tubing connection
5. 1 liter Ehlenmeyer flask containing soil
6. 250 ml square bottle containing boric acid
7. Fertilizer granules on soil surface

bottles were observed for color change and then replaced. Solutions removed were titrated with standard H_2SO_4.

Laboratory Analyses

Plant Sample Treatment

After harvesting from the greenhouse and the field all plant samples were dried in an oven at 55C for 24 hours. After samples were allowed to cool dry weights were determined gravimetrically. The samples were, thereafter, ground to pass a 40-mesh sieve. Total nitrogen and nutrient contents were determined.

Total Nitrogen Determination

Total nitrogen determination in 1980-1982 were made using the Wet Oxidation method described by Parkinson and Allen (1975). Five hundred milligrams of plant tissue were placed in 50 ml round bottom long neck reflux flasks and digested in 5 ml of the digest solution (350ml H_2O_2, 0.42g Se and 14g $Li_2SO_4 \cdot H_2O$ mixed in a flat bottomed boiling flask of one-liter capacity, and 420 ml H_2SO_4 carefully added while cooling). The reflux flasks were placed on the digestion rack for 3 hours. After cooling, each sample was diluted to 35 ml with distilled water and a 1 ml aliquot taken for steam distillation. Ammonia liberated by alkaline steam distillation was collected in H_3BO_3 and total nitrogen was determined by titration with standard H_2SO_4. Results obtained for duplicate determinations of each sample are reported as %N in oven dry plant tissue.

In 1983, total nitrogen determinations were made by the micro

Kjeldahl method described by Bremner (1965). Fifty milligrams of plant tissue were digested in 100 ml Kjeldahl flasks, using 3 ml 36N H_2SO_4 and 1.3g catalyst mixture (100:10:1 mixture of K_2SO_4:$CuSO_4$:Se). Samples were placed on digestion racks and digested for 2 hours. After cooling, each sample was diluted with 10 ml distilled water. Nitrogen contents were then determined by alkaline steam distillation and titration of ammonia liberated into H_3BO_3. Duplicate results are reported as %N in oven dry plant tissue.

Nutrient Analyses

The solution remaining from the wet oxidation process was analyzed for other nutrients when required. All determinations were made on a plasma emission spectrophotometer.

Statistical Analyses

Analysis of variance and other pertinent statistical analyses were obtained using the methods described by Steel and Torrie (1980).

RESULTS AND DISCUSSION

Laboratory Aeration Studies

Four nitrogen sources were applied to Charity clay and Granby loamy sand soils and the nitrogen lost by ammonia volatilization was determined. The two soils used were each maintained at two initial soil moisture levels, and a constantly moist air was passed over them for fourteen days. The experiment was arranged as a randomized complete block design with three replications. The results are reported in milligrams of nitrogen lost to prevent the shielding of differences in magnitude observed for percent nitrogen lost between the various rates. Even though there were significant interactions involving simple effects (Table 3), it would seem useful to examine the simple effects before a discussion of the interactions.

Effect of Nitrogen Source On Ammonia Volatilization

When fertilizers are applied to the soil, their chemical nature will determine the response to the characteristics of the soil. This will affect their decomposition and mobility. Bremner and Douglas (1971) observed that urea hydrolysis will progress in acid and alkali soils but at different rates. They ranked the hydrolysis rate of urea > urea phosphate, as the acid nature of the latter reduces the rate of reaction. When the soil condition is the same, it appears that the magnitude of ammonia volatilization is dependent on the fertilizer source. The controls in this investigation did not lose any nitrogen by volatilization, therefore, it is safe to consider that all nitrogen loss was from the applied fertilizers.

Table 3. Approximate probability of significance of the F statistic for various sources of variance for mg-N lost in laboratory aeration experiment, 1983.

Source of Variance	Approximate Probability
Fertilizer Source (FS)	<0.0005
Nitrogen Rate (R)	<0.0005
Moisture (M)	<0.0005
Soil (S)	0.003
FS x R	0.031
FS x M	0.019
FS x S	0.048
R x M	0.010
R x S	0.056
M x S	0.240
FS x R x M	0.500
FS x R x S	0.448
R x M x S	0.799
FS x R x M x S	0.999

The average nitrogen loss of each source was urea-urea phosphate- 2.37 mg N; urea- 1.87 mg N; urea phosphate- 0.32 mg N; and ammonium nitrate- 0.10 mg N. These losses were significant among sources. It is evident that by increasing the ratio of urea to phosphate beyond 1:1 ammonia volatilization is significantly increased over that from urea alone. This does not conform with the results expected due to the acid bonded to urea. Perhaps there is a saturation of the acid effect in time, because it was observed that there was a three to four day delay in ammonia volatilization from urea-urea phosphate relative to urea. Urea phosphate shows less loss than urea. Ammonium nitrate which forms a soluble reaction product thereby preventing the formation of ammonia was seen to lose the least amount of nitrogen.

Effect Of Nitrogen Rate On Ammonia Volatilization

The rate of nitrogen applied influenced the amount of ammonia nitrogen volatilized. Ammonia volatilization increased with the rate of application. A plausible explanation perhaps is that at the higher rates of application an optimum concentration suitable for reaction with urease is maintained for a longer period thus increasing total loss. Also maybe there is a saturation of the soil exchange sites in the fertilizer environment thereby losing the unadsorbed ammonia. Average losses were recorded as 60 mg N/kg- 0.35 mg; 120 mg N/kg- 1.56 mg; and 200 mg N/kg- 2.74 mg.

Effect Of Initial Moisture Content On Ammonia Volatilization

Jewitt (1942) observed a correlation between the rate of water loss and that of ammonia. He concluded that moisture content itself seems to be of no consequence but rather the rate of evaporation. Volk (1959) and Ernst and Massey (1960) observed different amounts of loss from soils at varying moisture contents. The results of this study support the theory that initial moisture content affects ammonia volatilization. Preliminary investigations indicated that only negligible ammonia losses result from moisture contents above field capacity in unsaturated soils and this can be understood as the ability of the soil solution to retain more ammonia in solution. By reducing the initial moisture content below field capacity higher ammonia volatilization results; this is because the fertilizer is being dissolved but the soil solution is inadequate to retain ammonia, therefore it is volatilized.

The two soil moisture levels used showed significant differences in ammonia loss with loss at field capacity being 0.38 mg N and loss at 25% of field capacity being 1.95 mg N.

Effect Of Soil Texture On Ammonia Volatilization

The cation exchange capacity of the Charity clay is higher than that of the Granby loamy sand so it would be expected to adsorb more ammonia. Since the soil pH values were similar it was not expected that there would be significant differences in soil reaction, thus the nitrogen losses may be attributed to differences in CEC. The two soils showed a significant difference in nitrogen loss, the Charity clay losing 0.56 mg N and the Granby loamy sand 1.77 mg N.

Effect Of The Interaction Of Nitrogen Source And Moisture

The interaction of nitrogen source and moisture was significant (Table 3). This significance can be attributed mainly to losses from urea-urea phosphate and urea at 25% of field capacity moisture level (Table 4). There was no significant difference between sources at field capacity. However, at 25% of field capacity the ranking of loss was as follows: urea-urea phosphate > urea > ammonium nitrate = urea phosphate.

Table 4. The effect of the interaction of nitrogen of nitrogen source and soil moisture content on ammonia volatilization in laboratory aeration studies, 1983.

Source	Soil Moisture Content	
	100% F•C[a]	25% F•C
	mg N/culture	
Urea	0.87	2.87
Urea phosphate	0.01	0.63
Ammonium nitrate	0.02	0.19
Urea-Urea phosphate	0.62	4.12
LSD (5%)	1.59	

[a] F•C = 1/3 bar field capacity.

Effect Of The Interaction Of Nitrogen Source And Rate Of Application

Ammonia volatilization from each source increased with rate. At the higher rates of application (120 and 200 mg N/kg), volatilization losses from urea-urea phosphate and urea were significantly higher than at the lower rate of 60 mg N/kg (Table 5). Among the sources, urea-urea phosphate and urea lost significant amounts of ammonia in comparison to

urea phosphate and ammonium nitrate. At the two highest rates of application, there was a similar pattern of relative efficiency with urea-urea phosphate and urea losing more ammonia than the other two sources. Urea phosphate and ammonium nitrate lost insignificant amounts of nitrogen at all rates.

Table 5. The effect of the interaction of nitrogen source and rate of application on ammonia volatilization in laboratory aeration studies, 1983.

Source	Nitrogen rate [a](mg N/culture			
	0	48	96	160
	---------mg N/culture---------			
Urea	0.00	0.56	2.34	4.58
Urea phosphate	0.00	0.03	0.38	0.85
Ammonium nitrate	0.00	0.07	0.10	0.23
Urea-urea phosphate	0.00	0.74	3.44	5.30
LSD (5%)		2.25		

[a] Corresponds to 0, 60, 120 and 200 mg N/kg soil

Effect Of The Interaction Of Nitrogen Source And Soil Texture

Ammonia volatilization losses from the nitrogen sources were higher from the Granby loamy sand than from the Charity clay (Table 6). Urea-urea phosphate and urea showed significant losses on the Granby loamy sand but not on the Charity clay. It is noteworthy that losses from urea phosphate and ammonium nitrate were very low and, therefore, not significant between soils. Perhaps the ammonia produced was in low enough concentration to not exceed the adsorption capacity of either soil. The general pattern of ammonia loss on both soils was similar with loss from urea-urea phosphate = urea > urea phosphate = ammonium nitrate.

Table 6. The effect of the interaction of nitrogen source and soil texture on ammonia volatilization in laboratory aeration studies, 1983.

Source	Soil	
	Granby loamy sand	Charity clay
	mg N/culture	
Urea	3.21	0.53
Urea phosphate	0.36	0.27
Ammonium nitrate	0.14	0.06
Urea-urea phosphate	3.36	1.38
LSD (5%)	1.59	

Effect Of The Interaction Of Initial Moisture Content And Rate Of Application

The amount of ammonia volatilized at the lower moisture content was higher among all rates of application (Table 7). With the soils at field capacity there were no significant volatilization losses between all the rates applied. When the moisture content was changed to 25% of field capacity, volatilization losses between the higher rates of 120 and 200mg N/kg were significantly greater than for 60mg N/kg rate of application.

Table 7. Effect of the interaction of nitrogen rate and initial soil moisture content on ammonia volatilization in laboratory aeration studies, 1983.

Rate	Initial Moisture Content	
	100% F•C[b]	25% F•C
mg N/culture [a]	mg N/culture	
0	0.00	0.00
48	0.08	0.62
96	0.47	2.66
160	0.96	4.52
LSD (5%)	1.59	

[a] Corresponds to 0, 60, 120 and 200mg N/kg soil.

[b] F•C = 1/3 bar field capacity.

Greenhouse Cropping Studies

Four nitrogen fertilizer sources were applied to Charity clay and Granby loamy sand soils at four different rates and the nitrogen lost by ammonia volatilization was indirectly determined as a relative crop response. Each of these 16 fertilizer treatments was mixed with the soil. An additional 4 treatments on each soil were included where urea-urea phosphate was broadcast on the soil surface after seeding the first crop. These treatments were then mixed with the soil between the first and second croppings. Three croppings of oats were grown for five weeks each with the soil gravimetrically maintained at field capacity. The above soil portions of the oats were harvested, dried and weighed before nitrogen concentrations were determined. The soils were screened and repotted between crops.

There was an interesting pattern of development of statistical significance of interactions as cropping progressed (Table 8). First considering the crop yield it is indicated that there was no difference due to the sources during the first cropping. The simple effects of the nitrogen rate and soil type were the only factors significant. By the second cropping, yields were now significantly influenced by the nitrogen sources and there was a significant interaction between nitrogen rate and soil type. At the third cropping, the interaction of nitrogen source, nitrogen rate and soil type was significant. Now considering the nitrogen uptake, the interaction of nitrogen rate and soil type was significant at the first cropping. The second and third croppings were similarly affected by the interaction of nitrogen source, nitrogen rate and soil type. The pattern of significant effects suggests that with time and cropping, the sources showed difference in

Table 8. Approximate probability of significance of the F statistic for various sources of variance in the greenhouse experiment, 1983.

	Yield 1	Yield 2	Yield 3	Uptake 1	Uptake 2	Uptake 3	Total Uptake
Source (Sce)	0.256	0.016	0.051	0.259	<0.0005	0.002	<0.0005
Rate (R)	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Soil (S)	<0.0005	0.001	<0.0005	<0.0005	0.596	<0.0005	<0.0005
Sce x R	0.718	0.802	0.792	0.652	0.009	0.222	<0.0005
Sce x S	0.163	0.215	0.211	0.070	<0.0005	0.048	<0.0005
R x S	0.167	<0.0005	0.002	<0.0005	<0.0005	<0.0005	<0.0005
Sce x R x S	0.0778	0.363	0.001	0.639	0.012	<0.0005	<0.0005

nitrogen availability efficiency which will be covered in the following discussion.

Crop Yield

During the first cropping, all the experimental units appeared healthy and there were no signs of nutrient deficiencies. In the course of the cropping, a few lower leaves were observed to dry out and wilt. This was not associated with ammonia volatilization injuries, but rather it was believed to be a result of greenhouse conditions.

The simple effect of nitrogen rate and soil type were statistically significant during the first cropping (Table 8). There was an increase in crop yield up to 120 mg N/kg application and this rate was determined as the optimum because yields obtained at 180 mg N/kg were lower (Table 9). Results obtained in the laboratory indicate that following ammonia volatilization, the residual nitrogen content of the soil will be ranked in the order of the nitrogen rate applied. Therefore, the increase in crop yield with rate should be expected. It is not clear, however, why the 180 mg N/kg application reduced yield especially since there was no obvious seedling damage. Perhaps there was salt injury to the roots. Crop yields were also higher on the Charity clay soil (Table 10). This was as expected because of the higher CEC of the clay soil. The higher CEC would be expected to cause greater retention and exchange of nutrients. At this point the nitrogen source did not significantly affect yield. This does not imply that ammonia volatilization was similar among all the sources, but rather that the residual nitrogen concentration from each source was adequate to supply the necessary crop nitrogen requirements.

Table 9. Effect of nitrogen rate on greenhouse crop yield, 1983.

Rate	Yield		
	Crop 1	Crop 2	Crop 3
mg N/kg	----------g/culture----------		
0	1.46	1.38	1.35
60	1.62	1.71	1.37
120	1.71	1.96	1.64
180	1.57	2.03	1.63
LSD (5%)	0.13	a	b

[a] Fertilizer rate x soil interaction significant, see Table 11.

[b] Fertilizer source x fertilizer rate x soil interaction significant, see Table 10.

Table 10. Effect of fertilizer source, nitrogen rate, and soil type on yield of 3 crops of oats grown in the greenhouse, 1983.

Fertilizer		Crop 1		Crop 2		Crop 3	
Source	Rate	Granby	Charity	Granby	Charity	Granby	Charity
	mg N/kg Soil	g/culture					
-	0	1.03	1.90	1.72	1.03	1.63	1.07
Urea	60	1.25	2.42	1.80	1.93	1.98	1.01
	120	1.19	2.18	1.45	2.57	1.89	1.46
	180	0.86	2.18	1.76	2.68	1.65	1.80
Urea phosphate	60	1.03	2.24	1.52	1.97	1.59	1.06
	120	1.21	2.41	1.60	2.79	1.98	1.80
	180	1.01	2.41	2.04	2.63	1.34	2.01
Ammonium nitrate	60	1.18	1.95	1.84	1.91	1.97	1.07
	120	1.11	2.33	1.61	2.32	2.04	1.46
	180	1.00	2.03	1.35	3.09	1.42	1.88
Urea-urea phosphate (surface)	60	1.09	1.97	1.40	1.65	1.53	1.02
	120	1.12	2.24	1.43	2.26	1.73	1.19
	180	1.08	2.03	1.61	1.91	2.04	1.17
Urea-urea phosphate (mixed)	60	1.12	2.00	1.63	1.50	1.53	0.92
	120	1.26	2.08	1.65	1.94	1.76	1.08
	180	1.05	2.02	1.52	1.73	1.96	1.08
LSD (5%)[a]		NS		NS[b]		0.51	

[a] Fertilizer source x nitrogen rate x soil type interaction.

[b] Nitrogen rate x soil type interaction significant, see Table 11.

In the course of the second cropping, differences among treatments were becoming discernible. While all the treatments appeared healthy there were those that were conspicuously smaller. The nitrogen source was now statistically significant as were the rate and soil type and their interaction (Table 8). Average crop yields were highest when urea phosphate was the source, followed by ammonium nitrate and urea in that order. These three sources were not statistically different from each other. Urea-urea phosphate was least efficient with yields significantly lower than from the other three sources. The yields from the two methods of application of urea-urea phosphate were not very different. The performance of urea-urea phosphate especially when mixed with the soil appears to account for the significance observed. Crop yields increased with nitrogen rate on the Charity clay soil and the two higher rates were similar and significantly different from the lower rates (Table 11). On the Granby loamy sand, yields were similar and not significant between the rates. The Charity clay soil gave yields significantly higher than on the Granby loamy sand at the two higher rates.

By the third cropping there was visual indication of possible nitrogen deficiency especially on the Charity clay soil. This observation was later supported by the finding of less than 2% N in most of the crops grown on the Charity clay soil (Table 44, appendix). The interaction of the nitrogen source, rate and soil type was significant (Table 10). At the 120 mg N/kg rate, yields for ammonium nitrate and urea-urea phosphate (incorporated and broadcast) were now higher on the Granby loamy sand than on the Charity clay. This change between soils is attributed to the soil aeration status and is further discussed in

Table 11. Effect of nitrogen rate and soil type on yield of 3 crops of oats grown in the greenhouse, 1983.

Rate of Nitrogen	Crop 1		Crop 2		Crop 3	
	Granby	Charity	Granby	Charity	Granby	Charity
mg N/kg Soil	g/culture					
0	1.03	1.90	1.72	1.03	1.72	1.07
60	1.13	2.11	1.64	1.79	1.64	1.01
120	1.18	2.25	1.55	2.38	1.88	1.40
180	1.00	2.14	1.66	2.41	1.68	1.59
LSD (5%)	NS		0.31		a	

[a] Fertilizer source x nitrogen rate x soil interaction significant, see Table 10.

the section on nitrogen uptake. All the sources showed increasing but not significantly different performances as the rates were increased on the Charity clay soil. However, on the Granby loamy sand soil, urea, urea phosphate and ammonium nitrate showed best performances at 120 mg N/kg rate. Actually when compared to the control, yields obtained on the Granby loamy sand were not statistically significant. Only the yields at 180mg N/kg applications of urea, urea phosphate and ammonium nitrate to the Charity clay were significant.

Nitrogen Uptake

Nitrogen uptake data show that there was a decrease in uptake for successive crops on the Charity clay, while the opposite was the case on the Granby loamy sand (Table 12). The former was as expected in response to nitrogen depletion via crop uptake, volatilization losses and immobilization. Table 8 shows the effect of nitrogen source was not significant for crop 1 but was for crops 2 and 3. The fact that all the sources may supply adequate nitrogen and other nutrients at the initial stages has been mentioned and these data support that observation. During the last two cropping periods, the urea-urea phosphate treatments were less effective than the other sources (Table 13).

At the first cropping the interaction of application rate and soil type was significant (Table 8). Nitrogen uptake was significantly higher on the Charity clay soil (Table 12). The effect of the CEC was mentioned earlier. Uptake at 120 mg N/kg application was highest and significant on the Granby loamy sand while on the Charity clay uptake at 120 mg N/kg was determined as the optimum rate of application.

There were significant single factor effects at the second cropping except for the soil type (Table 8). This leads to some

Table 12. Effect of nitrogen rate and soil type on nitrogen uptake by 3 crops of oats in the greenhouse, 1983.

Rate of Nitrogen	Crop 1		Crop 2		Crop 3		Total	
	Charity	Granby	Charity	Granby	Charity	Granby	Charity	Granby
mg N/kg Soil	mg N/culture							
0	71.8	41.7	19.9	64.5	16.5	51.7	108.3	158.0
60	107.6	49.1	42.0	65.8	16.5	58.0	166.1	172.9
120	117.5	52.3	91.1	64.3	21.6	65.9	230.1	182.5
180	114.6	46.2	105.7	71.3	41.6	61.4	261.9	178.9
LSD (5%)	9.65		a		a		a	

[a] Fertilizer source x nitrogen rate x soil type interaction significant, see Table 13.

Table 13. Effect of fertilizer source, nitrogen rate, and soil type on nitrogen uptake by 3 crops of oats in the greenhouse, 1983.

Fertilizer		Crop 1		Crop 2		Crop 3		Total	
Source	Rate	Charity	Granby	Charity	Granby	Charity	Granby	Charity	Granby
	mg N/kg Soil	mg N/culture							
-	0	71.8	47.4	19.9	56.7	16.5	45.1	108.3	149.2
Urea	60	120.7	49.7	48.8	74.2	16.8	65.8	186.3	189.6
	120	117.2	50.6	107.0	61.7	21.8	68.2	246.0	180.4
	180	125.9	40.1	134.7	72.4	56.1	63.3	316.8	175.8
Urea phosphate	60	115.4	47.8	49.2	60.6	16.4	54.6	181.0	163.0
	120	125.7	52.8	127.6	67.1	29.1	69.8	282.4	189.7
	180	134.2	48.6	138.1	94.1	60.9	54.5	333.1	197.3
Ammonium nitrate	60	98.7	46.2	49.0	76.1	17.3	67.0	165.0	189.3
	120	120.2	48.2	91.8	63.2	21.5	69.7	233.5	181.1
	180	111.9	46.2	145.9	56.6	56.2	52.5	314.0	155.3
Urea-urea phosphate (surface)	60	98.5	53.0	33.3	56.6	16.8	52.3	148.5	161.9
	120	118.3	51.4	76.9	60.7	18.9	60.4	214.1	172.4
	180	99.4	48.7	57.4	68.2	18.9	71.3	175.7	188.2
Urea-urea phosphate (mixed)	60	104.7	48.9	29.5	61.6	15.5	50.1	149.7	160.7
	120	105.9	58.4	52.0	69.0	16.6	61.3	174.5	188.7
	180	101.7	47.4	52.1	65.2	15.8	65.5	169.6	178.1
LSD (5%)[a]		NS[b]		30.9		14.9		41.4	

[a] Fertilizer source x nitrogen rate x soil type interaction.

[b] Nitrogen rate x soil type interaction significant, see Table 12.

considerable speculation about the aeration status of the Charity clay soil causing lower nitrogen efficiency especially since the soil type affected crop yield. Further observation will be necessary to confirm this effect. Nitrogen uptake increased with the rate of application. The uptake on the Charity clay soil from all nitrogen rates and sources was significantly greater than the control. At 120 and 180 mg N/kg rates responses were similar except when ammonium nitrate was the source. On the Granby loamy sand, only the uptakes at 120 and 180 mg N/kg when urea phosphate was the source were significantly different from the control. All the other uptake reported were similar.

At the third cropping, the interaction of the nitrogen source, rate and soil type was significant (Table 8). During this period nitrogen uptake was now significantly higher on the Granby loamy sand (Table 13). This was not as expected and perhaps goes to confirm the earlier speculation about the changes in the soil aeration status. It is believed that as water was applied to the soils daily, an anaerobic condition was created if only temporarily, leading to a lower nitrogen efficiency, to a lesser degree on the Granby loamy sand which will dry faster. This is probably the reason that the mixed urea-urea phosphate was less effective than the broadcast treatments on the clay soil. Except when urea phosphate was applied at 180 mg N/kg, nitrogen uptake from the Charity clay soil was lower from the treatments than from the control. This may be a result of reduced nitrogen efficiency discussed earlier. There was similar uptake from all the sources on the Granby loamy sand soil and this was significant at the rate of 120 mg N/kg.

Total nitrogen uptake was significantly affected by the interaction of the nitrogen source, rate and soil type (Table 13).

Urea, urea phosphate and ammonium nitrate gave significantly higher uptake than urea-urea phosphate on the Charity clay soil at the rates of 120 and 180 mg N/kg. Only the uptake at 180 mg N/kg rate applications of urea phosphate on the Granby loamy sand were significantly higher than from the control. On the other hand, only 60 mg N/kg applications of urea-urea phosphate on the Charity clay were not significant in comparison with the controls. For urea, urea phosphate and ammonium nitrate on the Charity clay soil, applications at 180 mg N/kg were optimum while 120 mg N/kg were optimum for the urea-urea phosphate treatments. On the Granby loamy sand applications at 120 mg N/kg was optimum. The total uptake data show that the urea-urea phosphate treatments are less efficient than urea, urea phosphate and ammonium nitrate.

As cropping progressed from crop 1 to crop 3, nitrogen concentration became better correlated with crop yield ($r = 0.03$, 0.95 and 0.98, respectively). It appears that uptake was not restricted during the first cropping thus there was no corresponding increase in the nitrogen content with observed increase in the crop yield. By the second and third croppings when the soil nitrogen content was diminishing, nitrogen content of the crops better related to the dry weight yield.

Field Studies

Broadcast Fertilizer Sources

This experiment consisted of factorial combinations of three fertilizer sources, four nitrogen rates and two types of fertilizer application (surface applied and tilled into the soil). Each treatment was replicated four times in a randomized complete block design. Corn ear leaves were taken at tasseling for nitrogen analysis and whole plants were harvested for nitrogen and grain yield determinations.

Yield data were obtained for three years (1980, 1981 and 1983) and there were considerable differences in yields obtained over the years of study. In accounting for the differences over the years, it is important to indicate that in 1980 there was a July windstorm which caused the crops to lodge, while in 1983 there was a seasonal drought.

Each year nitrogen rates significantly affected the yields obtained (Table 14). As there was no appreciable difference between yields at 134 kg N/ha and 202 kg N/ha; the former was considered as the optimum. Laboratory investigations suggest that even though ammonia volatilization may be higher with increasing rates of nitrogen applied, there is yet a higher residual nitrogen content from the higher rates. This may explain why an increase in yield with fertilizer rate increase was observed in the field.

The yields obtained by using different nitrogen sources were similar. It was felt that by using a lower ammonia volatilization potential fertilizer such as ammonium nitrate it would be possible to account for ammonia losses but this was not the case. There was also no positive effect observed for the acidic phosphate bond in the cogranulated urea-urea phosphate. For each nitrogen source used, it was

Table 14. Effect of nitrogen rate applied on the yield of corn grain in broadcast fertilizer studies, Charity clay, 1980, 1981, and 1983.

	Yield		
Rate	1980	1981	1983
kg N/ha	----------	Mg/ha	----------
0	3.88	5.45	5.08
67	6.33	7.58	7.08
134	7.02	8.96	7.58
202	6.96	9.28	7.71
LSD (5%)		0.38[a]	

[a] Comparison of rates within one year, combined analysis for 1980, 1981, and 1983.

of no importance to incorporate with the soil rather than to apply to the soil surface. The former treatment was expected to increase the exchange surface available for ammonium adsorption, reduce ammonia volatilization and thus increase available nitrogen. In 1981 there was a delay in rainfall following broadcast operations and while this would have been expected to aid ammonia volatilization and make the difference between the two application methods, it did not. While the possible higher loss of ammonia is not ruled out it is also possible that the dry crust which existed on the soil surface following cultivation prevented the dissolution of the fertilizers prior to further rainfall. In the other years perhaps rainfall was enough to move the broadcast fertilizer into the soil thereby reducing ammonia loss. Rainfall data is presented in the appendix (Tables 45-48).

Table 15 shows that the effect of the interaction of the year x nitrogen source x rate x method of application was not significant. This is not what would have been expected but as the results over the years appear to be consistent it is certain that cogranulated urea-urea phosphate would not give yield superior to that from urea.

Grain moisture content over the three years was affected by the nitrogen rate applied (Table 16). Data for 1980 indicate that there was no significant difference in moisture content at the various rates applied. In 1981, the 134 and 202 kg N/ha rates significantly reduced grain moisture content. All the nitrogen application rates significantly reduced the grain moisture content in 1983. There was no significant difference between fertilizer sources used and it did not matter that they were broadcast or incorporated. Table 17 shows that the 4-way interaction of the factors observed had no significant

Table 15. Effect of the interaction of year, nitrogen source, method of application, and rate of application on the yield of corn grain, Charity clay, 1980, 1981, and 1983.

Fertilizer		1980		1981		1983	
Source	Rate	Surface	Mixed	Surface	Mixed	Surface	Mixed
	kg N/ha	Mg/ha					
-	0	3.95	3.82	5.45	5.39	4.95	5.20
Urea-urea phosphate	67	6.39	6.14	7.77	7.77	7.52	7.15
	134	7.40	7.21	8.78	9.15	7.58	7.77
	202	7.21	7.40	9.03	9.40	7.65	7.84
Urea	67	6.02	6.39	7.27	7.46	6.71	6.89
	134	6.46	6.83	9.03	8.84	7.65	8.15
	202	6.83	6.89	9.22	9.72	8.02	7.71
Ammonium nitrate	67	6.83	6.52	7.84	7.58	7.21	7.21
	134	7.33	6.77	8.78	7.27	7.27	7.21
	202	6.96	6.46	9.15	9.15	7.65	7.46
LSD (5%)[a]		NS[b]					

[a] Year x source x rate x method of application.

[b] Comparison of rates within one year, combined analysis for 1980, 1981, and 1983.

Table 16. Effect of nitrogen rate on the moisture content of corn grain in broadcast fertilizer studies, Charity clay, 1980, 1981, and 1983.

	Moisture Content		
Rate	1980	1981	1983
kg N/ha		%	
0	36.4	37.6	36.9
67	35.6	37.2	32.0
134	35.2	36.1	32.6
202	35.1	35.8	33.4
LSD (5%)		1.4[a]	

[a] Comparison of rates within one year, combined analysis for 1980, 1981, and 1983.

Table 17. Effect of the interaction of year, nitrogen source, method of application, and rate of application on the moisture content of corn grain, Charity clay, 1980, 1981, and 1983.

Fertilizer		1980		1981		1983	
Source	Rate	Surface	Incorp	Surface	Incorp	Surface	Incorp
	kg N/ha	----------	----------	----------	----------	----------	----------
-	0	36.2	36.5	37.5	37.7	38.0	35.8
Urea-urea phosphate	67	37.3	34.4	36.5	36.1	30.6	32.6
	134	34.8	35.5	36.6	35.3	32.9	32.3
	202	34.6	34.5	35.4	36.0	33.1	33.1
Urea	67	35.5	35.4	40.5	36.6	31.9	32.5
	134	36.5	35.7	36.6	35.6	33.1	28.6
	202	35.1	36.4	36.3	35.1	33.7	33.7
Ammonium nitrate	67	35.7	35.7	36.6	37.1	32.9	31.9
	134	32.9	36.1	36.6	35.8	32.3	36.7
	202	34.9	34.9	36.1	35.9	32.7	34.0
LSD (5%)[a]				NS[b]			

[a] Year x source x rate x method of application.

[b] Comparison of rates within one year, combined analysis for 1980, 1981, and 1983.

influence on grain moisture content.

The nitrogen concentrations of the ear-leaf responded significantly to the nitrogen rates applied (Table 18). Nitrogen contents increased with the rate of application. There was no advantage associated with using a particular nitrogen source or whether they were broadcast or incorporated. Table 19 shows the 4-way interaction was not significant.

Nitrogen uptake data at maturity were available for 1981 and 1983. There was a significant difference between the two years with 1983 uptake being higher. To determine nitrogen uptake whole plants were used. As it was understood that there is a significant partitioning of nutrients between the stalk and the ear, these two portions were separately analyzed for nitrogen concentrations to maintain homogenous and representative samples. Ear nitrogen concentration was relatively higher than stalk nitrogen concentration. The nitrogen rate was the main factor influencing the nitrogen concentration of both parts (Tables 20 and 21). In 1981 there was an increase in nitrogen concentration along with rate, but in 1983 there was a broken pattern. The nitrogen sources used or the method of application were not significant (Tables 22 and 23). Nitrogen uptake was significantly influenced by the year x source x rate x method of application interaction (Table 24).

From all observations of the broadcast studies, the data suggest that there is a response to nitrogen up to 134 kg N/ha applications. There is a variability in the response over the years, however, it is advisable to incorporate urea-urea phosphate and urea following application.

Table 18. Effect of nitrogen rate on ear leaf nitrogen concentration of corn at tasseling, Charity clay, 1980, 1981, and 1983.

Rate	N Concentration
kg N/ha	------% N------
0	2.09
67	2.67
134	2.87
202	3.16
LSD (5%)	0.11[a]

[a] Combined analysis for 1980, 1981, and 1983.

Table 19. Effect of the interaction of year, nitrogen source, method of application, and rate of application on the nitrogen concentration of ear leaves at tasseling, Charity clay, 1980, 1981, and 1983.

Fertilizer		1980		1981		1983	
Source	Rate	Surface	Incorp	Surface	Incorp	Surface	Incorp
	kg N/ha	----------	----------	----------	% N ----------	----------	----------
	0	2.39	2.56	1.29	1.43	2.47	2.43
Urea-urea phosphate	67	3.20	3.15	1.86	1.87	3.15	2.82
	134	3.39	3.48	1.81	2.35	3.13	2.99
	202	3.69	3.71	2.33	2.29	3.57	3.37
Urea	67	2.98	3.13	1.88	2.08	2.97	2.89
	134	3.46	3.46	2.12	1.74	3.32	3.31
	202	3.53	3.73	2.40	2.51	3.66	3.46
Ammonium nitrate	67	3.14	3.23	2.28	1.82	2.78	2.86
	134	3.44	3.52	1.86	2.10	2.97	3.16
	202	3.57	3.62	2.43	2.52	3.32	3.28
LSD (5%)[a]				NS[b]			

[a] Year x source x rate x method of application.

[b] Comparison of rates within one year, combined analysis for 1980, 1981, and 1983.

Table 20. Effect of nitrogen rate on corn stalk nitrogen concentration in broadcast fertilizer studies, Charity clay, 1981 and 1983.

	N Concentration	
Rate	1981	1983
kg N/ha	----------% N----------	
0	0.62	1.01
67	0.81	0.94
134	1.02	1.05
202	1.24	0.93
LSD (5%)	0.14[a]	

[a] Comparison of rates within one year, combined analysis for 1981 and 1983.

Table 21. Effect of rate of application on corn ear nitrogen concentration in broadcast fertilizer studies, Charity clay, 1981 and 1983.

	N Concentration	
Rate	1981	1983
kg N/ha	----------% N----------	
0	0.91	1.49
67	1.08	1.42
134	1.27	1.42
202	1.41	1.32
LSD (5%)	0.12[a]	

[a] Comparison within each year, combined analysis for 1981 and 1983.

Table 22. Effect of the interaction of year, nitrogen source, rate. and method of application on corn stalk nitrogen concentration in broadcast fertilizer studies, Charity clay, 1981 and 1983.

Fertilizer		1981		1983	
Source	Rate	Surface	Incorp	Surface	Incorp
	k N/ha	% N			
-	0	0.60	0.64	1.01	1.02
Urea-urea phosphate	67	0.76	0.78	0.79	0.97
	134	1.02	1.02	1.30	0.93
	202	1.26	1.18	0.65	1.01
Urea	67	0.72	0.77	0.81	1.01
	134	1.07	0.98	0.90	1.00
	202	1.33	1.33	0.88	1.07
Ammonium nitrate	67	1.02	0.78	1.06	1.04
	134	1.03	0.99	0.91	1.29
	202	1.15	1.23	1.06	0.95
LSD (5%)[a]		NS[b]			

[a] Year x source x rate x method of application.

[b] Comparison within one year, combined analysis for 1981 and 1983.

Table 23. Effect of the interaction of year, source, rate, and method of application on corn ear nitrogen concentration in broadcast fertilizer studies, Charity clay, 1981 and 1983.

Fertilizer		1981		1983	
Source	Rate	Surface	Incorp	Surface	Incorp
	kg N/ha	% N			
-	0	0.91	0.91	1.50	1.48
Urea-urea phosphate	67	1.05	1.10	1.43	1.53
	134	1.20	1.25	1.53	1.37
	202	1.54	1.34	1.21	1.33
Urea	67	1.09	1.00	1.62	1.24
	134	1.36	1.26	1.25	1.56
	202	1.41	1.39	1.02	1.46
Ammonium nitrate	67	1.12	1.09	1.39	1.46
	134	1.34	1.23	1.28	1.54
	202	1.44	1.36	1.45	1.45
LSD (5%)[a]		NS[b]			

[a] Year x source x rate x method of application.

[b] Comparison within one year, combined analysis for 1981 and 1983.

Table 24. Effect of the interaction of year, source, rate, and method of application on nitrogen uptake by corn in broadcast fertilizer studies, Charity clay, 1981 and 1983.

Fertilizer		1981		1983	
Source	Rate	Surface	Incorp	Surface	Incorp
	kg N/ha	g/10 plants			
-	0	14.3	14.3	27.9	28.6
Urea-urea phosphate	67	23.5	25.6	33.1	35.8
	134	29.6	33.1	42.4	36.0
	202	38.0	34.4	29.5	39.7
Urea	67	21.3	23.8	40.4	33.0
	134	34.2	31.6	33.3	39.4
	202	34.4	35.8	29.0	40.2
Ammonium nitrate	67	26.8	22.0	37.3	38.7
	134	34.2	31.2	31.8	44.2
	202	34.1	36.3	38.8	37.7
LSD (5%)[a]			8.58[b]		

[a] Year x source x rate x method of application.

[b] Comparison within one year, combined analysis for 1981 and 1983.

Banded Fertilizer Studies

Five fertilizer sources were applied 5 cm to the side of and 5 cm below the seed on a Charity clay soil. One uniform rate of application was used and each treatment was replicated four times. Whole plant samples at the four-leaf stage and the ear leaf at tasseling were harvested for nutrient determinations. Grain yields were determined at maturity.

Observations made each year (1980, 1981, 1982) were similar in pattern but the yields were significantly different in magnitude. Yields were highest in 1981 and lowest in 1980. The yields obtained from the various treatments were not significantly different from each other (Table 25).

Nitrogen contents of whole plants at the four leaf stage were similar and not significantly different between sources, but there was a significant yearly variation (Table 26). Determinations in 1980 > 1981 > 1982. Phosphorus contents were considerably influenced by the sources that uptake from ammonium nitrate (34-0-0 + 0-46-0) > diammonium phosphate > monoammonium phosphate > urea phosphate > urea (46-0-0 + 0-46-0) . At this stage there was no vivid advantage of micronutrient availability between the sources but the yearly contents were significantly different (Table 27).

Ear leaf samples showed significantly different variability of nutrient composition over the years. The nitrogen content was significantly different among treatments with uptake from urea > diammonium phosphate > ammonium nitrate > monoammonium phosphate > urea phosphate (Table 28). Magnesium content was influenced by the sources and uptake from urea > diammonium phosphate > monoammonium phosphate >

Table 25. Effect of fertilizer sources banded to the side and below the seed on corn grain yield, Charity clay, 1980-1982.

Source	Yield		
	1980	1981	1982
	Mg/ha		
Urea phosphate	6.83	7.96	7.71
Diammonium phosphate	7.27	8.21	7.96
Monoammonium phosphate	7.08	8.34	8.53
Urea	6.64	8.09	8.27
Ammonium nitrate	7.27	8.09	7.71
LSD (5%)[a]		NS	

[a] Comparison within one year, combined analysis 1980-1982.

Table 26. Effect of fertilizer sources banded to the side and below the seed on the nutrient composition of corn at the four-leaf stage, Charity clay, 1980-1982.

Source	N			P			K			Ca		
	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982
	%											
Urea phosphate	4.52	4.40	4.00	0.47	0.46	0.44	0.00	3.78	3.95	0.99	0.69	0.48
Diammonium phosphate	4.46	4.44	4.04	0.47	0.47	0.45	0.00	3.99	3.73	0.95	0.69	0.47
Monoammonium phosphate	4.48	4.27	3.91	0.49	0.45	0.44	0.00	3.91	3.80	1.03	0.66	0.50
Urea	4.31	4.33	4.10	0.43	0.43	0.43	0.00	3.72	3.72	0.99	0.74	0.50
Ammmonium nitrate	4.53	4.44	4.07	0.48	0.50	0.46	0.00	3.99	3.78	0.97	0.74	0.48
LSD (5%)[a]		NS			0.02			NS			NS	

[a] Comparison within one year, combined analysis 1980-1982.

Table 27. Effect of fertilizer sources banded to the side and below the seed on the nutrient composition of corn at the four-leaf stage, Charity clay, 1980-1982.

Source	Mg			Zn			Mn			Fe		
	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982
	--------%---------			----------mg/kg----------								
Urea phosphate	0.55	0.54	0.34	22.5	22.9	27.1	52.7	40.2	35.9	1168.0	597.0	319.0
Diammonium phosphate	0.51	0.52	0.35	26.8	24.2	26.6	54.4	37.3	56.0	1360.3	632.5	356.0
Monoammonium phosphate	0.54	0.50	0.36	22.6	22.7	25.8	54.5	42.3	43.4	956.5	720.0	343.5
Urea	0.53	0.53	0.34	23.8	25.4	27.0	51.2	44.8	37.1	1259.3	605.5	311.0
Ammonium nitrate	0.51	0.55	0.33	24.8	26.0	24.6	50.9	40.7	38.5	1083.5	667.0	314.8
LSD (5%)[a]		NS			NS			NS			NS	

[a] Comparison within one year, combined analysis 1980-1982.

Table 28. Effect of fertilizer sources banded to the side and below the seed on the nutrient composition of corn ear-leaf at tasseling, Charity clay, 1980-1982.

Source	N			P			K			Ca		
	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982
	%											
Urea phosphate	3.65	3.07	2.65	0.38	0.29	0.29	0.00	2.22	1.79	0.95	0.70	0.48
Diammonium phosphate	3.83	3.13	3.84	0.38	0.30	0.30	0.00	2.12	1.83	1.00	0.74	0.49
Monoammonium phosphate	3.69	3.10	2.75	0.37	0.29	0.29	0.00	2.19	1.88	0.94	0.69	0.47
Urea	3.79	3.26	2.93	0.37	0.30	0.31	0.00	2.20	1.73	0.99	0.71	0.48
Ammonium nitrate	3.75	3.16	2.89	0.36	0.30	0.30	0.00	2.21	1.74	0.97	0.73	0.42
LSD (5%)[a]		0.072			NS			NS			NS	

[a] Comparison within one year, combined analysis 1980-1982.

ammonium nitrate > urea phosphate (Table 29). Calcium content was also influenced by the sources and uptake from diammonium phosphate > urea > ammonium nitrate > urea phosphate > monoammonium phosphate. Iron uptake was considerably variable over the years with 1980 ear leaf contents greater than those of 1981 and least in 1982. Urea phosphate enhanced iron uptake over ammonium nitrate, urea, diammonium phosphate and monoammonium phosphate.

It thus stands to reason that when fertilizer sources are placed in a band below the soil and near the seeds, their yield efficiencies are similar. When certain secondary or micronutrients are low in the soil, there may be some advantage to using certain fertilizer sources. Keeping the fertilizer in a band makes it possible to regulate mineralization and diffusion, thereby, retarding ammonia volatilization and nitrogen loss.

Fertilizer With The Seed

Four nitrogen fertilizers were applied in contact with corn seed at four rates to determine contact salt toxicity levels and the relative response to each fertilizer. Each treatment was replicated four times. Additional nitrogen was side-dressed following germination. Stand counts were made periodically. The nitrogen concentration of ear leaves was determined at tasseling and the grain yield was determined at maturity. This study was conducted at two locations, on a Charity clay soil and a Conover loam soil.

The rainfall distribution over the first two weeks after planting appeared to influence stand counts and yields (Table 30). Rainfall data (Tables 45-52, appendix) suggest that when there is some rainfall in

Table 29. Effect of fertilizer sources banded to the side and below the seed on the nutrient composition of corn ear-leaf at tasseling, Charity clay, 1980-1982.

Source	Mg			Zn			Mn			Fe		
	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982
	--------%---------			----------mg/kg----------								
Urea phosphate	0.55	0.42	0.32	15.9	25.1	26.2	26.5	20.9	18.7	183.0	115.5	97.63
Diammonium phosphate	0.58	0.42	0.33	17.9	23.5	26.3	27.6	23.5	20.1	149.3	115.8	102.8
Monoammonium phosphate	0.57	0.41	0.31	15.1	23.5	25.9	26.2	22.3	20.5	135.0	109.0	98.70
Urea	0.61	0.43	0.34	16.5	27.9	27.0	27.7	21.3	18.5	147.8	123.5	104.5
Ammonium nitrate	0.55	0.44	0.30	22.4	27.8	24.1	26.2	21.5	20.2	128.8	145.5	104.5
LSD (5%)[a]		0.025			NS			NS			NS	

[a] Comparison within one year, combined analysis 1980-1982.

Table 30. Probability of a significant F test for yield and stand count (35-40 days after planting) compared to rainfall at 3 intervals after planting for the fertilizer applied with the seed study on a Conover loam and a Charity clay soil for 1980-1983.

Component		Year			
		1980	1981	1982	1983
		Conover Loam			
Probability:	Stand Count	NS	NS	NS	NS
	Yield	NS	NS	5%	NS
Rainfall:	0-5 days	6.10	6.35	0.00	20.83
(mm/ha)	6-10 days	15.24	54.36	7.37	20.07
	11-15 days	0.00	0.51	16.26	14.99
		Charity Clay			
Probability:	Stand Count	10%	5%	NS	NS
	Yield	NS	5%	NS	NS
Rainfall:	0-5 days	1.02	9.14	19.81	45.97
(mm/ha)	6-10 days	27.43	2.79	35.05	11.94
	11-15 days	47.24	1.02	18.29	30.48

this period the stands are relatively well established. The rainfall appears to reduce or eliminate any toxic effects that might have been due to the fertilizer applied. Stand counts were generally observed to increase until about 30 days after which they became steady. The last counts made within a period of 35 to 40 days following planting were found to be very closely related to the grain yields obtained.

After considering the nature of the responses observed from the stand counts, it is the opinion of this author that only the final counts can be of appropriate use in this discussion. It would appear either per chance or insignificant when an effect is observed early in the counts and this same effect is not observed at later counts.

Charity Clay

The final counts were not affected by the sources in 1980, 1981 or 1983 (Table 31). Stand counts in 1980 were steady at the various rates, but application at the rate of 6 kg N/ha gave stand counts higher than those of the control (Table 32). For this reason, this rate was discontinued and a higher rate of 44 kg N/ha included for subsequent years. The leaf-burn at this location appeared more severe than on the Conover loam soil and this effect was reflected in the grain yields. The differences in yields obtained from the various fertilizers were not significantly different (Table 33).

The interaction of nitrogen source and application rate significantly influenced final stand counts in 1981 (Table 34). The stand counts were reduced as the rate of fertilizer increased for all the sources. Damage from urea-urea phosphate and urea was more pronounced as would have been expected from these sources known to have

Table 31. Effect of nitrogen source on the final stand count when fertilizer was applied in contact with the seed, Charity clay, 1980-1983.

Source	Year			
	1980	1981	1982	1983
	-----number of plants per 12.2 meter row-----			
Urea phosphate	42	36	46	47
Urea-urea phosphate	-	22	47	47
Urea	40	21	47	47
Ammonium nitrate	42	34	45	47
LSD (5%)[a]	NS	b	NS	NS

[a] Comparison within one year.

[b] Interaction of nitrogen source and application rate significant, see Table 34.

Table 32. Effect of nitrogen rate on final stand count when fertilizer was applied in contact with the seed, Charity clay, 1980-1983.

	Year			
Rate	1980	1981	1982	1983
kg N/ha	--------number of plants per 12.2 meter row---------			
0	41	39	46	47
6	43	-	-	-
11	41	31	46	48
22	41	23	48	46
44	-	34	45	47
LSD (5%)[a]	NS	b	NS	1

[a] Comparison within one year.

[b] Interaction of nitrogen source and application rate significant, see Table 34.

Table 33. Effect of nitrogen source on corn grain yield when fertilizer was applied in contact with the seed, Charity clay, 1980-1983.

Source	Yield			
	1980	1981	1982	1983
	Mg/ha			
Urea phosphate	7.58	7.52	8.29	5.50
Urea-urea phosphate	-	5.11	8.35	5.94
Urea	7.44	4.43	8.20	5.73
Ammonium nitrate	7.69	6.77	8.20	6.08
LSD (5%)[a]	NS	b	b	NS

[a] Comparison of treatments within one year.

[b] Interaction of nitrogen source and rate significant, see Table 35.

Table 34. Effect of the interaction of nitrogen source and rate on the final stand count when fertilizer was applied in contact with the seed, Charity clay, 1980-1983.

Fertilizer		Stand Count			
Source	Rate	1980	1981	1982	1983
	kg N/ha	number of plants per 12.2 meter row			
-	0	41	39	46	47
Urea phosphate	6	42	-	-	-
	11	42	38	44	48
	22	42	34	47	45
	44	-	32	46	47
Urea-urea phosphate	6	-	-	-	-
	11	-	29	46	48
	22	-	13	50	47
	44	-	10	44	47
Urea	6	43	-	-	-
	11	40	21	47	48
	22	37	12	50	46
	44	-	5	45	48
Ammonium nitrate	6	44	-	-	-
	11	42	38	46	47
	22	43	33	44	47
	44	-	26	44	47
LSD (5%)[a]		NS	5[b]	NS	NS[c]

[a] Comparison within one year.

[b] Source and rate significant, see Tables 31 and 32.

[c] Rate significant, see Table 32.

a higher volatilization potential. The ammonia lost has a direct effect of causing seedling damage which could culminate in yield reduction. In support of this it was observed at maturity that yields from urea-urea phosphate and urea were significantly lower than yields from urea phosphate and ammonium nitrate (Table 33). Even though yields decreased with increasing amounts of fertilizer, the significantly low yield from ammonium nitrate compared to urea phosphate at 44 kg N/ha (Table 35) was unexpected. The interaction of the nitrogen source and the application rate was statistically significant. It is apparent that by increasing the concentration of fertilizer in contact with the seed, toxicity is increased. A higher osmotic potential is induced which is detrimental to crop growth.

Stand counts in 1982 were similar over the various rates and at each count. There was a good rainfall distribution following planting and this might have eliminated any source or rate effects. The yields obtained (Table 35) do not show any particular gradient and this result suggests that the rainfall may have eliminated any toxic effects of fertilizer contact with the seeds. The yields at 11 kg N/ha were lowest contrary to expectations, and the yields at 44 kg N/ha followed the highest returns from the control (Table 36).

The rate of fertilizer applied significantly affected stand counts in 1983 (Table 32). Stand counts were reduced at the rate of 22 kg N/ha. The highest application at 44 kg N/ha did not follow the expectation of a lower stand count. The interaction of the nitrogen source and application rate was not significant as the stand counts were relatively similar (Table 34). There were no significant effects influencing the grain yields. There was rainfall the day following

Table 35. Effect of the interaction of nitrogen source and rate on corn grain yield when fertilizer was applied in contact with the seed, Charity clay, 1980-1983.

Fertilizer		Yield			
Source	Rate	1980	1981	1982	1983
	kg N/ha	Mg/ha			
-	0	7.65	8.15	8.40	5.77
Urea phosphate	11	7.52	8.09	8.15	5.45
	22	7.52	6.71	8.02	4.76
	44	-	7.15	8.59	6.02
Urea-urea phosphate	11	-	6.64	7.77	6.46
	22	-	3.57	8.65	5.70
	44	-	2.07	8.59	5.83
Urea	11	7.33	5.08	8.02	6.21
	22	7.33	2.76	8.09	5.39
	44	-	1.75	8.27	5.58
Ammonium nitrate	11	7.77	7.71	8.21	6.27
	22	7.65	6.64	8.27	6.33
	44	-	4.57	7.90	5.95
LSD (5%)		NS[a]		1.29[b]	

[a] 1980 analyzed separately.

[b] Comparison of treatments within one year, combined analysis for 1981-1983.

Table 36. Effect of nitrogen rate on corn grain yield when fertilizer was applied in contact with the seed, Charity clay, 1980-1983.

Rate	Yield			
	1980	1981	1982	1983
kg N/ha	----------	Mg/ha	----------	
0	7.65	8.15	8.40	5.77
11	7.54	6.88	8.04	6.10
22	7.38	4.92	8.26	5.55
44	-	3.88	8.34	5.84
LSD (5%)	NS[a]	b	b	NS[a]

[a] Comparison within one year.

[b] Interaction of source x rate significant, see Table 35.

planting and it appears that it eliminated the toxic effects of the contact fertilizers since yields from 44 kg N/ha application were even higher than from the control. It was also observed that the relative efficiencies of the fertilizers varied with the rates of application (Table 35).

Conover Loam

Even though early counts in 1980 were affected by the interaction of the nitrogen source and the rate of application, this effect was not observed at the final stand count (Table 37). There was no difference in stand counts between the various sources (Table 38). At the final count, only the 11 kg N/ha application had stand counts lower than the control (Table 39). Due to the similarity with the control, the 6 kg N/ha rate was discontinued for subsequent years and a 44 kg N/ha rate included. Grain yields this year were also observed to be significantly affected by the interaction of the nitrogen source and the rate of application (Table 40). Urea phosphate and ammonium nitrate performed better than urea. Except for urea applications, the sources showed a decrease in yields with increasing rates when a fertilizer application was made.

The following year, 1981, no factor was statistically significant. Qtand counts were similar for the sources (Table 38), and at the various rates (Table 39). This year showed the lowest yields on this location as well as a lower inter-location yield.

The interaction of the fertilizer sources and the rate of application significantly influenced stand counts in 1982 (Table 37). Stand counts were observed to decrease with increasing fertilizer rates

Table 37. Effect of the interaction of nitrogen source and rate on final stand counts when fertilizer was applied in contact with the seed, Conover loam, 1980-1983.

Fertilizer		Stand Count			
Source	Rate	1980	1981	1982	1983
	kg N/ha	number of plants per 12.2 meter row			
-	0	62	49	58	-
Urea phosphate	6	60	-	-	-
	11	64	45	57	47
	22	62	43	53	44
	44	-	42	52	45
Urea-urea phosphate	6	-	-	-	-
	11	-	46	51	46
	22	-	48	31	46
	44	-	50	16	47
Urea	6	62	-	-	-
	11	59	42	46	46
	22	63	45	32	47
	44	-	46	12	46
Ammonium nitrate	6	64	-	-	-
	11	57	45	59	46
	22	64	47	54	46
	44	-	43	46	45
LSD (5%)[a]		NS	NS	7[b]	NS

[a] Comparison within one year.

[b] Source and rate significant, see Tables 38 and 39.

Table 38. Effect of nitrogen source on final stand counts when fertilizer was applied in contact with the seed, Conover loam, 1980-1983.

Source	Stand Count			
	1980	1981	1982	1983
	----number of plants per 12.2 meter row-----			
Urea phosphate	62	43	54	45
Urea-urea phosphate	-	48	33	46
Urea	61	44	30	46
Ammonium nitrate	62	45	53	46
LSD (5%)[a]	NS	NS	b	NS

[a] Comparison within one year.

[b] Interaction of source x rate significant, see Table 37.

Table 39. Effect of nitrogen rate on final stand count when fertilizer was applied in contact with the seed, Conover loam, 1980-1983.

	Stand Count			
Rate	1980	1981	1982	1983
kg N/ha	---------number of plants per 12.2 meter row---------			
0	62	49	58	47
6	62	-	-	-
11	60	45	53	46
22	63	46	43	46
44	-	45	32	46
LSD (5%)[a]	NS	NS	b	NS

[a] Comparison within one year.

[b] Interaction of source x rate significant, see Table 37.

Table 40. Effect of the interaction of nitrogen source and rate on corn grain yield when fertilizer was applied in contact with the seed, Conover loam, 1980-1983.

Fertilizer		Yield			
Source	Rate	1980	1981	1982	1983
	kg N/ha	Mg/ha			
-	0	9.65	5.52	9.65	8.53
Urea phosphate	11	10.09	6.02	10.16	8.90
	22	9.78	5.64	9.59	8.53
	44	-	5.70	8.21	8.46
Urea-urea phosphate	11	-	6.02	8.84	8.65
	22	-	6.02	6.83	8.65
	44	-	6.21	3.19	8.65
Urea	11	8.71	5.77	7.77	8.40
	22	10.22	6.02	6.46	9.09
	44	-	5.70	2.88	8.21
Ammonium nitrate	11	9.40	6.02	10.22	9.28
	22	9.28	5.89	9.53	8.15
	44	-	5.45	6.90	7.96
LSD (5%)		0.93[a]		1.43[b]	

[a] 1980 analyzed separately.

[b] Comparison of treatments within one year, combined analysis for 1981-1983.

(Table 39). As was expected, urea-urea phosphate and urea considerably reduced stand counts particularly at the higher rates of application. This reduction in stand counts resulted in lower yields from urea-urea phosphate and urea (Table 40). Yields were reduced with increasing fertilizer rates. At 44 kg N/ha ammonium nitrate had a more severe effect of reducing stand counts and yield than did urea phosphate. A similar observation was made on the Charity clay soil the previous year. Perhaps there is the formation of nitric acid in concentrations strong enough to be detrimental to crop growth.

Twenty-five days after planting, in 1983, the differences between sources disappeared and stand counts became steady. The effects of the fertilizers and the application rates were not significant upon yields (Tables 41 and 42). It is expected that the good rainfall distribution early in the season contributed to this lack of variation.

The observations from the two locations suggest that when there is not adequate rainfall to dilute the fertilizer applied in contact with the seed, increasing the rate of application will contribute to a reduction in stand counts and consequently grain yields. Various fertilizer sources will show different degrees of toxicity as urea-urea phosphate and urea have been shown to be more detrimental than urea phosphate and ammonium nitrate in contact with the seeds. With a good rainfall distribution, stand counts made over a period of 40 days may be similar as the toxic effects of the fertilizers can be reduced or eliminated. If there is not adequate rainfall, then stand counts will decrease until about 30 days after which counts become steady.

Table 41. Effect of nitrogen source on corn grain yield when fertilizer was applied in contact with the seed, Conover loam, 1980-1983.

Source	Yield			
	1980	1981	1982	1983
	Mg/ha			
Urea phosphate	9.84	5.72	9.40	8.60
Urea-urea phosphate	-	5.94	7.13	8.62
Urea	9.53	5.75	6.69	8.56
Ammonium nitrate	9.45	5.72	9.06	8.48
LSD (5%)	a	NS[b]	a	NS[b]

[a] Interaction of source x rate significant, see Table 40.

[b] Comparison within one year.

Table 42. Effect of nitrogen rate on corn grain yield when fertilizer was applied in contact with the seed, Conover loam, 1980-1983.

	Yield			
Rate	1980	1981	1982	1983
kg N/ha	----------	Mg/ha	----------	
0	9.65	5.52	9.65	8.53
11	9.40	5.95	9.25	8.81
22	9.76	5.89	8.10	8.60
44	-	5.77	5.30	8.32
LSD (5%)	a	NS[b]	NS[b]	NS[b]

[a] Interaction of source x rate significant, see Table 40.

[b] Comparison within one year.

SUMMARY AND CONCLUSION

Laboratory, greenhouse and field studies were conducted to determine the relative efficiencies of urea phosphate, cogranulated urea-urea phosphate, urea and ammonium nitrate as nitrogen fertilizers. Measurements were made as ammonia nitrogen volatilized, and crop yield and nitrogen uptake.

In the laboratory studies the amount of ammonia volatilized was significantly different among the sources. Only urea-urea phosphate lost more nitrogen than urea. It has been said that laboratory aeration studies often underestimate wind speed in the field, therefore, these losses observed may not show absolute losses possible but they do indicate that relative to urea a 1:1 ratio of urea bonded to phosphate proves more efficient while increasing the ratio will result in reduced efficiency.

Maintaining soil moisture below field capacity resulted in a higher loss of nitrogen. The observations made support the school of thought that initial soil moisture content is important in determining ammonia volatilization. Nitrogen losses from the coarser textured Granby loamy sand were significant over the losses from the finer Charity clay. This is an indication of the capability of the soils to adsorb ammonia and reduce ammonia volatilization as the CEC of the soils increase.

The controls did not give any indication of ammonia loss. Thus it is believed that ammonia volatilization was from the applied fertilizers and this will decrease as time goes by until there is an equilibrium as

determined by the soil characteristics. Nitrogen losses from the fertilizer applications increased with the rate used.

Under the treatments used, the higher rates of application 120 and 200 mg N/kg lost significantly more nitrogen than the control. Urea-urea phosphate lost more than urea, even though ammonia volatilization was delayed for about three days.

The greenhouse studies indicate that the interaction of nitrogen source, rate and soil is a factor affecting crop yield and nitrogen uptake. Urea phosphate and ammonium nitrate were most effective at 120 mg N/kg application and this is determined as the optimum rate since yields at 180 mg N/kg were not significant over those at 120 mg N/kg. Yields and nitrogen uptake decreased with each cropping indicating a reduction in nitrogen availability. Initially yields were higher on the Charity clay but this reversed in time pointing to the adsorption capacity of the Charity clay. Urea-urea phosphate when broadcast did not give significantly different yields compared to mixing with the soil. Nitrogen uptake from urea phosphate = urea > ammonium nitrate >> broadcast urea-urea phosphate = mixed urea-urea phosphate.

Incorporating the fertilizers in the field did not show any advantages over leaving the fertilizer on the surface. The rate of nitrogen applied significantly increased yields up to 134 kg/ha N. Since yields increased with rate it implies that even though more nitrogen is lost there is enough available for crop uptake to make a difference.

There was variation in fertilizer performance over the years, therefore, seasonal weather will also be a factor to consider. It is sufficient to conclude that urea phosphate is as effective or better

than urea while urea-urea phosphate may be even less effective than urea.

When the fertilizers were band applied there was no difference in their performance. Banding is thus considered a method of retarding ammonia volatilization and making it feasible to use any of the sources without performance concerns.

Application of the fertilizers in contact with the seeds caused seedling damage and yield reductions moreso as the rates applied increased. Fertilizer in contact with the seed may have been toxic, increasing the osmotic potential and retarding inbibition. Stand counts, however, indicate that it is only early in the season up to 25 days that there is the detrimental effect of this method. After this period stand count equilibrates and there is no further risk of seedling damage. However, when there is adequate moisture following planting, there could be a reduction in toxic effect.

In conclusion, urea phosphate as a fertilizer performed better than urea but urea-urea phosphate was less effective. Even though there may be more ammonia volatilized at the higher rates of nitrogen application, there is still enough nitrogen supplied to increase crop yield and nitrogen uptake at the higher rates. Banding is an effective method as it eliminated any discrimination between the sources. Applying fertilizer with the seed faces risk of toxicity as the fertilizer rate increases which causes a reduction in crop yield. As nitrogen sources, the efficiency of these fertilizers can be ranked as urea phosphate = ammonium nitrate > urea $\geq$ urea-urea phosphate.

APPENDIX

Table 43. Effect of fertilizer source, initial moisture level, and soil type on loss of nitrogen by ammonia volatilization in a laboratory aeration study, 1983.

Fertilizer		Charity Clay		Granby loamy Sand	
Source	Rate	FC[b]	25% FC	FC	25% FC
	mg N/culture	mg N/culture			
-	0	0	0	0	0
Urea	48	0.00	0.15	0.30	1.78
	96	0.00	5.80	1.54	2.01
	160	0.11	1.94	5.01	11.27
Urea phosphate	48	0.00	0.02	0.00	0.92
	96	0.00	0.19	0.42	1.29
	160	0.00	1.96	0.00	1.45
Ammonium nitrate	48	0.00	0.13	0.00	0.15
	96	0.00	0.11	0.00	0.30
	160	0.00	0.28	0.13	0.52
Urea-urea phosphate	48	0.00	1.12	0.32	1.54
	96	0.01	3.69	2.17	7.87
	160	0.10	6.12	2.37	12.61
LSD (5%)		4.49			

[a] Corresponds to 0, 60, 120, and 200 mg N/kg soil.

[b] FC = Initial soil moisture level at field capacity (1/3 bar).

Table 44. Effect of nitrogen source, rate, and soil type on the nitrogen concentration of oats in the greenhouse, 1983.

Fertilizer		Crop 1		Crop 2		Crop 3	
Source	Rate	Charity	Granby	Charity	Granby	Charity	Granby
	mg N/kg	% N					
-	0	3.81	4.05	1.92	3.44	1.55	2.99
Urea	60	4.96	3.96	2.53	4.08	1.69	3.33
	120	5.34	4.22	4.18	4.25	1.49	3.69
	180	5.77	4.70	4.98	4.03	3.25	3.90
Urea phosphate	60	5.23	4.66	2.50	4.04	1.54	3.59
	120	5.32	4.35	4.77	4.20	1.62	3.56
	180	5.66	4.77	5.19	4.54	3.09	4.07
Ammonium nitrate	60	5.07	3.97	2.57	4.10	1.61	3.40
	120	5.14	4.38	3.98	3.91	1.47	3.43
	180	5.53	4.62	4.79	4.23	3.06	4.00
Urea-urea phosphate (mixed)	60	4.99	4.88	2.01	3.99	1.67	3.51
	120	5.26	4.57	3.39	4.26	1.59	3.53
	180	4.90	4.52	2.91	4.27	1.59	3.52
Urea-urea phosphate (broadcast)	60	5.23	4.38	1.96	3.77	1.69	3.30
	120	4.93	4.69	2.65	4.17	1.56	3.52
	180	5.03	4.45	3.01	4.30	1.46	3.44
LSD (5%)		0.63		0.58		0.55	

Table 45. Daily precipitation (inches) at the Saginaw Valley Bean and Beet Research Farm, 1980.

Date	April	May	June	July	August	September	October
1	-	-	0.28	-	-	0.52	0.10
2	Tr	-	Tr	-	Tr	0.60	Tr
3	-	-	0.20	Tr	-	-	-
4	0.64	-	-	0.12	-	-	0.80
5	-	Tr	-	-	0.18	-	-
6	-	-	0.66	Tr	Tr	-	0.10
7	0.07	Tr	0.98	1.03	Tr	-	-
8	0.72	-	-	-	0.89	-	-
9	0.15	-	0.07	-	-	0.60	-
10	0.03	Tr	-	-	0.08	-	-
11	Tr	-	-	0.41	0.48	-	0.03
12	0.32	-	-	-	-	0.08	Tr
13	-	0.56	-	-	Tr	0.48	Tr
14	-	Tr	0.05	0.02	-	0.02	0.73
15	0.50	Tr	Tr	0.17	-	0.01	Tr
16	-	-	-	0.29	-	-	0.30
17	Tr	-	-	Tr	Tr	1.16	0.69
18	-	1.20	-	-	-	Tr	Tr
19	0.09	-	0.71	Tr	Tr	-	Tr
20	-	-	-	2.21	0.33	0.03	0.16
21	-	-	-	0.11	0.10	-	-
22	-	-	-	0.07	-	0.94	-
23	-	-	-	-	-	-	-
24	0.72	0.03	-	-	-	-	0.34
25	Tr	-	-	Tr	-	0.17	0.01
26	0.01	-	0.38	-	-	-	Tr
27	-	-	-	1.46	-	-	-
28	0.19	0.01	0.71	Tr	Tr	-	-
29	0.35	0.62	-	-	-	-	-
30	0.12	0.18	-	-	-	-	-
31	-	-	-	0.01	0.05	-	-
Total	3.91	2.60	4.04	5.90	2.11	4.61	3.26

Table 46. Daily precipitation (inches) at the Saginaw Valley Bean and Beet Research Farm, 1981.

Date	April	May	June	July	August	September	October
1	0.02	-	-	0.05	0.46	0.29	1.54
2	-	-	-	Tr	Tr	Tr	-
3	Tr	-	0.04	-	Tr	-	-
4	0.14	-	-	0.20	-	1.00	0.01
5	Tr	0.11	-	-	0.07	-	Tr
6	-	-	-	-	-	Tr	0.41
7	-	-	-	-	0.09	0.61	0.05
8	0.90	-	0.25	-	-	0.10	-
9	-	-	0.05	-	-	-	-
10	Tr	-	0.06	-	0.45	-	-
11	-	2.93	-	-	0.01	-	-
12	0.58	-	-	Tr	-	-	-
13	-	-	-	0.20	-	-	-
14	0.50	Tr	1.10	-	-	-	-
15	-	0.01	0.06	-	-	0.01	0.29
16	-	Tr	Tr	0.02	-	-	-
17	0.07	-	-	-	1.05	1.77	-
18	-	-	-	-	-	-	0.20
19	Tr	-	-	Tr	-	-	Tr
20	-	-	-	0.06	-	-	-
21	-	-	-	0.08	-	0.78	0.23
22	-	-	1.16	-	-	-	Tr
23	0.57	Tr	-	-	-	-	Tr
24	0.12	-	-	Tr	-	-	-
25	0.02	0.25	-	-	-	-	-
26	Tr	0.11	-	0.59	-	0.61	-
27	-	Tr	-	Tr	0.05	2.26	0.01
28	0.15	-	Tr	1.21	0.31	-	-
29	0.36	0.11	-	-	-	0.02	-
30	-	-	0.37	-	0.74	1.64	-
31	-	-	-	-	0.60	-	-
Total	3.43	3.52	3.09	2.41	3.83	9.09	2.74

Table 47. Daily precipitation (inches) at the Saginaw Valley Bean and Beet Research Farm, 1982.

Date	April	May	June	July	August	September	October
1	-	-	0.72	-	-	0.03	-
2	Tr	-	-	-	0.25	0.12	-
3	0.17	-	-	0.24	0.01	-	-
4	Tr	-	-	-	-	-	-
5	-	Tr	-	-	-	-	-
6	0.32	Tr	-	-	-	Tr	-
7	-	0.19	-	0.05	-	-	0.02
8	-	-	-	-	0.50	-	-
9	-	-	-	-	-	-	-
10	Tr	Tr	0.19	-	-	-	0.17
11	Tr	-	-	0.25	-	-	Tr
12	-	0.15	Tr	-	-	-	Tr
13	0.22	-	-	-	-	0.04	-
14	-	Tr	-	0.40	-	1.60	-
15	-	Tr	0.82	-	-	0.04	0.08
16	-	0.02	0.01	-	-	0.02	0.02
17	0.32	-	-	-	-	0.45	-
18	-	0.19	0.21	1.40	-	-	Tr
19	-	0.01	0.74	-	-	-	Tr
20	0.20	-	0.33	-	-	0.03	0.25
21	-	-	Tr	-	-	0.01	-
22	-	-	Tr	Tr	0.17	0.33	Tr
23	-	0.78	-	-	-	Tr	-
24	-	Tr	-	-	-	0.03	-
25	Tr	-	0.03	-	1.31	0.09	-
26	0.04	0.03	-	0.12	-	Tr	-
27	-	0.79	0.04	0.14	Tr	0.23	-
28	-	-	-	-	-	-	-
29	-	0.56	Tr	-	0.31	-	0.06
30	Tr	Tr	-	0.05	-	-	-
31	-	0.60	-	-	-	-	0.16
Total	1.27	3.32	3.09	2.65	2.55	3.02	0.76

Table 48. Daily precipitation (inches) at the Saginaw Valley Bean and Beet Research Farm, 1983.

Date	April	May	June	July	August	September	October
1	-	-	-	-	0.21	-	-
2	-	1.40	-	-	-	-	-
3	0.62	0.05	0.72	-	Tr	-	Tr
4	Tr	Tr	0.12	0.01	0.11	-	0.39
5	-	-	-	-	-	-	0.08
6	Tr	0.11	Tr	-	-	0.46	0.02
7	0.27	1.00	-	-	-	-	-
8	-	-	-	-	-	-	0.23
9	0.65	-	0.11	-	-	-	-
10	0.14	-	0.03	-	-	0.29	-
11	Tr	-	-	-	1.48	-	-
12	-	-	-	-	-	-	0.03
13	0.35	-	-	-	-	0.13	1.07
14	0.69	0.02	-	0.05	-	-	0.08
15	Tr	-	Tr	-	-	0.02	-
16	-	-	-	-	-	1.13	Tr
17	0.16	-	-	Tr	-	-	-
18	Tr	-	-	Tr	0.05	1.40	-
19	-	1.06	-	-	-	-	-
20	-	Tr	-	0.50	-	1.36	-
21	-	Tr	-	-	0.55	0.02	-
22	-	0.85	-	-	Tr	Tr	-
23	-	-	-	Tr	-	Tr	0.99
24	-	-	-	-	-	-	-
25	-	0.47	-	-	-	0.27	0.06
26	-	-	-	-	Tr	-	Tr
27	-	-	1.80	-	-	-	-
28	0.66	-	0.16	0.37	-	-	-
29	-	0.66	-	0.90	0.03	-	-
30	1.01	0.44	0.61	-	0.07	0.03	-
31	-	0.09	-	0.08	-	-	-
Total	4.55	6.15	3.55	1.91	2.50	5.11	2.95

Table 49. Daily precipitation (inches) at the Soils Farm (Conover loam), 1980.

Date	April	May	June	July	August	September
1	0.16	-	-	-	-	0.43
2	0.10	-	0.35	0.02	0.11	0.29
3	0.72	-	0.70	-	1.07	0.30
4	Tr	-	-	-	-	-
5	Tr	-	-	0.41	-	-
6	-	-	0.49	0.19	0.60	-
7	-	-	Tr	Tr	Tr	-
8	0.02	-	0.94	Tr	-	-
9	0.37	-	0.08	-	0.05	0.80
10	0.10	-	0.01	0.07	-	0.17
11	Tr	0.09	-	-	0.17	-
12	0.07	Tr	-	-	0.06	0.01
13	-	0.37	-	0.01	-	0.04
14	0.02	0.53	0.37	-	0.02	0.34
15	0.27	Tr	0.06	Tr	-	-
16	0.05	0.03	0.32	-	-	-
17	-	-	-	0.50	0.06	1.06
18	-	1.23	-	-	0.12	0.04
19	-	0.01	0.09	-	-	-
20	-	-	0.39	Tr	3.56	-
21	-	-	-	0.24	0.04	0.05
22	-	-	-	0.03	0.17	-
23	-	-	-	-	-	0.78
24	-	-	-	-	-	-
25	0.24	Tr	-	-	-	-
26	Tr	-	-	-	-	0.02
27	-	-	-	0.94	-	-
28	0.29	-	Tr	0.10	-	-
29	0.21	-	-	Tr	-	-
30	0.10	0.06	-	0.33	-	-
31	-	0.56	-	0.10	-	-
Total	2.76	2.88	3.81	2.94	6.03	4.33

Table 50. Daily precipitation (inches) at the Soils Farm (Conover loam), 1981.

Date	April	May	June	July	August	September
1	0.04	-	-	Tr	-	Tr
2	-	-	-	-	-	Tr
3	-	-	-	-	-	Tr
4	0.23	-	-	0.01	0.05	1.18
5	-	-	-	-	-	0.18
6	-	Tr	-	-	-	Tr
7	-	-	-	-	-	Tr
8	-	-	0.08	-	0.27	-
9	0.54	-	0.39	-	0.13	-
10	-	0.25	0.09	-	0.22	-
11	0.90	1.89	-	-	Tr	-
12	0.86	0.09	-	Tr	-	-
13	0.03	-	1.68	0.04	-	-
14	1.67	-	0.49	-	-	Tr
15	-	0.16	0.36	-	0.30	-
16	-	Tr	-	0.05	0.01	Tr
17	0.03	-	0.01	-	-	0.56
18	-	-	-	-	-	0.17
19	-	-	-	-	-	-
20	0.13	-	-	-	-	-
21	-	-	-	0.48	-	-
22	-	-	0.56	Tr	-	1.52
23	0.66	-	0.02	-	-	-
24	0.12	-	-	Tr	-	-
25	-	0.43	Tr	-	-	0.03
26	Tr	0.17	-	0.11	-	0.41
27	Tr	Tr	-	0.13	0.34	-
28	0.04	Tr	-	0.29	0.35	0.01
29	0.42	-	-	0.45	0.62	0.65
30	Tr	0.09	-	-	0.98	-
31	-	-	-	-	-	-
Total	5.67	3.08	3.68	1.56	3.27	5.13

Table 51. Daily precipitation (inches) at the Soils Farm (Conover loam), 1982.

Date	April	May	June	July	August	September
1	Tr	Tr	1.40	-	-	-
2	-	-	0.02	-	0.06	-
3	0.27	-	Tr	0.72	-	Tr
4	0.10	-	0.08	Tr	0.11	-
5	-	-	-	-	-	-
6	0.61	-	-	-	-	0.25
7	-	-	-	-	-	Tr
8	-	0.29	0.14	-	0.02	-
9	-	-	-	-	0.11	-
10	-	Tr	0.18	-	-	-
11	0.02	-	-	0.44	-	-
12	-	-	-	0.17	-	-
13	0.03	0.64	-	-	-	-
14	-	-	-	-	-	-
15	-	-	0.08	0.05	-	0.06
16	0.03	0.22	0.47	-	-	0.02
17	Tr	0.02	-	-	-	Tr
18	-	-	-	0.84	-	0.63
19	-	0.14	0.79	0.27	-	-
20	0.11	0.13	Tr	0.08	0.44	0.03
21	-	-	0.09	-	-	Tr
22	-	0.34	-	-	-	0.06
23	-	0.09	-	-	0.03	0.21
24	-	0.04	-	-	-	0.06
25	-	Tr	-	-	0.20	1.55
26	-	-	0.10	0.01	-	0.06
27	Tr	0.04	Tr	0.97	-	1.08
28	-	0.35	0.01	1.69	-	0.70
29	-	Tr	0.23	-	-	-
30	-	Tr	-	-	0.28	-
31	-	-	-	-	-	-
Total	1.17	2.30	3.59	5.24	1.25	4.71

Table 52. Daily precipitation (inches) at the Soils Farm (Conover loam), 1983.

Date	April	May	June	July	August	September
1	-	0.25	0.02	0.13	Tr	-
2	0.18	1.12	-	-	-	-
3	0.31	-	Tr	-	-	-
4	0.13	0.08	0.54	-	-	-
5	-	-	-	Tr	-	-
6	0.14	-	0.20	-	-	0.74
7	0.28	0.04	0.04	-	-	0.01
8	Tr	1.03	-	-	-	-
9	Tr	-	-	-	-	-
10	0.67	-	0.04	-	-	-
11	Tr	-	-	-	1.00	0.11
12	Tr	-	-	-	0.07	-
13	0.10	-	-	-	-	-
14	0.82	-	-	-	-	-
15	0.08	0.03	-	-	-	-
16	0.04	-	0.23	-	-	0.44
17	0.23	-	-	-	Tr	0.08
18	-	-	-	0.76	0.06	0.07
19	Tr	0.04	-	Tr	Tr	1.75
20	-	0.61	-	-	-	-
21	-	Tr	-	-	-	0.57
22	-	0.17	-	1.06	0.45	0.09
23	-	0.54	-	-	Tr	0.10
24	-	-	-	-	-	-
25	-	0.04	-	-	-	-
26	-	0.21	-	-	-	0.01
27	-	-	0.37	-	-	-
28	0.23	-	2.64	-	-	-
29	0.57	0.38	0.22	0.20	-	-
30	0.15	0.08	-	0.18	-	-
31	-	0.13	-	0.31	0.58	-
Total	3.93	4.75	4.30	2.64	2.16	3.97

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