

SURFACE APPLICATION OF
NITROGENOUS FERTILIZERS

by

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A handwritten signature in dark ink, reading "David E. Kissel", is written over a horizontal line.

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GENERAL INTRODUCTION

Continually rising energy costs are having an increased impact on American farming practices. The cost of fertilizer nitrogen is especially affected by this trend. A large amount of the fertilizer nitrogen applied in the United States is surface applied, often in the form of urea or urea-ammonium nitrate solutions. Surface application of these materials is often the only practical means of application, such as in pasture fertilization, winter wheat topdressing and minimum tillage fertilization. As always, the ultimate goal for the producer in these farming systems is maximum yield with minimum input. To accomplish this, he must have a high level of fertilizer use efficiency with minimum damage to the crop from fertilizer application.

This thesis examines two aspects of this goal. The first portion considers application of fluid fertilizer materials (containing urea and ammonium nitrate) to winter wheat and established grasses. Damage to the crop in the form of leaf burn is examined and evaluated in terms of yield and crop quality.

The second portion considers NH_3 loss as a gas from surface applied urea - specifically the effects of soil buffering capacity on NH_3 volatilization.

EFFECT OF NITROGEN SOURCE ON LEAF BURN AND
YIELD FOR WHEAT, BERMUDAGRASS AND FESCUE

INTRODUCTION

Surface application of fertilizers, particularly nitrogen, to established crops has become an accepted method of enhancing crop yield. Surface application, or topdressing, is often the only practical means of fertilizing such crops as established fescue and bermudagrass. In the case of wheat, surface application of all or a portion of the fertilizer necessary allows the grower more flexibility in his management program. Time of application can be controlled to meet the growers specific economic and agronomic needs.

The rapid increase in use of fertilizer materials in the last 20 years (Hargett and Berry, 1980) has been accompanied by a rapid expansion in fertilizer technology. One of the areas in which much industry effort has been exerted is in the development of fluid fertilizers and fertilizer suspensions. The use of fluid fertilizers (here defined as both clear liquid materials and suspension materials) holds several advantages over dry fertilizer products. Fluids can be handled by pumping the product instead of scooping it or moving it with augers or conveyor belts. Consequently fluids can be handled with less physical effort than dry products. Fluid materials are easily stored and are not subject to caking and collection of moisture, as are some dry products. Field application of fluids is often more accurate than dry products, particularly if the material is broadcast, or surface applied. Finally, fluids are easier to "prescription blend" with a wide assortment of micronutrient materials, if needed.

Fluids can also be blended with herbicides for a complete "weed and feed" program, if components are compatible.

Clear liquid fertilizers (or fertilizers in which all nutrient material is in solution) have been used for many years. Their chief disadvantage has been their cost, which has been higher than comparable dry products. Suspension fertilizers have gained popularity in the last few years for this reason - they combine the versatility of the clear liquids with the lower cost of dry products. A suspension is basically a mix of a liquid base, small fertilizer crystals and a suspending agent, usually attapulgite clay, to hold the fertilizer crystals in suspension and prevent their settling out. A high-analysis fertilizer material can thus be handled as a fluid, with a cost comparable to a dry product.

One disadvantage to suspensions has been the technology necessary in their production. A sizable initial investment has been necessary on the part of the fertilizer dealer in the establishment of a suspension plant and its storage and handling equipment. The actual production of a suspension material in the plant involves accurate metering and handling of component materials.

One area of suspension production which is very critical is the production of the colloidal gel, using attapulgite clay or some similar suspending agent. This gel "holds up" the small fertilizer crystals, preventing their settling out and plugging up the mixing and/or application apparatus. A recently introduced product, developed by the Tennessee Valley Authority - National Fertilizer Development Center, is a base fertilizer product which already has the attapulgite clay suspended. Consequently, the fertilizer dealer need only add the appropriate amounts of the products

he wishes to suspend and mix. This greatly reduces the time and effort on the part of the dealer in preparation of the suspension.

The study described here was designed to compare the performance of the new TVA product, UAN with gelled clay, against established clear liquid fertilizers. This product is a urea-ammonium nitrate-attapulgitic clay suspension, with 31% nitrogen and 1.5% attapulgitic clay content. Technically, this product, which will be termed 31% UAN suspension for the purpose of this study, is a suspension only because it has attapulgitic clay suspended in it. The urea-ammonium nitrate content is low enough that all of the nutrient components are in solution.

OBJECTIVES OF THE STUDY

1. To compare crop yields produced after application to the soil surface of four fertilizer materials:
 - a. 31% UAN suspension
 - b. 28% (or 31%) UAN solution
 - c. 24-8-0 suspension
 - d. 28-0-0-2S solution
2. To compare leaf burn caused by spraying the above fertilizer materials on leaf surfaces, and to measure, if possible, the effects of the resulting leaf burn on crop yield.
3. To determine the effects of application date (climatic conditions), application rate and spray droplet size on leaf burn and crop yield

LITERATURE REVIEW

Surface application of plant nutrients in the form of manure was probably man's first use of fertilizer. Surface application of nitrogenous fertilizers to already growing crops has been practiced for the major part of this century. Early work on surface application of fertilizers was carried out in the mid-1930's. Cook and Millar (1936) described a study in which sodium nitrate and ammonium sulfate were applied to winter wheat early in the spring. After five years of study, no clear trends towards a profitable increase in yield could be seen from either source, but some plots did show significant increases in yield. Articles describing the benefits of topdressing winter wheat and pastures in New Zealand were published in the late 1930's. Syme (1938) found application of nitrogen fertilizer to pastures "warranted only for special purposes, such as the production of early spring grass." Woodcock and Mallo (1938), on the other hand, found there was a definite benefit from surface application of ammonium sulfate in the spring where a cereal crop followed cereal crop, or where heavy rains had leached much of the available nitrogen from the soil profile.

Lewis, Proctor and Trevains (1938) found that yields of winter wheat could be significantly increased if nitrogen was applied to the soil surface in the spring. Yield increases were noted from both early (February-March) and late (April-May) spring applications. Yield increases were due primarily to an increase in the number of grains per head.

Later work noted that spring application of nitrogen to winter wheat also increased the protein content of the grain. Gardner (1950) found that nitrogen applied as ammonium sulfate at the rate of 7.3 kg N/ha (.31 cwt/acre) increased the average percent protein of the grain by .36%. Grain yield was also increased by 403 kg/ha (3.6 cwt/acre), over an unfertilized check. He found, however, that the climatic conditions of the growing season, the location of the study and the variety studied all had some effect on the response to surface applied nitrogen.

Most of the topdressing studies performed in the first half of this century were concerned with application of dry fertilizer materials. In the early 1950's, interest began to rise in using fertilizer solutions, particularly UAN, or urea-ammonium nitrate solution, as a topdressing source. Also, about this same time, interest began to develop in foliar fertilization - the application of liquid fertilizer to the foliage of growing crops, and subsequent uptake of nutrients by the plant through the leaf tissue. The point where surface application of liquid fertilizer materials ceases to be considered a topdress application and becomes foliar fertilization is somewhat ambiguous. One possible point of differentiation is the amount of fertilizer material which actually contacts the soil surface. If the majority of the solution sprayed reaches the soil surface, the application could be considered topdressing. If the majority of the spray remains on the leaf surfaces of the crop, the application could be considered foliar fertilization. Another difference might be the concentration of the spray solution and the rate of nutrient applied per acre. Topdressing solutions are generally at least 20% N, and more commonly 28-32% N. They are often applied at rates to supply 30 to 50 kg N/ha. Foliar fertilizer solutions, on the other hand, generally have analyses

with nitrogen contents below 15% N, and are applied at rates which deliver anywhere from slightly more than 1 kg N/ha, (Mederski and Volk, 1956), to 80 kg N/ha (Garcia and Hanway, 1976).

The problem encountered when studying the effects of topdressed applications of nitrogenous fertilizers is that some of the solution applied will remain on the leaf surface. The proportion of the spray applied remaining on the leaf surface will depend primarily on the amount of leaf area present, and somewhat on the physical properties of the spray solution and the leaf surface. In general, if the application is made in the spring, the later the application, the greater the leaf area of the crop. Consequently, if the application is delayed long enough, it essentially ceases to be a topdress application and becomes instead a foliar application, because of the amount of spray remaining on the leaf surfaces of the crop.

Fertilizer solutions remaining on leaf surfaces from what was intended to be a topdress application can be detrimental for several reasons, two of which are related to the urea content of the solution. Urea will be hydrolyzed, to some extent, by urease which is present in all plant tissue. (Fisher and Parks, 1958) The NH_3 subsequently produced can be either lost to the atmosphere by volatilization, or absorbed into the leaf tissue. Depending on the amount of NH_3 absorbed, leaf burn to the affected leaf can result, perhaps followed by a yield reduction. The extent of yield reduction can depend on a) degree of injury, b) growth stage at which injury occurs, and c) climatic conditions following injury.

Consequently, this review also considers the past work done on foliar fertilization, in particular regard to the effects of foliar fertilization on leaf burn. Although the topic of foliar fertilization is not of direct

interest to this paper, the effects of fertilizer solutions remaining on leaf surfaces, and subsequent crop injury, is of interest and will be discussed.

Early work concerning foliar fertilization was carried out by Chesnin and Shafer (1953). They applied urea solutions to wheat (*Triticum aestivum*, L.), corn (*Zea mays*, L.), bromegrass (*Bromus beibersteinii*), and alfalfa (*Medicago sativa*). A wide range of sensitivity of leaf burn, to different N rates and application methods, between crops was noted.

Finney, et al (1957), studied the effects of spraying urea solution on Pawnee wheat during the fruiting period. They found the protein content of the grain to increase by as much as 6.8% (actual) following foliar application of urea. Significant increases in yield were noted in later work, when higher concentrations of urea were used. The concept of combining two field operations in one was studied by Thorne (1957). He applied 2,4-D in combination with either urea or ammonium nitrate solutions to winter wheat. Some leaf burn was evident the first year of the study, but soon disappeared. Rain fell 12 hours following application the second year, so no leaf burn was noted. Solid fertilizer applications were included as a check in the study. Thorne found that fertilizer nitrogen uptake from the solid fertilizers to be twice that of the liquid sources. Also, the dry fertilizers increased yield slightly more than did the liquids. Ammonium nitrate and urea had the same effect, whether in the liquid phase or as solids. Thorne concluded that the low uptake of fertilizer nitrogen would make the combination of topdressing nitrogen with a weedkiller spray an undesirable practice.

The general conclusion that fertilizer nitrogen uptake is greater from solids than from liquids was upheld by Nowakowski (1961). He compared 4 nitrogen fertilizers (ammonium sulfate, ammonium nitrate, calcium nitrate and urea) for their effects on established and newly sown grass. He found that N uptake was greater where dry forms of the fertilizer were used. Nitrate levels in the grass were also higher from solid fertilizer sources. There were no differences among sources in the amount of dry matter produced.

The effects of using a more complete fertilizer solution as a foliar fertilizer source began to be studied in the mid 1950's. Mederski and Volk (1956) used a 1-2-1 ratio of N-P-K at various rates as a foliar fertilizer source on several field crops: corn, soybeans, alfalfa, sugar beets, oats and wheat. The application to wheat was made when the crop was 20 cm tall. No significant differences were reported in yields of any of the crops. Their conclusion was that foliar fertilization was not a useful supplement to sound fertilizer practices except for special nutritional problems (i.e., some micronutrients) which cannot be solved by fertilizer application to the soil.

Garcia and Hanway (1976) studied the effects of a N-P-K-S solution applied foliarly to soybeans. They found a significant increase in yield, due primarily to an increase in the number of seeds formed. They also found sulfur to be an essential nutrient in the spray solution for a yield response.

Vasilas, et al (1980) applied ^{15}N labeled urea, along with potassium polyphosphate and potassium sulfate to soybeans to supply 84+9+28+5 kg/ha of N-P-K-S for two years. The potassium polyphosphate and potassium sulfate solutions were also applied without urea. Yield differences were

non-significant the first year with either source. The N-P-K-S solution provided a significant yield increase the second year. Of the total ^{15}N applied, 44 and 67% were recovered in the first and second years respectively. Approximately 94% of the recovered ^{15}N was in the seed.

Application of fertilizer solutions to plant leaf surfaces often results in leaf burn, depending on a wide range of environmental conditions. This was noted by Chesnin and Shafer (1953), who found that rate of application and droplet size affected the amount of leaf burn. Increasing the nitrogen rate increased leaf burn (which was predominant along the leaf margins). Also, at all rates, a coarse droplet produced more leaf burn than a fine droplet. Wittwer, et al (1963) commented in a review article on foliar fertilization that "burning of leaf margins could be avoided by applying low volume sprays as a fine mist where there is no coalescing of the droplets on the leaf surfaces or runoff to the tips and margins." This is in reference to foliar application where foliar absorption is the desired goal. Garcia and Hanway (1976) noted that "excessive rates of application at any one spraying can result in serious leaf burn and should be avoided."

Neumann (1979) conducted a laboratory study in which he compared the damaging effects of various fertilizer solutions on leaf tissue by vacuum infiltrating leaf segments with fertilizer solution and then measuring the leakage of UV-absorbing materials into distilled water. Threshold concentrations were established for fertilizer levels which caused membrane damage. He found no evidence for a relationship between onset of membrane damage and pH, molarity, conductivity or osmotic potential of various test solutions.

Yamada, Wittwer and Bukovac (1964) studied the penetration of various ions through isolated cuticles. They found that stomata were not necessary

for cuticular penetration, and the rate of penetration was higher entering the leaf than leaving it. In another laboratory study, Pooviah and Leopold (1976) studied the effects of inorganic salts on tissue permeability. They used CaCl_2 and $(\text{NH}_4)_2\text{SO}_4$ and found the two compounds had opposite effects on leakage of betacyanin from beet root tissue. Calcium decreased the permeability of the membrane, while NH_4^+ increased it. Application of Ca^{++} was also found to reverse the effects of NH_4^+ .

In a field study where ^{15}N labeled urea was applied in a N-P-K-S mix to soybeans, Vasilas, et al (1980) found leaf burn from the fertilizer application to vary significantly from year to year. In the first year of the study, the spray was applied in the afternoon and significant leaf burn resulted. The second year, morning application and irrigation were credited with reducing leaf burn to non-significant levels. In either year, no burning occurred when urea was absent from the fertilizer. The burn noted in the first year of the study was attributed primarily to NH_3 . They conjectured that urea was absorbed into the leaf molecularly intact. Urea hydrolysis may then occur (due to the presence of urease in plant tissue) and subsequent volatilization as NH_3 may result. The amount of NH_3 produced may increase with increasing temperature, resulting in increased leaf burn. This would have been the case in the first year of the study, when the applications were made in the afternoon, when temperatures were warmer.

A field study conducted by Parker and Boswell (1980) examined the effects of foliar fertilization of soybeans. They found yield values to be negatively correlated with visual foliage injury. Correlation coefficients ranged from -.86 to -.89. They felt that injury could be attributed to salt damage, with some salts apparently more phytotoxic than others.

For injury to occur via salt damage, the applied salt must first penetrate the leaf surface and enter the leaf metabolic pathways. An excellent review article (Franke, 1967), discussed the mechanisms of foliar penetration of solutions. He described the pathways by which entry into the leaf are sought at three sites: the cuticle, the cell wall and the plasma membrane. He felt that foliar absorption takes place in 3 stages:

1. Penetration of surface applied substances into the cuticle and cell wall via diffusion, either limited or free.
2. The substances, now in the free space of the cell wall, are adsorbed or bound to the surface of the plasma membrane.
3. The adsorbed substances are taken into the cytoplasm by a process requiring metabolically derived energy.

Several points he discussed are of particular interest:

1. Overall, the cuticle is negatively charged. These charges must first be neutralized by cations. Additional application of cations would then be expected to penetrate the cuticle. The cuticle exhibits a polarity gradient, being primarily apolar at the exterior and highly polar at the interior, near the cell wall. Consequently, the possibility exists of special paths within the cuticle for the penetration of ionic species. Otherwise, the entire leaf surface would be expected to be uniformly interspersed with bound ions.
2. Ectodesmata may play a significant role in penetration of the cell wall. Ectodesmata are fine structures in the outer walls of epidermal cells. They extend from the cuticle through the wall to the lumina of epidermal cells, providing an almost direct

connection between the protoplasts of the cell with the outside of the leaf.

Ectodesmata are predominantly found in special sites, such as along anticlinal walls, at the base of hairs or in epidermal cells surrounding hairs. In studies using stained material as tracers, absorption into the leaf is often limited to areas where absorption proceeds rapidly. Along anticlinal walls and hairs are sites particularly active in absorption. The abundant supply of ectodesmata in these areas may be related to this more rapid absorption. Where anticlinal walls reach the leaf surface, slight depressions form which trap rain, dew or sprays. (Linskens, 1966). Ectodesmata crowd tightly along these anticlinal walls. Also, work has been done demonstrating that binding sites of radioactive ions and urea are lined up along the anticlinal walls. (Yamada, et al, 1966).

3. Penetration of urea and ions applied together with urea through the cuticle exhibits kinetics markedly different from other substances. The penetration of urea exceeds that of ions by 10 to 20 fold, and is independent of concentration. Apparently, urea seems to penetrate by a process of facilitated diffusion, while penetration of ions is determined by their solubility, partition and molecular size. With the exception of urea, the mechanisms of uptake of nutrients by leaves parallels those for roots. (Wittwer and Teubner, 1959). Apparently, non-facilitated diffusion is greatest with cations and least for anions (chloride, phosphate, sulfate). (Wittwer, Bukovac and Tukey, 1963).

Since foliar sprays generally contain both urea and ammonium nitrate, entry into the leaf through the cuticular membrane could be expected to occur quite rapidly (due to the association of the ions with urea). With a spray application of highly concentrated solution, or of a high rate of solution, large amounts of urea and NH_4^+ would be expected to accumulate either in the cell wall free space or at the surface of the plasma membrane. It is at this point that damage most likely occurs. Salt damage, from the hygroscopic effects of the NH_4^+ or other ions present on the plasma membrane, as speculated by Parker and Boswell (1980) would be one possibility. Urea hydrolysis and NH_3 toxicity, as speculated by Vasilas, et al (1980) is another possibility. At any rate, the presence of high concentrations of fertilizer components at this point can be considered damaging to the plasma membrane, resulting in leaf burn.

MATERIALS AND METHODS

1980 Studies

The first year of the study was conducted in 1980. The four fertilizer sources used were:

1. 31-0-0-1.5 clay UAN suspension - (provided by the Tennessee Valley Authority)
2. 24-8-0 suspension - formulated from the base 31-0-0-1.5 suspension, 10-43-0 ammonium polyphosphate clear liquid and tap water
3. 28-0-0-UAN solution - (provided by the Allied Chemical Company)
4. 28-0-0-2S - (provided by the Allied Chemical Company)

Bermudagrass study. Treatments the first year were applied to two crops: an established field of bermudagrass (*Cynodon dactylon*, L.), and a growing crop of winter wheat (*Triticum aestivum*, L., variety "Centurk 78"). Applications were made at two separate dates in the spring, "early" and "late", the actual date depending upon the crop being considered. The early date was selected to provide conditions in which the crop was essentially dormant and climatic conditions which would enhance leaf burn were at a minimum. (Essentially, mild days, cool nights.) The late date was selected for conditions which would maximize leaf burn, and still provide adequate time for the crop to respond to the nitrogen. Conditions conducive to leaf burn were an adequate covering of green, actively growing foliage and hot days.

Treatments were applied at rates of 84 and 168 kg N/ha. Application was made with a constant pressure, tractor-mounted sprayer with a boom width of 3.05 m. Five nozzles were mounted on the boom on 50 cm center spacing. The boom was maintained at a height from 43 cm to 50 cm above the ground. This gave an effective width coverage per plot of 2.5 m.

Two types of nozzles were used to provide different droplet sizes. A Vee-Jet nozzle, produced by Spraying Systems Company, was used to provide a fine droplet - nozzle No. SS8004 was used for the lower rates; nozzle No. SS8006 for the higher rates. A Raindrop nozzle, manufactured by the Delavan Company was used to provide a coarse droplet - nozzle No. RA-2 was used for the low rates, nozzle No. RA-5 for the high rates. Application rates were controlled by a) selection of nozzle, b) selection of boom pressure, and c) selection of ground speed. Application pressures and ground speeds were arrived at using calibration charts provided by Spraying Systems and Delavan, and measured densities of the respective fertilizer materials. A randomized, complete block design with four replications and thirty-three treatments were used. The fixed variables in the study were:

<u>Nitrogen source</u>	31-0-0-1.5 clay
	28-0-0 UAN
	24-8-0 suspension
	28-0-0-2S
<u>Nitrogen rate</u>	84 kg N/ha
	168 kg N/ha
<u>Time of application</u>	Early
	Late
<u>Nozzle</u>	Coarse droplet
	Fine droplet

An unfertilized check was included in each block. Individual plots measured 3.1 m by 9.1 m. Alleys between each block measured 6.1 m. The site chosen for the study was a two year old stand of bermudagrass on the John Carlin farm in Saline County. The site was level to gently sloping, on an Elmo silt loam soil. A complete description of this soil can be found in the appendix.

The early treatment was applied to the bermudagrass on 22 Apr. 1980. Wind conditions were calm, the air temperature was 24 C. Little or no bermuda was actively growing.

The second application was carried out on 9 June 1980. Again, there was no wind and the air temperature was 24 C. At this date, the grass in the study was actively growing, measuring in height approximately 15 to 25 cm. The study was examined four days later, on 13 June, for leaf burn. Each plot was checked for visual differences in leaf burn from the unsprayed checks. No visible leaf burn was evident, and consequently, no leaf burn ratings were assigned.

The study was designed so that the nitrogen rates utilized were not yet at the optimal level for yield production of bermuda. With nitrogen rates only part way up the yield response curve, any differences resulting between the two rates would be emphasized and more clearly reflect the effects of the respective treatments.

The study was harvested 8 July 1980. The air temperature was 40.5 C or 105 F. The bermuda was cut with a Carter flail harvester, which harvested a strip 92 cm wide out of the center of each plot.

The harvested material was blown into a bag which had a known empty weight. In this manner, the total yield from each plot was weighed on a set of milk scales hung from a tripod. A canvas tent was placed around

the tripod to prevent wind from affecting scale measurements. A random sample was taken from each bag following the taking of yield weights and placed in a paper sack. A weight was taken of this sack and its contents with a portable triple beam balance. This sample was returned to the lab where it was dried five days at 65 C. Dry weights of the sack and contents were taken following cooling to room temperature. The moisture of the sample was then calculated. This moisture was used to adjust the wet weight of the total forage harvested from each plot to a dry matter yield in kilograms. Finally, this yield was adjusted to a hectare basis, to give dry matter yield in kilograms per hectare. This sample was saved for analysis for nitrogen and phosphorus content.

Crop growth following harvest was minimal due to the extremely dry summer. The study was examined in mid-September, and regrowth from the clipping height was only 2 to 3 cm. It was not possible to obtain a second harvest.

Wheat study. The wheat study of 1980 was similar to the bermudagrass study in design. The 28-0-0-2S solution, Suran, was not available at the time the plots were laid out in the fall of 1979, consequently not enough room was included for both early and late treatments of this product when the fertilizer was applied to the rest of the field in September. As a result, only late treatments were applied to the Suran plots.

The experimental design was a randomized, complete block design, with four replications and twenty-nine treatments. The fixed variables were the same as in the bermuda study, with the above mentioned exception. Plot dimensions were 2.6 m by 9.15 m, with alleys 6.1 m between blocks. The site selected for this study was at the North Agronomy Farm, Kansas State

University, Manhattan. The site was on a moderate slope, Smolan silt loam soil. A complete description of this soil can be found in the appendix.

The first application date for the wheat was 18 Mar. 1980. Wind speeds were between 32 and 45 km/hr. Air temperature was 8 C. Due to poor planting conditions in the fall, emergence for the majority of the study did not occur until mid-February. At the time of the first application, the stand was very sparse, with plant height no more than 4-5 cm. Four days following fertilizer application, no visual evidence could be seen on sprayed plots of leaf burn. Individual plants, when examined closely, also showed no damage which could be attributed to the spray application. Consequently, no leaf burn ratings were assigned for the first application date.

Growth on the study continued to be sparse through April, and concern arose that, due to the thin stand, differences in leaf burn from the second application date might be difficult to detect and visually rate. In order to compensate for the thin stand, it was decided to delay the second application date as late as possible. This would allow leaf area to increase to the point where differences in leaf burn between plots would be visible, if present. This would, however, delay the nitrogen application to the point where the crop might not be able to show a yield response to nitrogen. However, it was felt that, if possible, some measurement of leaf burn differences should be obtained.

The second application date for the wheat was 15 May 1980. There was little or no wind, and the air temperature was 20 C. The plants in the study site were either at jointing or 4-5 days prior to jointing.

The study was examined five days later, and significant differences were visible among plots in leaf burn. Each plot was assigned a burn rating

according to the visual damage present. The scale used ranged from 1 to 5, with a rating of 1 being equal to little or no burn visible, and a rating of 5 equal to the most severely burned plot in the study. A rating of 5 does not imply that the burn was the most severe possible, rather that that particular plot was the most severely damaged of any plots sprayed. The burn was evident as dead tissue along the leaf margin and tip. The growth of the plants was not severely depressed among any of the plots sprayed, and the study had grown to the point where damage was not visible by 10 days after spraying.

Ten days after the second application date, whole plant samples were taken from each plot, dried, ground and later analyzed in the laboratory for N and P levels.

The study was harvested 30 June 1980. The air temperature was 43 C, or 110 F. Harvest was performed mechanically with a Gleaner "E" model combine modified for plot work. The header width was reduced to 1.95 m in order to harvest only the middle from each plot. The bin elevator was modified to feed grain into a small container while the plot was harvested. The container was weighed on a set of milk scales to obtain the weight of the grain harvested. A small sub-sample was taken from the container for moisture determinations and laboratory analysis for N and P. All plot yields were adjusted to a moisture of 12.5%. The plot weights obtained in the field were later converted to yields in kg grain/ha.

1981 Studies

Because of questions which arose concerning leaf burn during the 1979-80 studies, the basic experiment was continued for a second year. Certain changes were made in the experimental design to better explain the

effects of the fixed factors on leaf burn and yield. One source, the 28-0-0-2S product Suran, was dropped from the study. Two additional checks were included; one to better explain the effects of attapulgite clay on leaf burn, and the other to measure yield response from a dry fertilizer source. The study was again put out on two crops - winter wheat (*Triticum aestivum*, L., variety "Newton"), and tall fescue (*Festuca arundinacea*, Schreb.). Both sites were located at the North Agronomy Farm, Kansas State University, Manhattan. The wheat was located on a level to slightly sloping site on Smolan silt loam soil. The fescue was an established stand situated on Wymore silty clay loam. Complete descriptions of these soils can be found in the appendix.

Wheat study. To better evaluate the effects of attapulgite clay and fertilizer solution on leaf burn and yield, four additional checks were included in the study which were not included in 1979-80. Two checks consisted of ammonium nitrate, applied as dry granules at the early application date, at N rates of 56 kg N/ha and 112 kg N/ha. This allowed the yield response to the added nitrogen alone to be measured, without the influence of any possible negative effect on yield due to leaf burn from sprays. The second check consisted of two treatments where ammonium nitrate was applied as above, at the early application date. At the second, or later, application date, a suspension of 1.5% attapulgite clay and water was sprayed on the plots. This was applied at the same liters per hectare rate as the high rate of liquid fertilizer. This allowed any leaf burn and subsequent yield reduction due solely to attapulgite clay to be measured.

To eliminate one possible variable, the UAN clear liquid was adjusted to a nitrogen content of 31%. In this manner, nitrogen content of the

spray solution was eliminated as a variable in leaf burn, at least from the two nitrogen-only sources.

The study was a randomized, complete block design with 4 replications and 23 treatments. Each plot measured 3.1 m by 9.1 m, with an alley 6.1 m between blocks. The fixed variables in the study were:

<u>N-Source</u>	31-0-0-1.5 clay	UAN suspension
	31-0-0 UAN clear liquid	
	24-8-0 suspension	
<u>N-Rate</u>	56 kg N/ha	
	112 kg N/ha	
<u>Time</u>	Early application	
	Late application	
<u>Nozzle</u>	Coarse droplet	
	Fine droplet	

Since the nitrogen application rates were increased from the 1979-80 studies, only two nozzle types instead of four were necessary to achieve the proper rates. The nozzles used were: for coarse droplets, Raindrop nozzles, RA-4, manufactured by the Delavan Co.; and Vee-Jet nozzles, 8004, manufactured by the Spraying Systems Co., Inc. The application equipment was otherwise the same as described previously.

The early treatment was applied 23 Feb. 1981. Air temperature was 15.5 C, wind speed approximately 24 km/hr. The foliar growth this year was excellent, and much of the spray applied remained on the leaf surfaces of the wheat plants.

The study was examined for leaf burn damage 2 and 7 days after application. No burn was evident across the plots which had been sprayed at

either time, so no leaf burn ratings were assigned. Fertilizer droplets were still visible 2 days later on the leaves of many of the plants which had been sprayed.

The second application date for the wheat was 1 Apr. 1981. There was little or no wind, and the air temperature was 21 C. The tractor used for spray application was driven over all the plots, whether they received a spray application or not. This was done in order to eliminate any variable caused by damage from the tractor tires to the growing plants.

The study was examined 4 days later, and significant leaf burn was evident on some plots. Consequently, a rating was assigned to each plot sprayed according to the severity of damage. The ratings ranged from 0 to 5, depending on the amount of leaf burn. A rating of 0 indicated no burn evident; a rating of 1 indicated little burn evident; and a rating of 5 indicated that that plot received damage as severe as any of the plots sprayed. Ratings of 2, 3 and 4 were given to plots with intermediate damage.

The study continued rapid accumulation of leaf area, and within 10 days no leaf burn was evident when looking across the plot area.

The study was harvested 19 June 1981. The method of harvest was the same as previously described.

Fescue study. Because of space limitations, the fescue study was confined to 3 replications in a randomized, complete block design with 23 treatments. Also, the size of each individual plot was reduced to 2.45 m by 6.1 m, with a 6.1 m alley between blocks. The treatment structure was the same as that previously described for the 1980-81 wheat study.

The first application date was the same as the wheat study, 23 Feb. 1981. The study was examined for leaf burn 2 and 7 days following spray application. No damage could be seen to the few green leaves present, so no burn ratings were assigned.

The second application date for the fescue study was 1 May 1981. Green foliage on the fescue ranged in height from 15 to 30 cm. The study was examined for leaf burn seven days later, and some leaf burn was evident on sprayed plots. Leaf burn ratings from 0 to 5 were assigned, in the same manner as described for the 1980-81 wheat study.

The plots were harvested 1 June 1981, by means of a mechanical flail harvester, the same method as previously described for the 1979-80 bermuda study. A random sample was retained of the forage from each plot for moisture determination and chemical analysis.

Laboratory Analysis

Plant tissue. Leaf tissue was placed in a paper sack and dried in a forced-air dryer at 60 C for five days. The dry tissue was then ground in a self-cleaning Udy rotary-abrasion mill. Seven to ten grams of finely ground tissue was collected and stored in sealed plastic vials. Prior to being weighed out for analysis, the samples were re-dried for 24 hours at 45 C.

A sulfuric digest was performed on the dried tissue following a procedure described by Linder and Harley (1942). A 0.25 g sample of tissue was weighed into a digestion tube and 2 ml of concentrated H_2SO_4 was added. The tubes were placed in a heating block under a fume hood. One milliliter of 30% H_2O_2 was then added to the tube to enhance the speed of digestion, and the tube was heated at 375 C for approximately 45 minutes. The tubes

were allowed to cool; an additional ml of peroxide was added and the tubes reheated. This process was repeated until the digest solution was clear. The solution was diluted to 50 ml with distilled water.

Nitrogen and phosphorus determinations were carried out on the dilute solutions with a Technicon AutoAnalyzer II, a continuous flow, automated system for chemical determinations with a recording spectrophotometer. The nitrogen determinations were based on a colorimetric procedure in which a green color is formed by the reaction of ammonia, sodium nitroprusside, sodium hypochlorite and sodium salicylate in a buffered alkaline medium at a pH of 12.8-13.0. The ammonia-salicylate complex is read at 660 nm on a spectrophotometer (Technicon Industrial Systems, 1977). The phosphorus determination was based on a procedure in which orthophosphate reacts with molybdate and antimony ions followed by reduction with ascorbic acid at an acidic pH. The phosphomolybdenum complex forms a blue color, which was read on the spectrophotometer at 660 nm (Technicon Industrial Systems, 1977).

Grain. Analysis of wheat grain was performed in the same manner as plant tissue. After drying in an oven at 45 C for 24 hours, the grain was ground through the Udy mill and stored in sealed plastic vials. The sample was re-dried for 24 hours at 45 C prior to being weighed out for analysis. The procedure for determination of grain nitrogen and phosphorus was carried out in the same manner previously described. An estimate of the grain protein content was arrived at by multiplying the grain nitrogen percent by a factor of 5.7.

Statistical Analysis

Field data obtained from the 1979-80 wheat and bermuda studies, and the 1980-81 wheat and fescue studies, was analyzed using the Statistical Analysis System (SAS), developed at North Carolina State University. All data was analyzed by analysis of variance (ANOVA). A Fisher's Least Significant Difference (LSD) was calculated at the 5% level of confidence for all factors.

RESULTS AND DISCUSSION

1980 Studies

Wheat study. (Tables 1 and 2.) The primary goal of the field studies was to compare the fertilizer sources used for amount of leaf burn caused, and determine if any resulting leaf burn was detrimental to the final yield of the crop. In these terms, the study was successful in demonstrating a significant difference in the amount of leaf burn caused among fertilizer sources. Leaf burn from the late fertilizer application date was probably reduced by significant rainfall the night following application. Rainfall of 2.2 cm was recorded, commencing 18 hours after completion of application. However, significant differences in leaf burn were still recorded. The 31% UAN suspension caused a mean leaf burn rating of 3.25, while the 28% UAN solution and the 28-0-0-2S solution caused significantly less leaf burn, with burn ratings of 2.63 and 2.69 respectively. (Mean leaf burn values are averaged over N-rate and droplet size.) The 24-8-0 suspension caused even less leaf burn, with a mean burn rating of 2.00. This was significantly less than any of the other sources.

Grain yield differences among fertilizer sources were non-significant. There was also no correlation between leaf burn and grain yield. Yields were reduced in this study due to several factors. The site was seeded late (29 Oct.). The site received 5.7 cm rainfall the following day, resulting in severe compaction and erosion. The result was poor emergence of the wheat seedlings and a low plant population going into the winter.

Table 1. 1980 WHEAT STUDY

TRT	N-Source ¹	N-Rate kg N/ha	Time ²	Nozzle ³	Yield kg/ha	Leaf Burn	Prot.	% P
1	Check	--	---	---	1861	--	15.2	.398
2	31-0-0 C	90	E	C	1599	--	16.0	.402
3	"	90	E	F	1700		16.5	.406
4	"	90	L	C	1284	2.50	15.9	.391
5	"	90	L	F	1230	4.00	15.9	.385
6	"	45	E	C	1418		15.8	.399
7	"	45	E	F	1519		15.4	.389
8	"	45	L	C	1324	4.25	15.7	.396
9	"	45	L	F	1169	2.25	15.8	.414
10	28-0-0 L	90	E	C	1331		16.4	.398
11	"	90	E	F	1680		16.0	.398
12	"	90	L	C	1351	3.00	16.1	.389
13	"	90	L	F	1519	3.25	16.0	.393
14	"	45	E	C	1707		15.3	.402
15	"	45	E	F	1875		15.2	.397
16	"	45	L	C	948	1.75	15.8	.393
17	"	45	L	F	1492	2.50	15.9	.409
18	24-8-0 C	90	E	C	1492		16.5	.391
19	"	90	E	F	1337		15.5	.384
20	"	90	L	C	1478	1.25	16.0	.400
21	"	90	L	F	1371	3.00	15.9	.407
22	"	45	E	C	1431		16.2	.375
23	"	45	E	F	1579		15.0	.400
24	"	45	L	C	1485	1.75	15.9	.406
25	"	45	L	F	1512	2.00	15.3	.401
26	28-0-0-2S	90	L	C	1230	2.50	15.6	.388
27	"	90	L	F	1519	3.50	16.1	.413
28	"	45	L	C	1324	3.00	16.0	.393
29	"	45	L	F	1337	1.75	15.2	.404
LSD(.05)					356	0.60	0.4	.016

¹ 31-0-0 C = 31% UAN Suspension
 28-0-0 L = 28% UAN Solution
 24-8-0 C = 24-8-0 Suspension formulated from 31-0-0 C and 10-34-0
 28-0-0-2S = 28% UAN Solution with 2% Sulfur

² E = Early Application
 L = Late Application

³ C = Coarse Droplet Nozzle
 F = Fine Droplet Nozzle

Table 2. 1980 WHEAT STUDY

MEAN VALUES	Yield kg/ha	Leaf Burn	Prot.	% P
<u>N-Source</u>				
31-0-0 C	1414	3.25	15.9	.398
28-0-0 L	1478	2.63	15.9	.397
24-8-0 C	1465	2.00	15.8	.395
28-0-0-2S	1364	2.69	15.8	.400
LSD(.05)	NS	.44	NS	NS
<u>N-Rate</u>				
45 kg N/ha	1431	2.41	15.6	.399
90 kg N/ha	1445	2.88	16.0	.396
LSD(.05)	NS	0.31	0.3	NS
<u>Application Date</u>				
Early	1552	----	15.8	.395
Late	1351	----	15.8	.399
LSD(.05)	155	----	NS	NS
<u>Droplet Size</u>				
Coarse	1391	2.50	16.0	.394
Fine	1485	2.78	15.7	.400
LSD(.05)	NS	NS	NS	.005

In fact, many of the seedlings did not emerge until warm weather in February. In April and May, moisture became limiting, and moisture stress during this period further reduced yields. The result of these conditions were grain yields 300 to 900 kg/ha below the average yield for the state of Kansas. These yield reducing factors may have masked any yield reduction due to leaf burn. There were no other significant effects due to fertilizer source.

The early date of application, as might be expected, gave a significant increase in grain yield over the late application. The late application was delayed until jointing, so a yield response would not be considered likely. As mentioned before, the late application was delayed until sufficient leaf area was present to allow maximum leaf burn differences to be manifested. The late application might be expected to increase the grain protein content, but this was not the case. Late application did show a trend towards increasing the tissue nitrogen and phosphorus contents.

The only significant effects due to rate of application were an increase in grain protein content and leaf burn with the higher application rate of 90 kg N/ha. Nitrogen apparently was not a factor in limiting yields, since the 45 kg N/ha rate yielded 1431 kg/ha; the 90 kg N/ha rate yielded 1445 kg/ha; and the unfertilized check yielded 1861 kg/ha.

There was a significant increase in grain phosphorus content due to the fine droplet nozzle. All other effects were non-significant. There was a trend, however, to both increased yield and increased leaf burn with the fine droplet nozzle. One factor noted at the time of application was that the larger droplets formed by the coarse droplet nozzle (the Raindrop nozzle) would roll off the leaf surface to the soil below. The smaller droplets formed by the fine droplet nozzle (the Vee-Jet nozzle) were more

likely to remain on the leaf surface or roll down into the whorl of the plant. Consequently, it may have been that more of the solution sprayed with the fine droplet nozzle remained on the leaf surfaces of the plant, resulting in greater leaf burn. This would mean that increased leaf burn due to the fine droplet nozzle was due, not so much to the actual size of the droplet at the point of contact with the leaf, but to the proportion of solution sprayed which remained on the leaf surface.

Photographs of the droplets produced by the two types of nozzles used are shown in Figures 1 and 2. The spray patterns were reproduced by spraying one pass of one nozzle over a black plastic sheet. The droplets produced were then photographed at a 1:2 reproduction ratio, then enlarged to approximately a 4:1 reproduction ratio. As is illustrated in the photographs, the droplets produced by the fine droplet nozzle are smaller and more uniformly spread over the entire surface. This would increase the leaf area contacted by the spray solution, and increase foliar uptake of the solution.

One other comparison made in this study was between 28% UAN and 28% UAN containing 2% sulfur, Suran. There were no significant differences in any of the main effects due to the presence of 2% sulfur.

Bermudagrass study. (Tables 3 and 4.) The treatment variables in the bermudagrass study were the same as the 1980 wheat study, with the exception of the Suran treatments, which were applied at both the early and late treatment dates.

Due to the heavy thatch remaining from the previous year's crop, no leaf burn measurements were able to be taken at either the early or late application dates. Some leaf burn may have occurred at the late date, since actively growing green plant material was present, but hidden by the dense

Fig. 1 Droplet size, spray pattern produced by fine spray nozzles

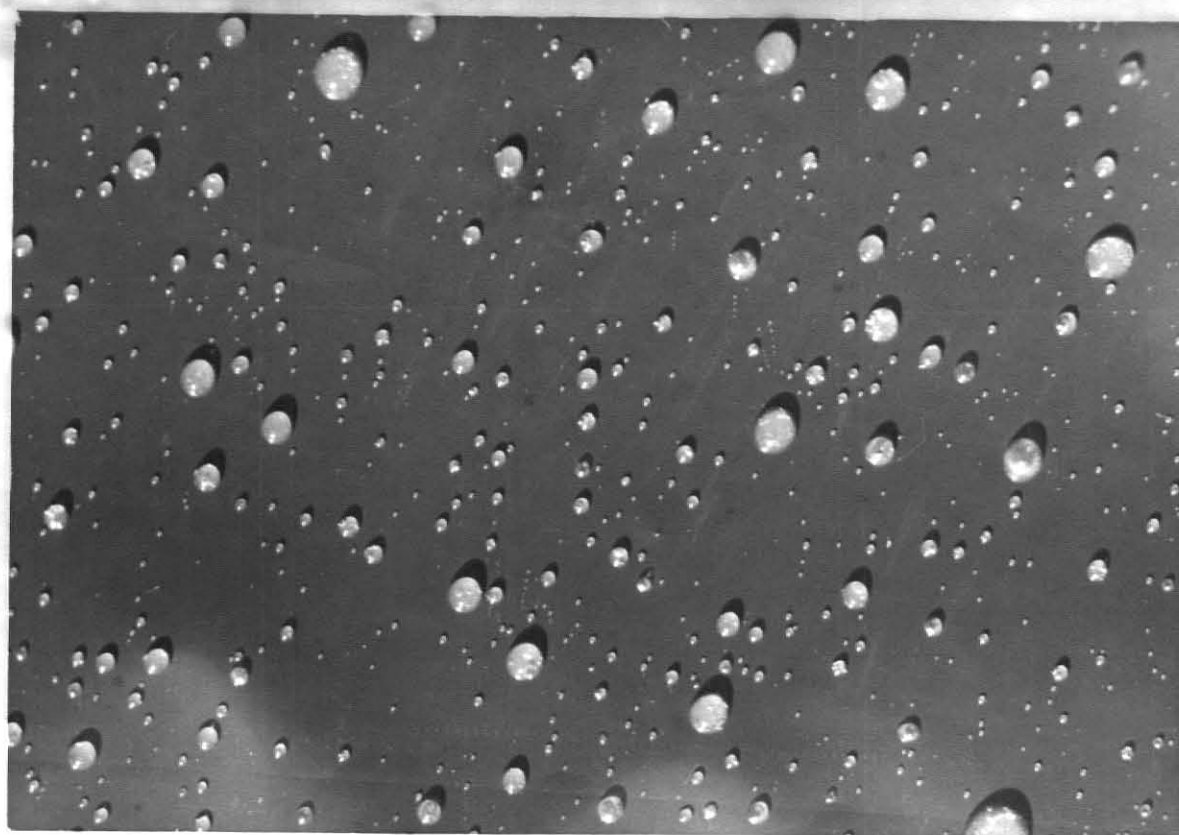
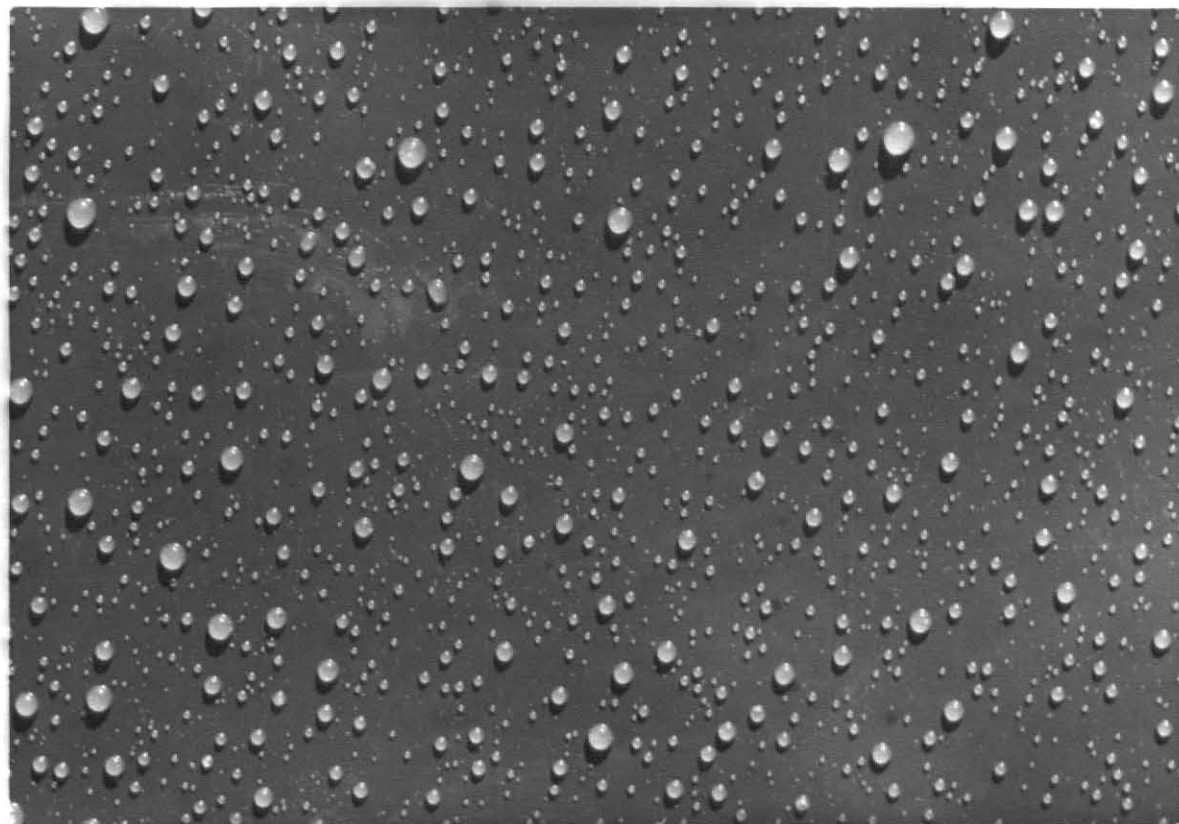


Fig. 2 Droplet size, spray pattern produced by coarse spray nozzles

Table 3. 1980 BERMUDAGRASS STUDY

TRT	N-Source ¹	N-Rate kg N/ha	Time ²	Nozzle ³	Yield kg/ha	% N	% P
1	Check	---	---	---	10160	1.37	.169
2	31-0-0 C	168	E	C	10255	1.35	.189
3	"	168	E	F	10908	1.52	.207
4	"	168	L	C	9905	1.44	.193
5	"	168	L	F	8140	1.14	.185
6	"	84	E	C	8464	1.25	.181
7	"	84	E	F	7877	1.30	.167
8	"	84	L	C	7388	1.41	.195
9	"	84	L	F	7968	1.52	.181
10	28-0-0 L	168	E	C	6615	1.38	.182
11	"	168	E	F	7017	1.50	.170
12	"	168	L	C	9885	1.28	.166
13	"	168	L	F	7513	1.51	.166
14	"	84	E	C	8760	1.40	.178
15	"	84	E	F	7544	1.36	.198
16	"	84	L	C	9640	1.41	.170
17	"	84	L	F	8273	1.57	.170
18	24-8-0 C	168	E	C	8066	1.33	.171
19	"	168	E	F	8105	1.46	.180
20	"	168	L	C	7162	1.32	.184
21	"	168	L	F	7858	1.10	.180
22	"	84	E	C	9210	1.28	.178
23	"	84	E	F	9813	1.36	.210
24	"	84	L	C	8410	1.57	.193
25	"	84	L	F	10087	1.47	.186
26	28-0-0-2S	168	E	C	7473	1.22	.185
27	"	168	E	F	8521	1.24	.184
28	"	168	L	C	8001	1.16	.181
29	"	168	L	F	8501	1.88	.183
30	"	84	E	C	7013	1.09	.175
31	"	84	E	F	8653	1.32	.171
32	"	84	L	C	6922	1.20	.172
33	"	84	L	F	10466	1.33	.168
LSD(.05)					1935	0.22	.020

¹31-0-0 C = 31% UAN Suspension

28-0-0 L = 28% UAN Solution

24-8-0 C = 24-8-0 Suspension formulated from 31-0-0 C and 10-34-0

28-0-0-2S = 28% UAN Solution with 2% Sulfur

²E = Early Application

L = Late Application

³C = Coarse Droplet Nozzle

F = Fine Droplet Nozzle

Table 4. 1980 BERMUDAGRASS STUDY

MEAN VALUES	Yield kg/ha	% N	% P
<u>N-Source</u>			
31-0-0 C	8863	1.36	.187
28-0-0 L	8156	1.43	.175
24-8-0 C	8589	1.36	.185
28-0-0-2S	8194	1.30	.177
LSD(.05)	NS	0.12	NS
<u>N-Rate</u>			
84 kg N/ha	8530	1.37	.181
168 kg N/ha	8370	1.36	.181
LSD(.05)	NS	NS	NS
<u>Application Time</u>			
Early	8393	1.33	.183
Late	8508	1.39	.179
LSD(.05)	NS	NS	NS
<u>Droplet Size</u>			
Coarse	8323	1.32	.181
Fine	8578	1.41	.181
LSD(.05)	NS	0.09	NS

thatch above. Consequently, no visual burn was evident when the plots were surveyed following application. Also, no browning of leaf margins or tips or spot burning at the site of droplet impact were found on individual green leaves which were examined in the plots sprayed.

Yields were substantially reduced by what turned out to be one of the driest and hottest summers of record for Kansas. The following rainfall data, collected at the Salina airport, which was approximately two miles from the site of the study, reflects the difference between the summer of 1980 and the 25 year average rainfall during the period in which bermuda would be actively growing.

Table 5. COMPARISON OF 1980 RAINFALL AND 25-YEAR AVG. RAINFALL

	1980 Rainfall (cm)	Avg. Rainfall (cm)
April	3.20	6.53
May	3.86	9.53
June	0.48	11.81
July	2.77	8.53
August	8.92	7.72
September	0.48	9.42
Total	19.71	53.54

A deficit of almost 34 cm of rainfall during the growing season was received. This deficit was coupled with temperatures which more often than not exceeded 38 C (100 F), during the month of July. Consequently, visible crop response to the fertilizer treatments were negligible.

The only significant differences found among the main effects were among the fertilizer sources. The 28% UAN solution gave a significantly higher tissue nitrogen content than the other sources. This effect probably relates back to the dry matter yield of the 28% UAN treatments, which

was lowest of the four sources, although not significantly so. The higher N content of the dry matter from the 28% UAN treated plots is probably due to the concentrating effect of the tissue nitrogen not being diluted through increased yield, while the low phosphorus uptake could also be related to the fact that not as much dry matter yield was present in the plots treated with 28% UAN.

Any other effects which might have been present due to the main variables were either reduced or masked due to the moisture stress placed on the crop in late May and June. Because of the dry weather, the bermudagrass was only harvested once.

1981 Studies

Wheat study. (Tables 6 and 7.) Upon examination of the data from the 1980 wheat study, it was found that there were several effects which could not be fully explained, due to the design of the experiment. It was not clear whether the increased leaf burn noted from the 31% UAN suspension was due to nitrogen content, clay content or some other factor, such as pH or lack of phosphorus in the spray. Also, if yield was reduced due to the late application, it was unclear whether this was due to the resulting leaf burn or simply lack of time for the crop to respond to the fertilizer. Consequently, modifications were made to the 1981 study to, hopefully, answer these questions.

The stand going into the winter was excellent in the 1981 study. The winter was relatively mild, with adequate moisture until mid-April. A period of 3-4 weeks was experienced in late April and early May where rainfall was limited, and the wheat plants were subjected to moisture stress for a short duration. Water stress at this time may have reduced the

Table 6. 1981 WHEAT STUDY

TRT	N-Source ¹	N-Rate kg N/ha	Time ²	Nozzle ³	Yield kg/ha	Leaf Burn	Prot.	% P
1	Check	---	---	---	2412		11.9	.394
2	Amm. Nit.	56	E	---	2735		13.8	.387
3	"	112	E	---	2675		16.3	.342
4	Amm.Nit.+Clay	56	E,L	---	2755	0	13.4	.337
5	"	112	E,L	---	2688	0	16.7	.380
6	31-0-0 C	56	E	C	2547		14.8	.335
7	"	112	E	C	2937		16.5	.383
8	"	56	L	C	2648	2.00	14.3	.302
9	"	56	L	F	2493	3.25	14.9	.317
10	"	112	L	C	2560	2.75	17.2	.388
11	"	112	L	F	2486	4.25	16.6	.328
12	31-0-0 L	56	E	C	2648		13.8	.317
13	"	112	E	C	2507		16.7	.342
14	"	56	L	C	2755	2.25	15.4	.362
15	"	56	L	F	2520	2.25	15.2	.338
16	"	112	L	C	2500	2.75	15.7	.326
17	"	112	L	F	2574	3.50	16.1	.357
18	24-8-0 C	56	E	C	2715		14.3	.361
19	"	112	E	C	2399		16.8	.361
20	"	56	L	C	2600	1.75	14.3	.354
21	"	56	L	F	2668	2.50	14.2	.308
22	"	112	L	C	2520	2.25	16.1	.334
23	"	112	L	F	2513	4.25	15.9	.334
LSD(.05)					457	0.80	1.55	.076

¹ Amm. Nit. = Ammonium Nitrate
 Amm. Nit. + Clay = Ammonium Nitrate + 1.5% Attapulgite Clay
 31-0-0 C = 31% N UAN Suspension
 31-0-0 L = 31% N UAN Solution
 24-8-0 C = 24-8-0 Suspension formulated from 31-0-0 C and 10-34-0

² E = Early Application
 L = Late Application

³ C = Coarse Droplet Nozzle
 F = Fine Droplet Nozzle

Table 7. 1981 WHEAT STUDY

MEAN VALUES	Yield kg/ha	Leaf Burn	Prot.	% P
<u>N-Source</u>				
Ammonium Nitrate	2708	----	15.0	.364
Ammonium Nitrate + Clay	2722	0.00	15.0	.358
31-0-0 Clay	2614	3.06	15.7	.342
31-0-0 Liquid	2587	2.69	15.3	.340
24-8-0 Clay	2567	2.69	15.5	.342
LSD(.05)	NS	0.46	NS	NS
<u>N-Rate</u>				
56 kg N/ha	2648	2.00	14.4	.338
112 kg N/ha	2580	2.82	16.4	.353
LSD(.05)	NS	0.37	0.6	NS
<u>Application Date</u>				
Early	2648		15.4	.353
Late	2594		15.4	.340
LSD(.05)	NS		NS	NS
<u>Droplet Size</u>				
None	2715	0.00	15.0	.361
Coarse	2614	2.29	15.5	.347
Fine	2540	3.33	15.5	.331
LSD(.05)	NS	0.37	NS	NS

number and size of the grains in the heads and, consequently, reduced yields. However, grain yields in this study were far superior to the previous year, and above the average yield for the state.

There were no significant grain yield differences among any of the fertilizer sources, and no correlation between the yield and degree of leaf burn. There was a trend toward higher yields from the early applied dry treatments, compared to the fluid treatments. One possible explanation might be NH_3 volatilization from the fluids. There were no significant differences in grain protein or phosphorus content among fertilizer sources.

Time of application had no significant effect on yield, although the early application date did trend toward increasing yield over the late date.

There was no significant effect on yield due to nitrogen rate. The higher application rate (112 kg N/ha) did significantly increase the grain protein content from 14.4% for the 56 kg N/ha rate up to 16.4% at the high rate.

Droplet size had no effect on yield, grain protein or phosphorus content.

Amount of leaf burn was significantly affected by all variables (with the exception of time, for which leaf burn was not statistically considered as a factor). Fine droplet size and the high rate of application both significantly increased leaf burn. The 31% UAN suspension caused a significantly higher amount of leaf burn than did either of the other fluid sources, 31% UAN solution and 24-8-0 suspension, which had identical burn ratings. There was no leaf burn caused by spraying the 1.5% attapulgate clay suspension on plots already fertilized with ammonium nitrate.

Although no leaf burn ratings were taken for the early application date, some interesting observations were made in the 2 to 5 day period following application. The day following application, the plots were examined. It was found that most of the fertilizer material which had lodged on the wheat plants, either in the whorl or on the leaf, still remained in a liquid form on the leaf surface. This condition lasted for at least 3 days following application. Temperatures remained mild (in the range 8-16 C) with little or no wind throughout the period. Characteristic plants were noted and flagged for each treatment, and watched for several days. For at least 3 days following application, droplets of fertilizer remained on the leaf surfaces. Apparently atmospheric conditions were such that the droplets were not blown from the leaf or dessicated, and the cutin on the leaf prevented the material from entering the leaf. In only one instance was any leaf burn found associated with these droplets. In this case, a droplet (approximately 3 mm in diameter) caused a circle of burned tissue which extended another 3 mm out from the droplet. (The droplet had been produced with the fine droplet nozzle, and was much larger than a droplet normally produced by this nozzle. Possibly it was the end result of several drops running together.) After 3-4 days the size of the drop had diminished, and the spot of leaf burn had expanded somewhat. After 5-6 days, the droplet had disappeared, along with the majority of the other fertilizer drops which had been marked. (By this time, the wind had picked up somewhat during the day, and a light dew was noted on a couple of mornings.) The leaf containing the burn spot continued to grow normally, and eventually senesced naturally as the plant matured. No other leaves with such burn spots could be found, although it is hardly likely that this was a unique incident. In an earlier greenhouse study to evaluate the effects

Fig. 3 Fertilizer droplets on wheat leaf



Fig. 4 Tractor-mounted application equipment



Fig. 5 Typical leaf burn pattern from late application date

of droplet size on leaf burn, the same fertilizer sources were sprayed on seedling corn plants. In most cases, the droplets which remained on the leaf surface or in the whorl caused a spot of dead tissue to form. This type of burn did not appear detrimental to the damaged leaf or the plant as a whole, except in isolated cases where enough fertilizer material lodged in the whorl to cause severe damage and deformation to newly emerging leaves. There were no apparent differences in the degree of spot damage to the leaves due to droplet size or fertilizer source.

One other point of interest was noted from the early application date. In a few instances salt crystals from the two 31% UAN sources were found on the soil surface where a droplet had landed and been absorbed into the soil. Fertilizer deposits had then recrystallized at the soil surface.

Leaf burn for the second application date was entirely different from that described earlier. In both years of study, leaf burn from the second application date was a scorching of the leaf margin and tip. No droplets could be found on the leaf surfaces 2 days after application, and no instances of burn at the droplet impact site were found. Apparently, the leaf burn that occurred resulted from the fertilizer materials being absorbed into and translocated through the leaf.

The burned leaves soon grew out of the damage, with the dead part of the leaf sloughing off and the leaf eventually senescing as the plant matured.

Fescue study. (Tables 8 and 9.) Modifications to the study in 1981 were the same as those previously described for the wheat study. The same N rates as the wheat study, 56 and 112 kg N/ha, were used for the fescue study. The one modification to the study, as previously described, was to

Table 8. 1981 FESCUE STUDY

TRT	N-Source ¹	N-Rate kg N/ha	Time ²	Nozzle ³	Yield kg/ha	Leaf Burn	% N	% P
1	Check	---	---	---	3875		1.32	.187
2	Amm.Nit.	56	E	---	5096		1.67	.134
3	"	112	E	---	6125		1.47	.163
4	Amm.Nit.+Clay	56	E,L	---	5123	0.00	1.27	.166
5	"	112	E,L	---	6369	0.00	1.77	.148
6	31-0-0 C	56	E	C	4879		1.24	.159
7	"	112	E	C	5638		1.45	.154
8	"	56	L	C	4337	2.00	1.59	.155
9	"	56	L	F	4743	2.00	1.49	.146
10	"	112	L	C	4852	3.33	2.04	.147
11	"	112	L	F	5367	4.33	1.86	.141
12	31-0-0 L	56	E	C	4445		1.43	.116
13	"	112	E	C	5800		1.67	.179
14	"	56	L	C	5150	1.67	1.76	.157
15	"	56	L	F	4932	1.00	1.67	.284
16	"	112	L	C	5339	2.67	1.81	.147
17	"	112	L	F	5990	2.67	1.94	.184
18	24-8-0 C	56	E	C	3930		1.23	.187
19	"	112	E	C	5881		1.41	.167
20	"	56	L	C	4337	2.00	1.72	.194
21	"	56	L	F	3848	2.00	1.38	.154
22	"	112	L	C	5394	2.33	2.27	.205
23	"	112	L	F	5068	2.33	1.77	.234
LSD(.05)					1241	1.32	0.45	.070

¹Amm. Nit. = Ammonium Nitrate
 Amm. Nit. + Clay = Ammonium Nitrate + 1.5% Attapulgate Clay
 31-0-0 C = 31% N UAN Suspension
 31-0-0 L = 31% N UAN Solution
 24-8-0 C = 24-8-0 Suspension formulated from 31-0-0 C and 10-34-0

²E = Early Application
 L = Late Application

³C = Coarse Droplet Nozzle
 F = Fine Droplet Nozzle

Table 9. 1981 FESCUE STUDY

MEAN VALUES	Yield kg/ha	Leaf Burn	% N	% P
<u>N-Source</u>				
Ammonium Nitrate	5610		1.57	.149
Ammonium Nitrate + Clay	5746	0.00	1.52	.156
31-0-0 Clay	4969	2.92	1.61	.150
31-0-0 Liquid	5344	2.00	1.71	.178
24-8-0 Clay	4743	2.16	1.63	.190
LSD(.05)	893	0.67	NS	NS
<u>N-Rate</u>				
56 kg N/ha	4511	1.78	1.50	.173
112 kg N/ha	4894	2.94	1.80	.173
LSD(.05)	482	0.55	0.16	NS
<u>Application Date</u>				
Early	5096		1.40	.160
Late	4947		1.78	.179
LSD(.05)	NS		0.16	NS
<u>Droplet Size</u>				
None	5677	0.00	1.69	.191
Coarse	4901	2.33	1.87	.168
Fine	4992	2.39	1.69	.191
LSD(.05)	NS	NS	NS	NS

eliminate one replication (to 3 replications) and reduce the plot size slightly due to space limitations.

The site used had been in tall fescue for several years and had a good stand of grass from the previous year. Fairly dense thatch covered the soil surface from the previous year. The first fertilizer application was applied the same day as the wheat study, and subsequently examined on the same schedule. No leaf burn was evident on the plots 4 days following application. Also, no evidence of droplets remaining on green leaf surfaces was found, as in the wheat study. Grayish deposits from the 24-8-0 suspension were found on the covering thatch material and on green plant material and the soil surface beneath the thatch. Deposits from the other fertilizer sources could not be found.

Leaf burn resulting from the second application date was of the same type as previously noted on the wheat - scorching of the leaf tip and margins, with no evidence of burn at the site of droplet impact.

Mean leaf burn ratings of the main factors showed basically the same results as the wheat study. There was significantly greater burn caused by the 31% UAN suspension than the other two fluid sources, and significantly greater burn at the 112 kg N/ha application rate. The only difference between the two studies regarding leaf burn was that there was not a significant difference in leaf burn according to droplet size in the fescue study.

There were some significant yield differences in the fescue study. As in the wheat study, the ammonium nitrate treatments tended to yield higher, with the ammonium nitrate plus attapulgit clay treatments significantly higher in dry matter yield than the 24-8-0 suspension treatments. There were no other significant differences in yield due to fertilizer source.

There were also significant increases in dry matter yield and tissue nitrogen content at the 112 kg N/ha rate compared to the 56 kg N/ha rate, and a significant increase in tissue N content at the late application date, compared to the early application date. These three effects have been demonstrated before, and are the expected result when topdressing nitrogen to fescue.

SUMMARY AND CONCLUSIONS

The primary purpose for these studies was to compare 31% UAN suspension against UAN solution in terms of yield and leaf burn caused by the spray application of these materials to growing crops. In the two years of studies conducted on wheat and one year each on bermuda and fescue, no yield differences were found between these two sources. There were no yield differences due to either of the other fluid sources studied - 24-8-0 suspension and 28-0-0-2S.

Differences which were seen in these studies were the expected results, which have been well documented - better yield response with early application, higher protein content with late application, increased yield and protein content with increased nitrogen rate. All of these responses are well understood.

The effects of various factors on leaf burn were clearly seen in this study, but a better understanding of why these effects occur was not obtained. In all three studies in which leaf burn ratings were taken, the 31% UAN suspension caused significantly more leaf burn than the other sources. Admittedly, these ratings were not quantitative in nature. However, the ratings were assigned without bias, with no knowledge of the plot plan, and consequently the differences seen must be considered significant. Although the cause for increased leaf burn from the 31% UAN suspension was not found, some factors were ruled out. These were:

1. Attapulgate clay - The studies conducted the second year contained treatments where a water suspension with 1.5% attapulgate clay was sprayed onto plots already fertilized with dry ammonium nitrate. No leaf burn was found on these plots.
2. Nitrogen content - In the second year of the studies, the UAN solution contained the same nitrogen content as the UAN suspension - 31%. Significant differences in leaf burn were still noted.

One factor which may have influenced leaf burn, but which could not be evaluated in the field, was pH. (pH's of the materials used in these studies can be found in the appendix.) The pH of the 31% UAN suspension was higher than that of any of the other fertilizer sources. This was probably not a factor directly, since the water + clay suspension actually had the highest pH of any of the materials, 8.0. The higher pH material could become critical once the urea-containing spray was applied to the leaf surface. Once urea hydrolysis commences (due to the presence of urease in the leaf tissue) the NH_4OH concentration at the site of application would increase, elevating the solution pH. In a solution of already elevated pH, the pH where significant NH_3 volatilization could occur would be reached sooner. Leaf tissue damage from high NH_3 concentration could be the result.

Two years of field application data was felt to be adequate to illustrate the general trend, but that deeper insights into the problem cannot be achieved through field application studies. More detailed growth chamber and laboratory studies are needed to accurately describe the reactions taking place.

The results of the droplet size comparison were fairly clear cut, although significant differences were not always seen between the two

nozzles. Apparently, the larger, heavier droplets formed by the Raindrop nozzle roll off the leaf surface more easily than the droplets formed by the Vee-Jet nozzle. The droplets formed by this nozzle are small enough to become trapped in ridges formed along the midrib of the leaf, and remain on the leaf surface. Since more of the spray applied with the fine droplet nozzle remains on the leaf surface, more of the spray is absorbed directly into the leaf. A higher degree of leaf burn is the result.

Crop yield differences in all studies were non-significant among the fluid materials. There were substantial leaf burn differences. There was no statistical correlation between yield and leaf burn. Consequently, it appears, from within the confines of these studies, that degree of leaf burn had no effect on yield. It is possible, however, that the presence of even a slight amount of burn might reduce yield. In the studies conducted the second year, dry ammonium nitrate was applied as a check. In the fescue study, plots receiving ammonium nitrate yielded significantly higher than plots receiving fluid materials. A trend in this same direction was seen in the wheat study.

At first inspection, it might appear that leaf burn, which was found on all fluid treatments, is the cause of the yield differences. However, the fluid sources all contained urea, and could be subject to NH_3 volatilization, thus reducing the efficiency of the fertilizer. The ammonium nitrate source is not subject to volatilization of NH_3 , when applied to acid soils. Consequently, the yield differences between dry and fluid sources could be due to leaf burn, or it could be due to NH_3 volatilization or some other means of loss which was more pronounced with the fluid sources. On hindsight, it probably would have been better to use urea as a

dry source, or include both urea and ammonium nitrate, in order to estimate any reduction in fertilizer efficiency due to NH_3 volatilization.

EFFECTS OF SOIL BUFFERING CAPACITY
ON NH_3 VOLATILIZATION FROM SURFACE APPLIED UREA

INTRODUCTION

The use of urea as a fertilizer source is increasing rapidly for a number of reasons, among them is its use in bulk blends and nitrogen solutions, and its ease of handling for direct applications (Tisdale and Nelson, 1975). It is not corrosive to handling equipment, and it is not nearly as susceptible to caking in bulk storage as other nitrogen products. During the 10 year period from 1970 to 1980, the nation-wide use of dry urea has increased almost four-fold, to a rate of 2,071,792 tons in 1980, while the use of ammonium nitrate has declined during the same period. Only nitrogen solutions, which contain urea, and anhydrous ammonia have increased more in tonnage used during that period. (Hargett and Berry, 1980).

To be useful as a source of nitrogen for growing plants, urea must first be hydrolyzed through the action of the enzyme urease. The end product of this hydrolysis is ammonia, or ammonium, depending upon the state of the system. Since it is a positively charged compound ion, ammonium is held on the base exchange complex of the soil and is not susceptible to leaching. It remains in this state until acted upon by nitrifying bacteria, Nitrosomonas and Nitrobacter. The nitrates finally formed are susceptible to leaching, but are also useable by the crop as a nutrient.

Ammonia, on the other hand, is not a charged particle and depending on various climatic factors, can be volatilized into the atmosphere. The loss of ammonia by volatilization is the most serious drawback to the use

of urea as a fertilizer source. Depending on the environmental conditions, up to 50% or more of the nitrogen applied can be lost to the atmosphere when urea is applied to the soil surface. This greatly reduces the efficiency of urea as a fertilizer and can be a substantial loss to the grower.

Because of the advantages urea has as a source of fertilizer nitrogen, a great deal of work has been done examining NH_3 volatilization from urea, in order to better understand the processes involved and, hopefully, develop methods by which NH_3 losses can be reduced.

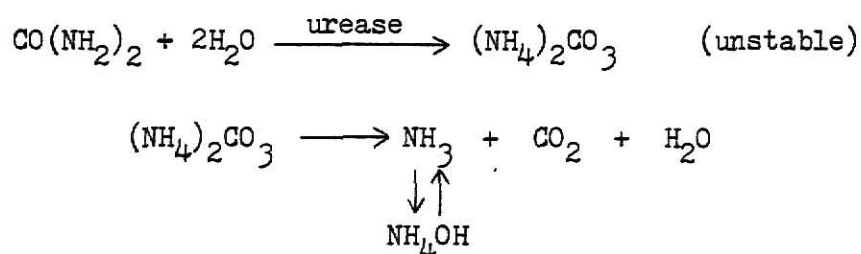
OBJECTIVE

To demonstrate the effect of soil buffering capacity on NH_3 volatilization from surface-applied urea.

LITERATURE REVIEW

The volatilization of ammonia from soils has been recognized as a potential source of substantial loss of nitrogen since the mid-1940's. (Jewitt, 1942; and Steenbjerg, 1947) Since then the processes involved have become better understood as many workers have studied the various factors affecting ammonia volatilization.

The soil reactions of urea in an acid or neutral pH soil can be described as follows:



The amount of NH_3 lost to the atmosphere is dependent on a wide variety of environmental factors in the soil and atmosphere. A discussion of the factors follows.

Soil Moisture

Jewitt (1942) found that soil moisture had little effect on NH_3 volatilization rate until air dry conditions were reached. These findings were upheld by Martin and Chapman (1951) and Gasser (1964). Other workers have found that declining soil moisture levels increase NH_3 volatilization (Trickey and Smith, 1955; Fenn and Escarzaga, 1976; and Prasad, 1976).

Mitsui, Ozaki and Moriyama (1954) found that NH_3 volatilization increased with waterlogged conditions, while Delaune and Patrick (1970) found NH_3 volatilization to be somewhat greater at 1/3 bar than under waterlogged conditions. Several workers have found that moisture loss from the soil enhances NH_3 volatilization (Lyster, O'Toole and Morgan, 1979; Kresge and Satchell, 1959; and Ernst and Massey, 1960). Chao and Kroontje (1964) found that rate of NH_3 volatilization and rate of water evaporation were not related; NH_3 loss decreased with time, while water loss remained constant. This relationship was not affected by the humidity of the air flowing across the soil surface.

Application Rate

Early workers studying the effects of application rate found that percent loss was not appreciably affected by application rate. (Martin and Chapman, 1951). The total loss from surface applied ammonium nitrate and ammonium sulfate was greater with higher application rates, but percent loss was not changed appreciably. Later workers have found, however, that higher application rates, particularly with urea, result in a higher percentage loss. (Kresge and Satchell, 1959; Simpson and Melsted, 1962; Overrein and Moe, 1967; Overrein, 1968; and Lyster, O'Toole and Morgan, 1979).

Chao and Kroontje (1964) found a linear relationship between the amount of NH_3 lost and the amount of NH_3 applied. Fenn and Kissel (1976) found that increasing application rates of $(\text{NH}_4)_2\text{SO}_4$ increased the initial soil pH and also increased percent NH_3 lost, while increasing application rates of NH_4NO_3 reduced the soil pH and reduced the percent NH_3 lost.

Urea Hydrolysis Rate

Some of the earliest work measuring urea hydrolysis rate was done by Gibson (1930). He found urea to hydrolyze readily and generally rapidly in 59 soils of varied character. Simpson and Melsted (1962) found that a 2 to 3 day lag existed between the time of urea application on plant foliage and significant NH_3 loss. They found the greatest amount of urea hydrolysis occurred during this period, as measured by the evolution of $^{14}\text{CO}_2$. Later work by Simpson and Melsted (1963) indicated that an increase in both temperature and pH increased the urea hydrolysis rate. Soil moisture and initial urea concentration had little effect on the hydrolysis rate.

Soil moisture and pH were two variables whose effects on urea hydrolysis were studied by Deluane and Patrick (1970). They found that urea hydrolysis occurred at approximately the same rates in waterlogged soils as at 1/3 bar moisture. Optimum hydrolysis occurred at approximately pH 8 under both conditions. This finding was contradicted by Petit, Smith, Freedman and Burns (1976), who found the activity of soil urease to be optimal between pH 6.5 and 7.0. The effects of temperature were further studied by Gould, Cook and Webster (1973), who found an increase in urease activity between 2 and 45 C. (As cited by Meyers, 1974).

Chao and Kroontje (1963) compared the relative values of chemical and biological urea hydrolysis, and found that chemical hydrolysis is very slow and relatively unimportant compared to enzymatic hydrolysis. They also found urea hydrolysis and NH_3 volatilization from ammonium carbonate to be first order reactions.

Overrein and Moe (1967) found the rate of urea hydrolysis to be directly proportional to the rate of urea application. Ammonia volatilization rates

increased exponentially with urea application rates. This resulted in a larger proportion of the added urea-N being lost at the higher application rates.

Moe (1967) found that addition of urease to a sand and a silt loam increased the urea hydrolysis rate and the rate of NH_3 volatilization during the early part of the incubation period. However, the treatment had no effect on the total volatile ammonia loss.

Zantua and Bremner (1976) found soil urease activity not to be substrate inducible. Addition of glucose did, however, temporarily increase urease activity. Their conclusion was that every soil has a stable level of urease activity, determined by "the ability of the soil constituents to provide protection against microbial degradation or other processes leading to inactivation of enzymes."

Soil pH

Soil pH was found to be of decisive importance in determining NH_3 loss by Steenbjerg (1947). He found losses to approach zero at pH 6.0 or less, and to increase rapidly with increasing soil pH. These findings were supported by Martin and Chapman (1951), who found that little loss occurred from NH_4NO_3 or $(\text{NH}_4)_2\text{SO}_4$ when the soil pH was below 7.2. Mitsui, Ozaki and Moriyama (1954) and Ernst and Massey (1960) found that increasing soil pH increased NH_3 volatilization.

Fenn and Kissel (1974) found that the majority of NH_3 loss from precipitate forming compounds, such as $(\text{NH}_4)_2\text{SO}_4$, was due to the formation and decomposition of the unstable intermediate $(\text{NH}_4)_2\text{CO}_3$ and not directly related to the initial soil pH. This decomposition of $(\text{NH}_4)_2\text{CO}_3$ to NH_4OH and CO_2 has the effect of increasing the soil pH in the zone of application,

thereby exerting an additional influence on NH_3 loss. This is supported by Lyster, O'Toole and Morgan (1979), who found total NH_3 losses not to be directly related to initial soil pH. Ryan, Curtin and Safi (1981) found NH_3 loss to be closely related to soil pH, CEC and CaCO_3 content.

Cation Exchange Capacity

Martin and Chapman (1951) found that CEC was important in determining total NH_3 losses from materials which quickly yielded NH_3 upon decomposition, such as NH_4OH . Overrein (1968) touched on the effects of CEC when, while studying NH_3 volatilization from forest soils, he found that the " NH_3 absorbing capacity" of humus played an important role in preventing relatively great NH_3 losses at moderate application rates, while a smaller proportion of the added N was being sorbed at the higher application rates.

Fenn and Kissel (1976) established a direct relationship between cation exchange capacity and NH_3 loss due to volatilization. These findings were later supported by Faurie and Bardin (1979); Lyster, O'Toole and Morgan (1979); and Ryan, Curtin and Safi (1981). Lyster, O'Toole and Morgan found NH_3 losses to be negligible from soils with a CEC greater than 25 meq/100 g, but to increase sharply when CEC dropped below that level. Faurie and Bardin found that soil pH and CEC controlled the free NH_3 content in the soil, and hence the amount of $\text{NH}_4\text{-N}$ susceptible to loss by volatilization.

Calcium Carbonate Content

The effect of CaCO_3 content on NH_3 volatilization was found by Steenbjerg (1947) to be very significant. Ammonia losses in his study were "extraordinarily" high when appreciable amounts of CaCO_3 were present. Calcium carbonate content was described as a buffer action against H^+ ions.

These findings were supported by Volk (1961) who found NH_3 losses to be higher for limed turf than for unlimed.

Fenn and Kissel (1974), in their work done on NH_3 volatilization from calcareous soils, found that the effects of CaCO_3 on NH_3 volatilization varied with the fertilizer source. Compounds which formed a precipitate with CaCO_3 , such as $(\text{NH}_4)_2\text{SO}_4$, had NH_3 losses affected only moderately by temperature. Compounds which do not form precipitates with CaCO_3 , such as NH_4NO_3 , showed higher loss rates and higher total losses at elevated temperatures. In 1975, the same workers found that increasing CaCO_3 content to 6.1% increased NH_3 loss rapidly; increased loss slightly from 6.1 - 9.7% CaCO_3 ; and none beyond 9.7% CaCO_3 . At low CaCO_3 contents (below 6.1%) the acidity of the ammonium compounds caused a reduction in the final soil pH.

Ryan, Curtin and Safi (1981) found that size of CaCO_3 particles plays an important role in determining NH_3 loss. They stated that total NH_3 loss was more closely related to clay-sized CaCO_3 content than total CaCO_3 content.

Soil Buffering Capacity

Soil buffering capacity against NH_3 loss (or against a rise in pH) was alluded to by Steenbjerg (1947), when he termed CaCO_3 content to be buffering against H^+ ions, or a decline in pH. He found NH_3 losses to increase dramatically as buffering against a decline in pH, or CaCO_3 content, was increased.

Martin and Chapman (1951) found that in very poorly buffered acid soils, NH_3 formation from applied urea increased the soil pH sufficiently to allow volatilization to occur. They found losses of NH_3 from urea to be relatively small except in poorly buffered soils.

Avnimelech and Laher (1977) defined soil buffer capacity in reverse terms. They define buffer capacity as

$$B = \frac{\Delta (H^+)}{\Delta A}$$

where B is the buffer factor, ΔA is the amount of acid added and $\Delta (H^+)$ is the resulting change in the hydrogen ion activity (pH). B approaches 0 when the buffering power of the soil increases to infinity, is unity for a system with no buffering power. They found that soil pH is the dominant factor controlling the extent of NH_3 volatilization only when the soil's buffer capacity is high (according to their definition) or when the concentration of NH_3 in the soil is low. At high pHs (high initial NH_3 concentrations), the dominant factor controlling the reaction is buffer capacity.

Vlek and Stumpe (1978), in a discussion of NH_3 volatilization from aqueous systems, found that ammonia volatilization capacity of aqueous systems is dependent on the buffering capacity of the system. Loss of NH_3 is accompanied by an equivalent loss of alkalinity (NH_3 (aq.), HCO_3^- , CO_3^{2-}), and depletion of the alkalinity will terminate the NH_3 volatilization process. Calcium carbonate, if present, can provide the necessary alkalinity to support NH_3 volatilization. Vlek and Stumpe stated that "Urea hydrolysis forms NH_4^+ and HCO_3^- . This process causes the pH of the solution to rise and provides water with the necessary buffering capacity to support NH_3 volatilization."

Temperature

Martin and Chapman (1951) observed that NH_3 volatilization losses from NH_4NO_3 and $(NH_4)_2SO_4$ increased with increasing incubation temperature.

Trickey and Smith (1955) found losses from a nitrogen solution of NH_4NO_3 and free NH_3 to increase with increasing temperature during the first hour of incubation, but to decrease with increasing temperature to five hours. The majority of this loss, however, was found to occur within the first hour after application.

Ernst and Massey (1960) again found increasing temperature to increase total NH_3 losses from urea, but Gasser (1964) found that loss of NH_3 from urea and $(\text{NH}_4)_2\text{SO}_4$ little affected by changing temperature, although the effect varied with different soils.

As already mentioned, Fenn and Kissel (1974) found that the effect of temperature on NH_3 loss depended on the CaCO_3 content of the soil and the source of fertilizer nitrogen. In 1976, Prasad again found that increasing soil temperature increased NH_3 losses, this time from sulfur coated urea, $(\text{NH}_4)_2\text{SO}_4$ and urea.

Surface Residue and Foliage

Trickey and Smith (1955) found that NH_3 volatilization losses were higher from nitrogen solutions sprayed on crop residue than when the same solutions were sprayed on bare soil. Simpson and Melsted (1962) found that loss percentages increased with increasing application rates when urea solutions were sprayed on plant foliage.

Atmospheric Humidity

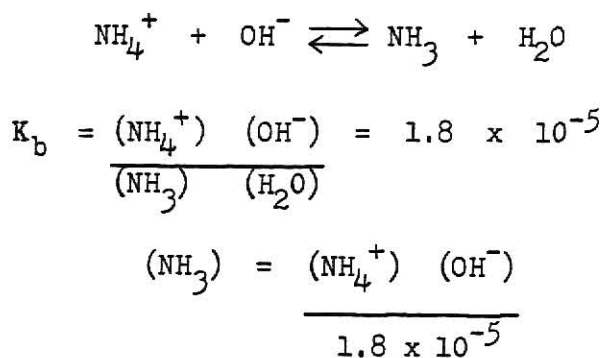
Chao and Kroontje (1964) found atmospheric humidity to have no effect on the relationship between ammonia volatilization and moisture evaporation from the soil surface. Ammonia losses decreased with time while water loss remained constant.

Hargrove, Kissel and Fenn (1977) found a close relationship between diurnal fluctuations in NH_3 loss and daily fluctuations in atmospheric humidity in studies conducted in the field.

Mechanisms of Loss

Probably among the first to propose a mechanism for loss of NH_3 from soils was Jewitt (1942). He suggested a mechanism by which the base exchange equilibrium in the soil tends to maintain the concentration of NH_3 in the soil solution at a constant level, while the normal buffered state of the soil solution maintains the OH^- concentration at a constant level. Ammonia is lost as from a dilute solution, at a constant rate proportional to the NH_3 concentration in the soil solution. This loss occurs over a time length depending on the reserves of NH_4^+ held on the base exchange complex. If the CEC is low, the rate of NH_3 loss is not constant, but comparable to that of a dilute solution, in which the NH_3 content declines progressively as volatilization occurs.

DuFlessis and Kroontje (1964) found that pOH might contribute directly to NH_3 volatilization from soils. They suggested that a low activity of OH^- prevents or retards NH_3 loss in acid soils. This principle would be expected to operate even more effectively in alkaline soils. An increase in the OH^- activity would favor a shift of the reaction to the NH_3 form, which then could be volatilized.



A discussion of theory of NH_3 volatilization from calcareous soils was conducted by Fenn and Kissel (1973). They found that the solubility of the potential reaction product was the major factor regulating loss from calcareous soils. When anions of soluble ammonium salts formed insoluble precipitates, soil surface pH increased (the site of application). This increase in pH was caused by the formation of $(\text{NH}_4)_2\text{CO}_3$ and its subsequent degradation into NH_4OH and CO_2 . Initially, CO_2 was found to evolve at a faster rate than NH_3 , causing a temporary formation of NH_4OH .

Literature Discussion

Volk (1959) stated that "urea is a physiologically alkaline form of ammonia". Once urea is hydrolyzed by urease, converted to $(\text{NH}_4)_2\text{CO}_3$ and further decomposed into NH_4OH and CO_2 , it is chemically no different from an initially alkaline form of nitrogen being applied in the first place.

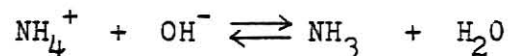
The amount of NH_3 susceptible to volatilization will depend basically on two factors:

1. The amount of alkalinity produced and the rate at which it is produced.
2. The ability of the soil to resist this increase in alkalinity (or rise in pH).

The amount of alkalinity produced, and the rate at which it is produced, is very susceptible to a wide range of environmental factors imposed on the system, such as moisture, temperature and application rate. This is because a biologically governed reaction, enzymatic hydrolysis of urea, is the first step in production of alkalinity from urea. From this point on, all the reactions involved are purely chemical in nature, until the point of nitrification is reached. Urea hydrolysis rate is governed, to some

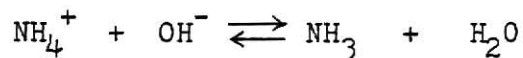
extent, by temperature and moisture. As urea hydrolysis rate is increased, the rate at which excess alkalinity is produced in the soil increases. It is here where the soil's ability to resist this increase in alkalinity determines the potential for ammonia volatilization.

DuPlessis and Kroontje (1964) showed that an increase in the OH^- content of the soil would favor a shift to NH_3 in the reaction:



The ability to resist this increase in OH^- and subsequent NH_3 loss can be termed the soil's buffering capacity. The CaCO_3 content of the soil can be considered a component of this buffering capacity, in a negative sense. (According to Steenbjerg, 1947, an increase in CaCO_3 content equals an increase in buffering against H^+ ions.)

One other factor entering into this discussion of the soil's ability to resist an increase in alkalinity is cation exchange capacity, or CEC. As shown by Fenn and Kissel, (1976), CEC has a definite effect on the amount of NH_3 lost from the system. In effect, at low CEC levels NH_3 is lost as from a dilute solution (Jewitt, 1942). This proceeds until enough alkalinity has been lost that no further volatilization can occur. If CEC is high, more of the ammonium produced is held on the base exchange complex of the soil, essentially causing the reaction -



to shift to the left, thus allowing less NH_3 to be available for loss.

MATERIALS AND METHODS

This study involved the application of urea to the surface of two soils and measuring the NH_3 evolved with time. One soil was Smolan silt loam; the other soil Smolan silt loam in which the buffering capacity had been increased. The study was conducted over a period of 52 days for Experiment 1, 23 days for Experiment 2.

A sample of Smolan silt loam soil was obtained from the North Agronomy Farm, Kansas State University, Manhattan. The soil was air-dried, then ground through a flail grinder to pass a 2 mm sieve. The soil was stored at ambient temperature in an airtight plastic container.

The buffering capacity of the Smolan soil was increased by the addition of hydroxy-aluminum polymers. An $\text{Al}(\text{OH})_x$ solution was prepared by the addition of 100 ml 1 M AlCl_3 solution to approximately 2.5 liters of distilled H_2O in a 1 gallon commercial blender. (Waring Commercial Blendor, Model 33BL12.) Reagent grade CaO , in the amount of 7.28 g, was added to the AlCl_3 solution while blending. This was equivalent to the addition of 60 meq AlCl_3 and 52 meq CaO per 100 g soil. This produced an $\text{Al}(\text{OH})_{2.6}$ polymer, which remained in suspension while blending. This was allowed to blend at medium speed for 30 seconds. Five hundred grams of air-dried Smolan soil was then added to the suspension while blending, and allowed to mix for 60 seconds at medium speed. This allowed the charged polymers to become trapped between the clay interlayers of the soil, effectively increasing the number of positive charges per gram of soil, increasing soil buffering capacity independently of cation exchange capacity. (Coleman and Thomas, 1964.)

The soil suspension was transferred to a Buchner funnel (covered with Whatman No. 2 filter paper). The initial liquid was removed from the suspension, then the moist soil was leached with distilled H_2O until no precipitate formed when $AgNO_3$ crystals were added to the leachate. This insured that all chloride from the $AlCl_3$ and all calcium from the CaO had been removed.

The moist soil was transferred to an evaporating dish and dried at a temperature of 30 C. Following drying, the soil was ground with a mortar and pestle to pass a 2 mm sieve. The dry soil was then placed in an airtight plastic container and stored at ambient temperature. This procedure was repeated until approximately 2 kg of soil was prepared, adequate for each experimental run. The soils for each experiment were prepared separately, and thus differed slightly in their initial pH and buffering at various base concentrations.

Prior to their use in the NH_3 volatilization study, a measurement was made of the buffering capacity of each soil. This involved the addition of a known amount of standard base to a soil-water suspension and measuring the resulting rise in pH. This was done by means of a serial titration.

Ten grams of air-dried soil were weighed into 150 ml Erlenmeyer flasks. Seventy-five milliliters of distilled H_2O were added to the flask. Aliquots of 0,1,3,5,8,11 or 15 ml of 0.911 N NaOH were added to respective flasks. The flasks were stoppered and shaken for 2 hours on an Eberbach reciprocating shaker. After the 2 hour period of shaking, suspension pHs were read immediately. The graphs obtained from the serial titrations are shown in Figures 6 and 7.

Fig. 6 Buffering curves - Experiment 1

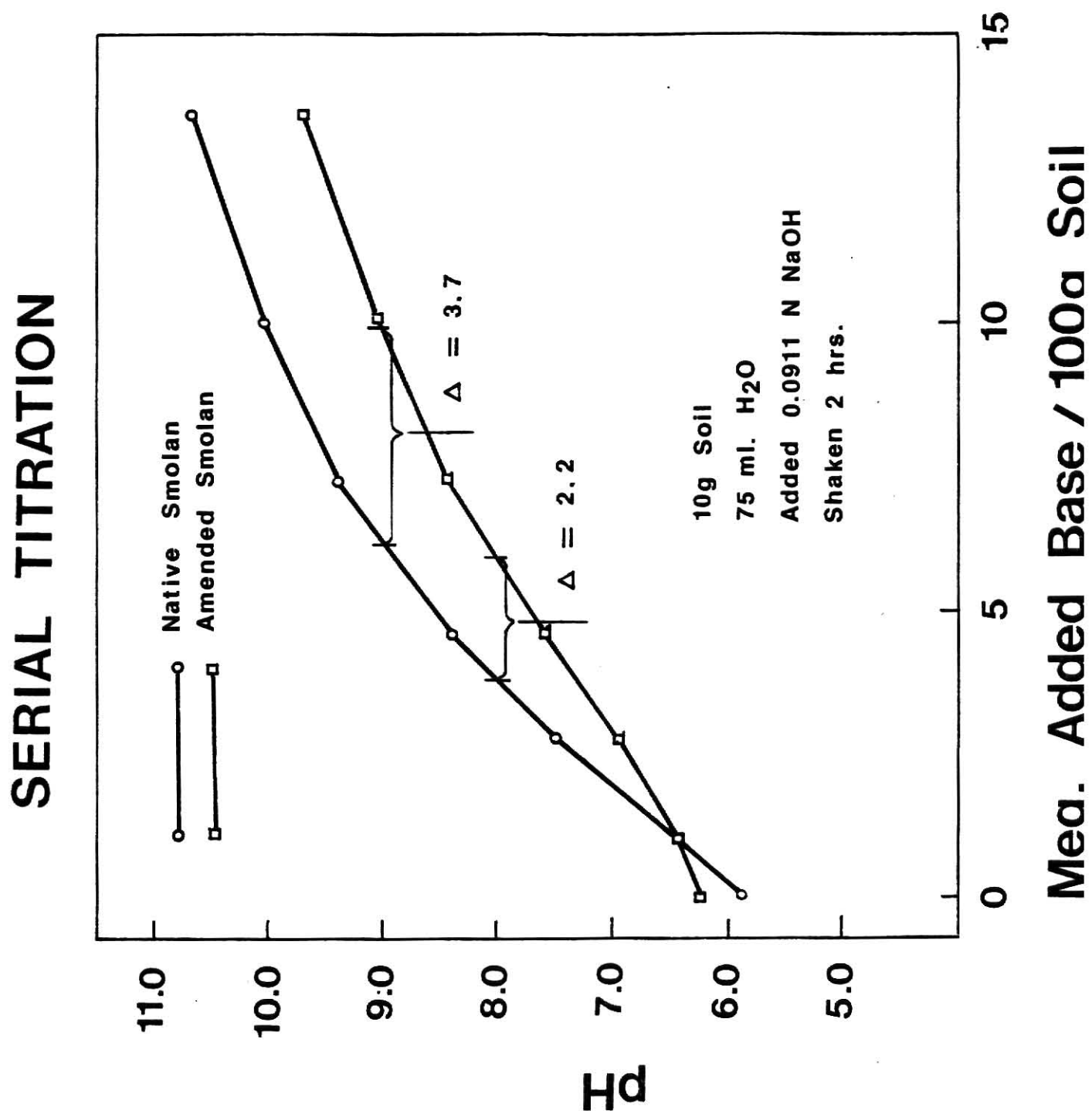
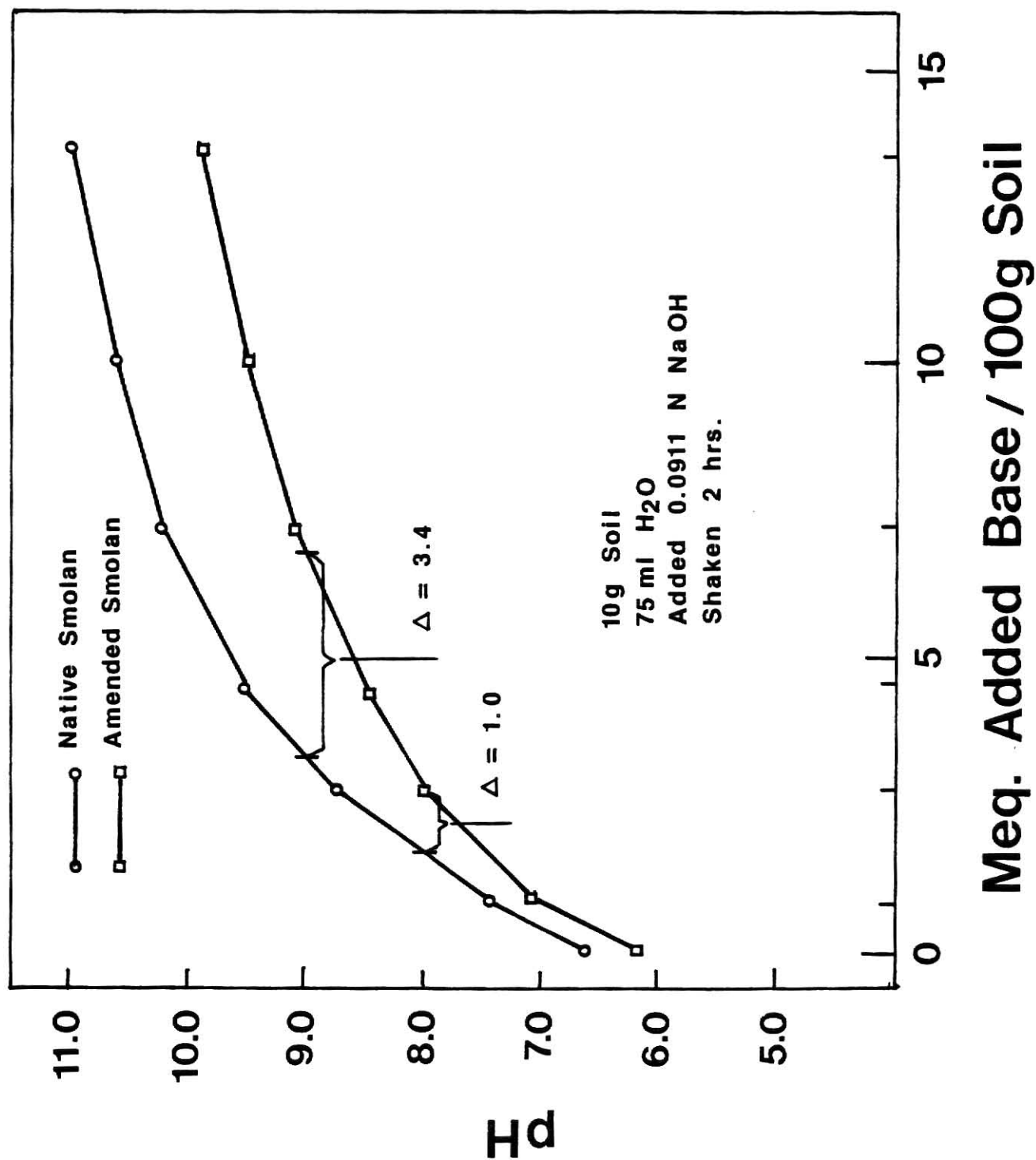


Fig. 7 Buffering curves - Experiment 2



Schematic Diagram of Ammonia Volatilization Apparatus

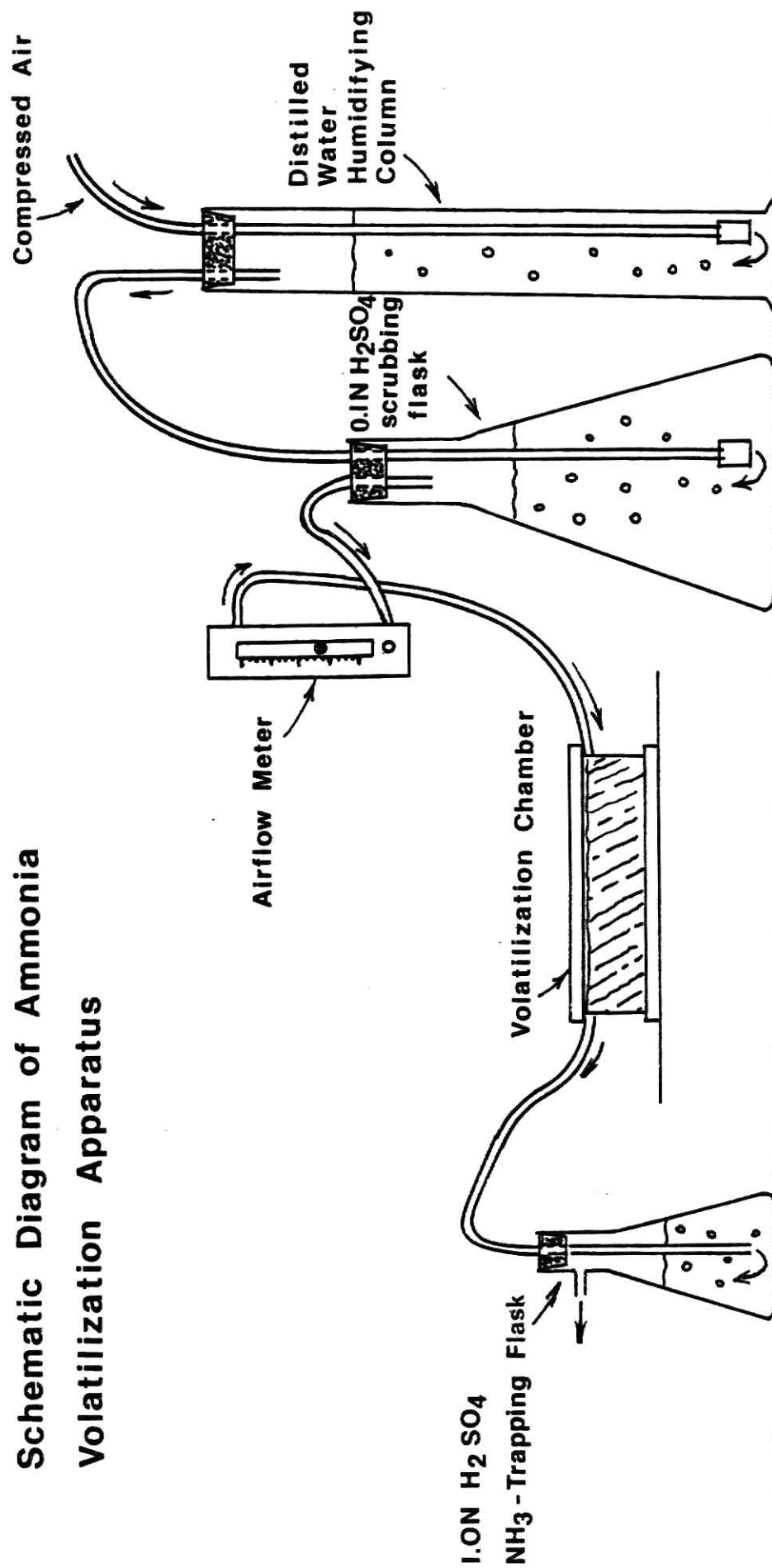


Fig. 8 Schematic diagram of ammonia volatilization apparatus

Experiment 1

Besides the two types of soil used (native Smolan and amended Smolan), two application rates of urea were used, 56 and 224 kg N/ha. These experimental units were replicated, giving a total of 8 chambers used in the study.

The basic experimental unit consisted of a plexiglas chamber 5 cm wide, 15 cm long and 6.5 cm deep. Moist soil was added to the chamber to a depth of 5.5 cm, leaving approximately 1 cm air space above the soil. After packing with soil, urea was applied evenly over the entire soil surface. A lid was clamped to the top of the chamber, and air flow was initiated through the chamber. After leaving the chamber, the air passed through a sulfuric acid trap to remove any evolved ammonia. The entire study consisted of an air manifold, a H_2SO_4 scrubbing flask, an air flow meter, 8 fertilized chambers and 8 acid trapping flasks.

Compressed air, which was obtained from compressed air lines in the lab, was passed through a 0.1 N H_2SO_4 scrubbing flask, containing approximately 2 liters of acid. This removed any atmospheric NH_3 from the airstream.

From the acid scrubber, the airstream entered a Dwyer VisiFloat air flowmeter, model VFB 68 BV. The desired air flow rate was calculated by multiplying the air space above each chamber (75 cm^3) by 8 chambers by 15. (Earlier work by Fenn and Kissel had found that an air flow rate in excess of 15 chamber volumes per minute will not limit NH_3 volatilization (1973)). This gave a desired air flow rate of 9 liters per minute.

The manifold used consisted of a section of iron pipe, I.D. 4 mm with 10 outlets with brass valves to control air flow rate.

The soil added to the chambers was initially moistened to 70% of soil water potential at 1/3 bar. (Soil water potential at 1/3 bar had previously been determined to be .25 g/g by means of a pressure plate membrane apparatus.) The amount of dry soil needed to fill each chamber was approximately 350 g.

The fertilizer used was reagent grade urea crystals. In Exp. 1, the urea to be applied to each chamber was made into a solution with distilled water, using as little water as possible to achieve dissolution at room temperature. The urea was added dry to the chamber of a small atomizer, and water added until dissolution was achieved. This solution was applied evenly over the soil surface. The chamber was rinsed with distilled water and this, too, was sprayed on the soil surface. In this manner, even distribution of the urea over the entire chamber was achieved.

The application rates were 90 and 360 mg urea per chamber, equivalent to 56 and 224 kg N/ha. Following application of the fertilizer, the rubber gasket of the lid was coated with silicone stopcock grease and the lid was sealed in place.

In earlier trials of this study, it was found that loss of moisture from the soil in the chambers could be substantial. Consequently, water was added to the soil periodically to maintain the soil at 70% of soil water potential at 1/3 bar. To accomplish this, each chamber was weighed following urea application, and then every 24 hours. Any loss of weight was considered to be H₂O loss, and distilled water was added to the chamber to make up the difference. Approximately 2.5 ml of distilled water was misted onto the soil surface. The balance of the necessary H₂O was injected below the soil surface with a hypodermic needle and syringe. The needle was inserted approximately .25 cm below the soil surface to make the injection,

and several injections (usually 5-10) were made in order to insure a fairly even distribution of moisture in the chamber. This method prevented any of the applied urea from being leached into the soil and reducing NH_3 losses.

After flowing through the soil chambers, the air and any evolved NH_3 were passed through an acid trap, consisting of 200 ml of 1 N H_2SO_4 in a 250 ml filtration flask.

Periodic measurements were taken of the pH at the soil surface. Measurements were made using a Fisher "Microprobe" combination pH electrode and an Orion digital pH meter, model 601A. Following calibration in pH 7.0 and 4.0 buffers, the electrode was rinsed with distilled water. The water clinging to the electrode after rinsing was adequate to give a pH measurement when the electrode was placed on the soil surface. Following pH measurement, the electrode was lifted from the soil and any soil clinging to the electrode was gently scraped off with a glass fiber.

The H_2SO_4 traps for NH_3 were changed initially daily, and then less frequently as the rate of NH_3 loss decreased. The volume of the acid in the trap was brought up to 250 ml in a volumetric flask. Approximately 50 ml of this volume was kept under refrigeration until ammonia could be determined on the sample, with the remainder being discarded.

The amount of NH_3 trapped was measured using a steam distillation procedure described by Bremner and Keeney (1965). A 5 ml aliquot of the collection acid was added to the 125 ml distillation flask. The flask was attached to the distillation unit, 5 ml of 5 N NaOH added to the flask, and capped immediately. Steam flow was then allowed into the flask. Distillation was continued until approximately 30 ml of distillate was collected

in a 50 ml Erlenmeyer flask containing a boric acid indicator solution. The distillate was titrated from a green color to a faint pink endpoint with 0.005 N H_2SO_4 .

Experiment 2

The amounts of NH_3 lost during Experiment 1 were found to be considerably less than expected, judging from previous trials of the study. Apparently the method of fertilizer application, as a solution, caused the urea to leach into the soil, thus reducing NH_3 losses. Consequently, in Experiment 2, a different method was used for urea application. The urea crystals were finely ground after being oven dried at 50 C. Application was made by "broadcasting" the small crystals as evenly as possible with a spatula across the soil surface. By careful application, a uniform distribution was achieved.

Certain other modifications were made to the design of the study in Experiment 2:

1. Two check chambers were added to the study. These consisted of 600 ml tall-form beakers packed with soil at 70% F.C., which had air passed over them at the same rate as the fertilized chambers. The air was passed through a H_2SO_4 trap. These chambers allowed any background NH_3 to be measured, and served as a reference level for urea hydrolysis measurements taken later. One chamber was used with each soil - the checks were non-replicated.

2. In order to increase the humidity of the air passing over the soil in the chambers to as close to 100% relative humidity as possible, the compressed air from the line was first passed through a finely divided "airstone" which broke the airstream into small bubbles into a distilled

water column. An airstone was also used to divide the airstream entering the sulfuric acid scrubber.

3. Because the preparation of the soil for increasing the buffering capacity was rather extensive, some concern arose as to the effects on urease activity in the buffered soil. Consequently, a study was carried out on the soil used for Experiment 2 to compare urease activity in the native Smolan silt loam and the amended Smolan.

The method followed a procedure outlined by Zantua and Bremner (1975). This, in turn, was a modification of a technique described by Douglas and Bremner (1970). The procedure involved incubation of 5 g of air-dried soil at 37 C for 5 hours after addition of a known amount of urea in solution sufficient to moisten the soil.

Following incubation, the urea remaining in the soil was extracted by shaking the incubation flask and soil with 50 ml of 2 N KCl • PMA extracting solution on an Eberback shaker for 30 minutes. The solution was filtered (Whatman No. 42 filter paper). The amount of urea in the extract was determined by the development of a red color following addition of a color reagent (diacetyl monoxime and thiosemicarbazide solution) to an aliquot of the extractant. The sample was incubated at 120 C for 30 minutes, and the red color intensity measured on a Bausch and Lomb Spectrophotometer model 88, with a micro-flow through sampler. From the amount of urea remaining in the two soils, an index of urease activity in the soils was obtained.

4. In Experiment 2, soil samples were periodically taken from each chamber in order to measure urea hydrolysis rate. After removal of the soil with a core sampler, the core was plugged in the chamber by placing a rubber stopper of equal size in the core to prevent any surface soil from crumbling into the core. Adjustments were made in the chamber weight

each time soil was removed to allow maintenance of a constant soil moisture. Also, adjustments were made for the amount of soil surface removed. Each sampling removed approximately 2% of the surface area of the chamber, so subsequent NH_3 collections were adjusted for that decrease in potential NH_3 volatilization surface.

The wet samples were weighed, then immediately shaken with 20 ml of 2 N KCl · FMA solution for 30 minutes, following a procedure outlined by Douglas and Bremner (1970). After shaking, the soil suspension was filtered through Whatman No. 42 filter paper. The filtered solution was then frozen until analysis could be performed. All 3 dates of measurements for urea hydrolysis were analyzed at the same time. Measurement of urea in solution was performed according to a method described by Keeney and Bremner (1967). Modifications were made to allow for smaller amounts of soil. A 5 ml aliquot of the extractant was added to a steam distillation flask, along with 5 ml potassium phosphate buffer and 1 ml urease solution. The flask was stoppered and incubated for 2 hours at 30 C. Following incubation, steam distillation for ammonia was performed as previously described.

The NH_3 fraction in the soil extract was determined by the same steam distillation method.

Cation exchange capacity (CEC) of the two soils used in Experiment 2 were determined by the Kansas State University Soil Testing Laboratory. The procedure used was a modification of a technique outlined by Jackson (1970), using Ba as the exchanging cation.



Fig. 9 Ammonia Volatilization Chambers

RESULTS AND DISCUSSION

Experiment 1

The ammonia loss and soil surface pH curves from the first study can be found in Figure 10. Buffering curves for the soils used in Exp. 1 can be found in Figure 6. A total of 8 meq extra buffering was added to the amended soil, per 100 g of soil. The measured differences in buffering between the native Smolan and the amended Smolan was 2.2 meq /100 g soil at pH 8.0, and 3.7 meq/100 g soil at pH 9.0.

In this experiment, the urea was added to the soil in the chambers by spraying it onto the soil surface as a solution. The small mister used to apply the spray was then rinsed with distilled water and this rinse was also sprayed onto the soil. This procedure was followed in order to insure an even distribution of the urea over the entire surface area. The mister was rinsed to be sure all urea had been applied to the chamber. Unfortunately, this procedure allowed the urea to be leached into the soil in the chamber, increasing the soil-urea contact and substantially reducing NH_3 loss. Figure 10 shows the losses from this study over a 24 day period, approximately the same length of time that Experiment 2 was run. Actually, Experiment 1 was allowed to run for 52 days. Ammonia losses continued throughout this period, with little or no leveling off of the loss curves. Approximate losses for the 52 day period are given in Table 10.

**Measurement of Ammonia Loss and
Soil Surface pH where Surface-Applied
Urea had been Leached into the Soil**

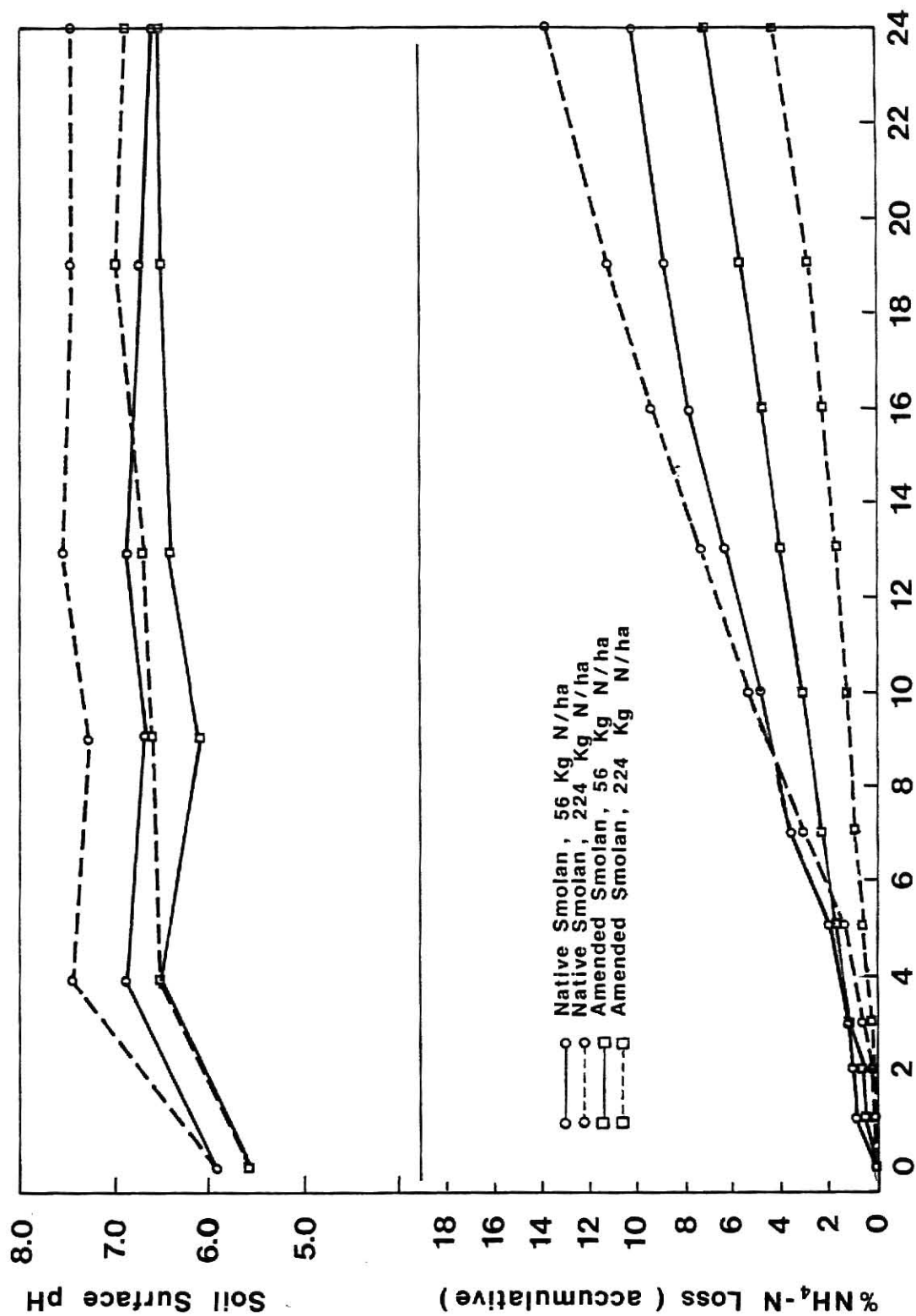


Fig. 11 Ammonia loss, soil surface pH's - Experiment 1

Table 10. TOTAL NH_4^+ -N LOSSES FOR EXPERIMENT 1

Soil	N-Rate	% NH_4^+ -N Loss
Native Smolan	224 kg N/ha	20.8%
Native Smolan	56 kg N/ha	14.7%
Amended Smolan	224 kg N/ha	11.7%
Amended Smolan	56 kg N/ha	11.9%

Losses for the 224 kg N/ha rate on the amended soil were initially less than the 56 kg N/ha rate, as illustrated in Figure 10. As the experiment was allowed to continue past 24 days, the difference in loss between the two rates gradually diminished until they were essentially the same.

Apparently enough water was added with the urea to leach the urea deep enough to reduce losses, but not deep enough to eliminate losses. Loss of NH_3 was also spread out over an extended period of time.

The graph of the soil surface pH's with time in Figure 10 (Exp. 1) illustrates the effect of added buffering on soil pH. The slope of the curve for the native soil is much steeper than the slope of the curve for the amended soil. Actual pH measurements should not be considered so much as the relationships of the curves. This is due to the fact that the soil/water ratio when pH measurements were taken could not be accurately controlled. The only moisture present when pH readings were taken, other than the soil water, was the droplet clinging to the end of the pH probe. Two measurements from each chamber were taken, and measurements usually varied little within chambers. Every effort was taken to be consistent in taking readings. Still, some inaccuracy in exact pH is to be expected by this method. The relationships in soil surface pH between treatments, however, can be considered accurate.

The soil surface pH of the amended soil at the 224 kg N/ha rate showed a steady, continuous increase until it exceeded the surface pH of the native soil at 56 kg N/ha after approximately 15 days. At this point, percent loss from the amended soil, 224 kg N/ha was roughly 2.5%. The soil surface pH of the native soil at the 224 kg N/ha rate increased to its highest point, pH 7.6, at 13 days, then gradually diminished. On the other hand, the surface pH of the amended soil at 224 kg N/ha did not reach its highest point, pH 7.1, until 19 days into the study, from which it gradually decreased. When the study was terminated, the relationship of the soil surface pH's was the same. The highest was the native soil at the 224 kg N/ha rate, followed by the amended soil at the same rate, then the native and amended soils at the 56 kg N/ha rate.

Experiment 2

A buffering curve for the two soils used in this experiment is shown in Figure 7. As in Exp. 1, 8 meq/100 g soil extra buffering was added to the amended Smolan. The measured difference in buffering at pH 8.0 was 1.0 meq/100 g soil, and $3/4$ meq/100 g soil at pH 9.0. The buffering at pH 9.0 in this experiment is essentially the same as that in Exp. 1.

Due to the problems encountered in Exp. 1 with leaching of the applied urea, a different method of application was used in Exp. 2. The urea applied was finely ground and gradually spread from the tip of a spatula. This method seemed to give sufficiently uniform coverage, and insured that all of the urea applied remained on the soil surface.

Ammonia loss and soil surface pH curves from Experiment 2 are given in Figure 11. Ammonia losses in this experiment were much higher than for Experiment 1. Total loss for the 23 day period are given in Table 11.

Measurement of Ammonia Loss and Soil Surface pH from Surface-Applied Urea

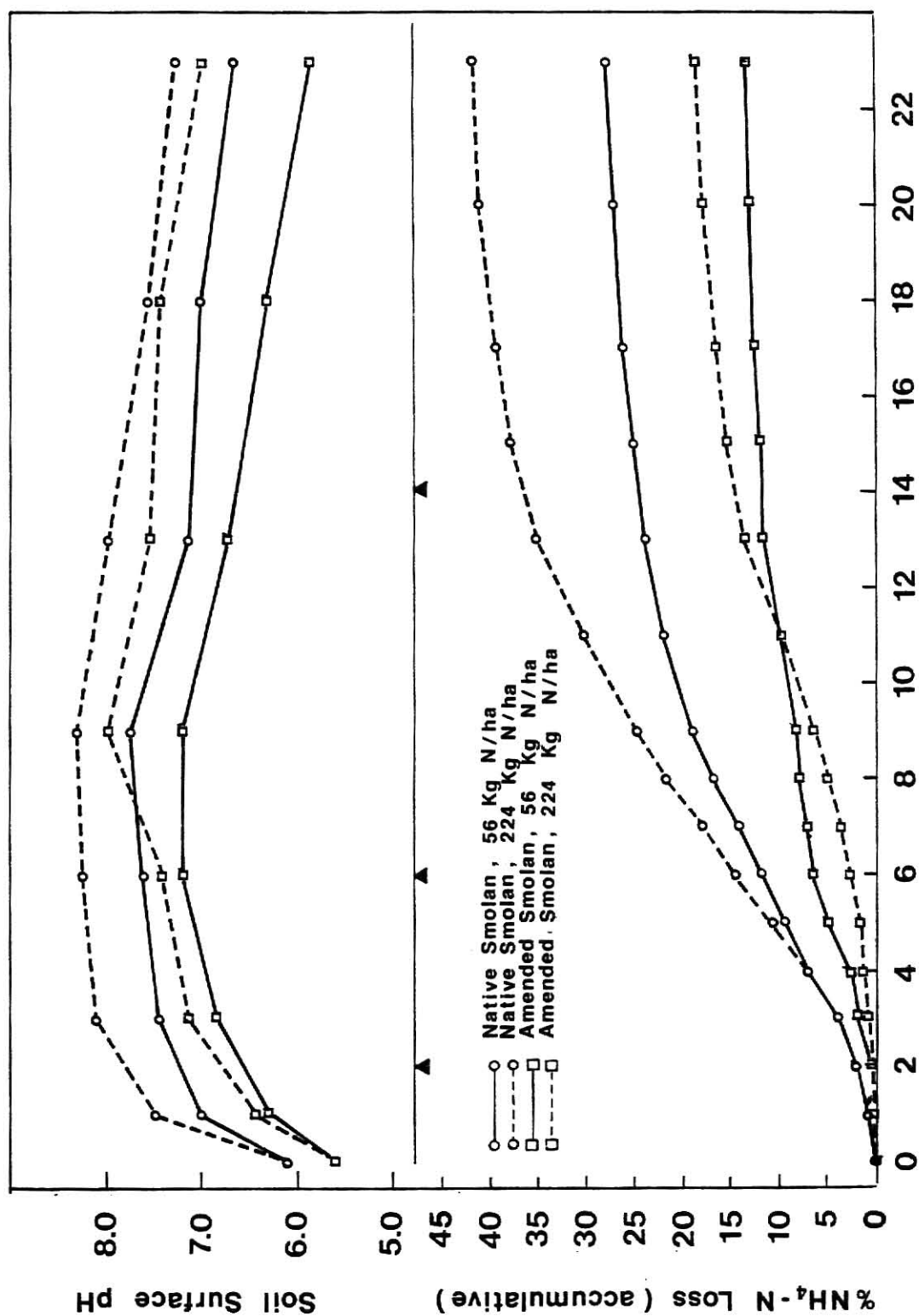


Fig. 11 Ammonia loss, soil surface pH's - Experiment 2

Table 11. TOTAL NH_4^+ -N LOSSES FOR EXPERIMENT 2

Soil	N-Rate	% NH_4^+ -N Loss
Native Smolan	224 kg N/ha	42.1%
Native Smolan	56 kg N/ha	27.6%
Amended Smolan	224 kg N/ha	18.4%
Amended Smolan	56 kg N/ha	12.6%

Total NH_3 losses for the native Smolan were approximately 2.2X the losses from the amended Smolan at both rates.

The loss curves and pH curves are generally of the same relationship as in Exp. 1, only of a greater magnitude. The leaching which occurred in Exp. 1 only slowed the loss, without affecting soil type effects or rate effects. Losses in Exp. 1 at 24 days were at approximately the same point in Exp. 2 in 6 days. This is illustrated in Table 12.

Table 12. PERCENT NH_4^+ -N LOSS OF RESPECTIVE EXPERIMENTS

Soil	N-Rate	Exp. 1 (24 days)	Exp. 2 (6 days)
Native Smolan	56 kg N/ha	10.3	11.6
Native Smolan	224 kg N/ha	13.9	14.2
Amended Smolan	56 kg N/ha	6.8	6.3
Amended Smolan	224 kg N/ha	4.6	3.0

From the 6th day after application until the 13th day after application, NH_3 loss from the amended soil, 224 kg N/ha treatment continued to increase. It exceeded loss from the 56 kg N/ha treatment on the amended soil at the 11th day following application. This was the same trend shown in Exp. 1, where loss from the amended soil at the high rate was essentially the same as loss from the amended soil, low rate at the end of 52 days.

The graphs of soil surface pH shown in Figure 11 demonstrate the same relationship as in Figure 10, from Exp. 1. The rise in soil surface pH of the amended soil receiving 224 kg N/ha was slower than that of the native soil receiving the same rate. Initially, the surface pH of the amended soil at the 224 kg N/ha rate was lower than the surface pH of the native soil which received 56 kg N/ha. By the end of 8 days, this situation was reversed. This reversal took place by the end of 17 days in Exp. 1. However, the amount of NH_3 lost from the amended soil, 224 kg N/ha treatment was similar in each case - 2.5% in Exp. 1, 4% in Exp. 2. In other words, at this point, little of the urea applied to this treatment had yet been lost. As illustrated in Figure 12, most of the urea applied had been hydrolyzed by the 6th day. In the case of the amended soil, 224 kg N/ha treatment, only slightly more than 10% of the applied urea was not hydrolyzed.

At the end of 24 days, the relationships of the soil surface pH's were the same in both experiments - the native Smolan, 224 kg N/ha treatment highest; followed by the amended Smolan, 224 kg N/ha treatment; the native Smolan, 56 kg N/ha treatment and the amended Smolan, 56 kg N/ha treatment.

In Experiment 2, the rate of urea hydrolysis was measured. (Figure 12.) Hydrolysis of urea was apparently more rapid in the amended soil at the low rate than in the same treatment on the native soil. This difference did not show up in the amount of NH_3 lost. There was much less difference between the two treatments in amount of urea hydrolyzed at 6 days, and at 14 days essentially all urea had been hydrolyzed in both treatments. Urea hydrolysis rate was essentially the same for both soils at the high application rate.

The measurement of the amount of ammonia and ammonium which remained in the soils is shown in Figure 13. This graph is basically a reversal

Fig. 12 Measurement of urea hydrolysis rate

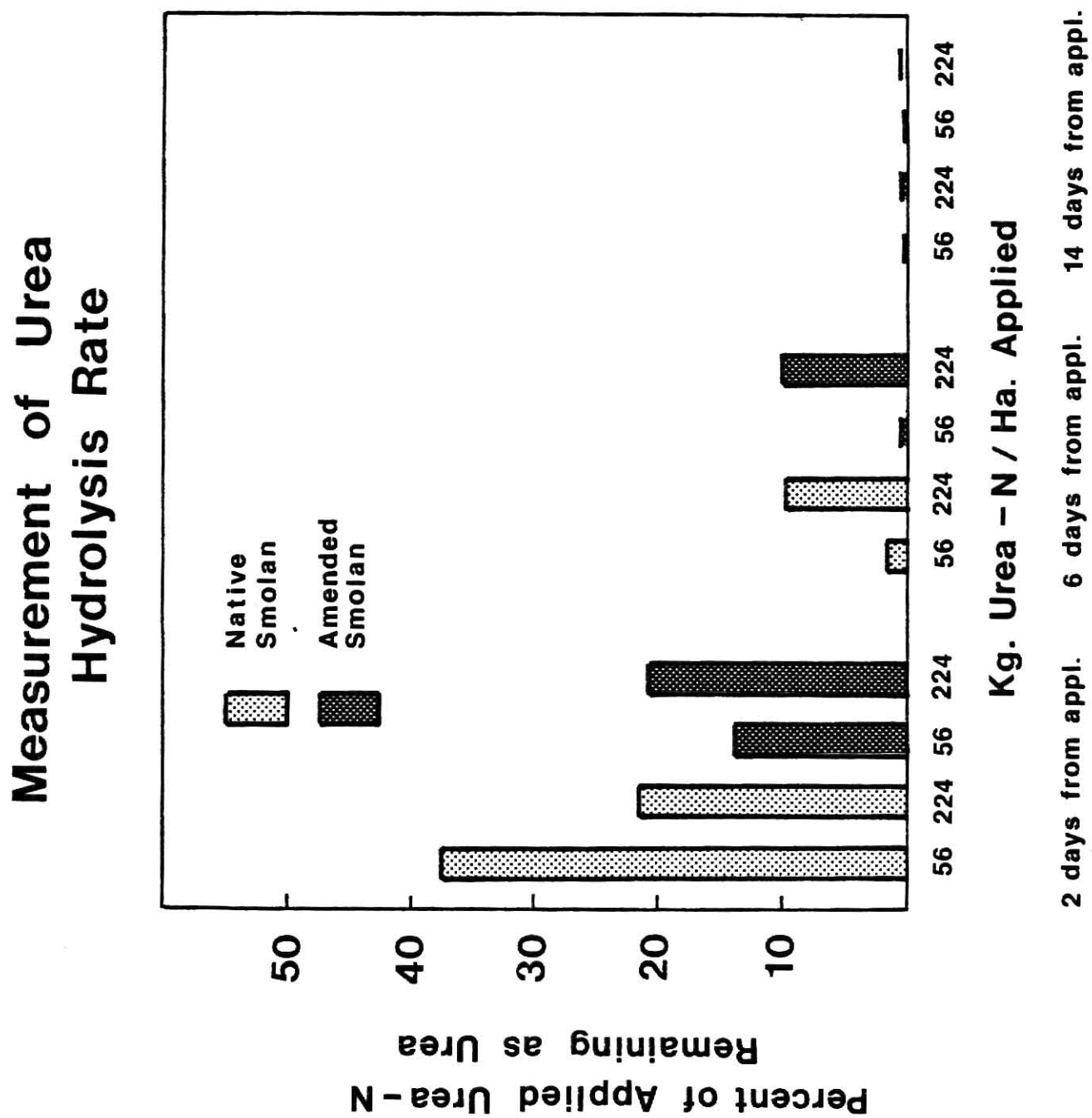
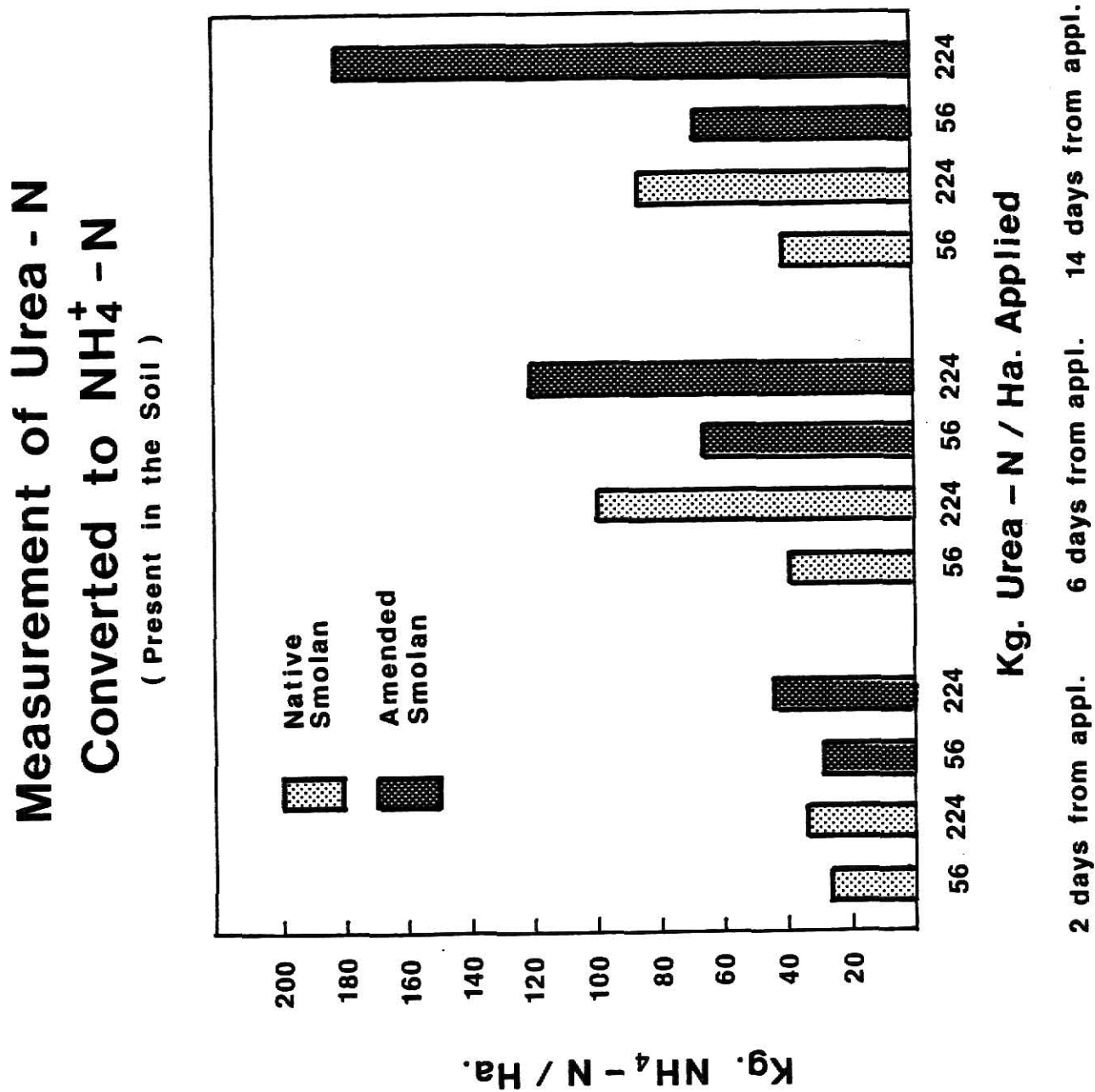


Fig. 13 Measurement of NH_4^+ -N present in the soil



of the NH_3 loss graph, i.e., NH_3 which was not volatilized remained in the soil. Consequently, the amended soils showed a more rapid build-up of soil NH_4^+ -N than the native soil treatments.

Measurement of the CEC of the two soils used in Experiment 2 indicated that the procedure for the addition of buffering capacity also reduced the CEC of the soil. The native Smolan CEC was 19.0 meq/100 g soil, the amended Smolan CEC was 13.0 meq/100 g soil. If this difference in CEC between the two soils were to have any effect, it would be expected to cause greater loss with the amended soil. This was not the case - apparently CEC had little or no effect on NH_3 loss in this study.

SUMMARY AND CONCLUSIONS

The purpose of these laboratory studies was to demonstrate the effect of soil buffering capacity on NH_3 volatilization from surface applied urea. The results, especially from the second experiment, clearly show a substantial difference between soils of different buffering capacities. More than twice as much loss on a percentage basis was found from the native soil at both N rates used than the amended soil with increased buffering capacity.

Apparently soil buffering capacity has more effect on NH_3 volatilization at higher application rates. As was inferred in Exp. 1, and clearly seen in Exp. 2, the NH_3 loss from the amended soil at the high rate was delayed, when compared to the same rate on the native soil. In both experiments, a delay was seen in the rise of soil surface pH of the amended soil at the high rate. In Exp. 2, NH_3 losses were initially lower at the high rate than the low rate for the amended soil, but after a period of 10-14 days, this relationship was reversed. At about the same time, a sharp increase is seen in the surface pH of the high rate chambers. (This was seen in both replicates, with very little deviation from the mean in either case.) Urea is being continually hydrolyzed, as seen in Figure 12, beyond 6 days. As hydrolysis occurs, NH_4OH is being continually added to the system. Initially, the buffering of the soil is adequate to suppress any rapid increase in pH. Eventually, the addition of large amounts of NH_4OH overcomes the soil's resistance to a rise in pH. It is at this point

that the pH starts to increase rapidly and NH_3 loss begins to increase as well. At some time following this point, urea hydrolysis is completed, and the addition of NH_4OH to the system ceases. Ammonia loss, however, is still occurring due to the high pH of the system. As NH_3 is lost without any additional NH_4OH being added, the pH begins to decline. As the soil pH declines, NH_3 losses decrease. It is for this reason that a gradual decline in the loss curve is seen, instead of an abrupt cessation of NH_3 loss. Eventually, conditions will exist in the soil mass as a whole where NH_3 losses will cease, or at least become nonsignificant.

Similar conditions exist in the other treatments being considered, but are not as obvious as in the case where high application rate and high buffering are combined. In the amended soil at the low application rate, the system does not experience the high levels of NH_4OH that the high application rate eventually does. Ammonia loss occurs because there are sites in the soil where conditions are adequate for loss to occur. However, the soil surface, as a whole, is not subject to as large an amount of alkalinity as at the high rate, and is capable of better resisting an increase in soil surface pH. In the native soil at either application rate, the soil buffering capacity is inadequate to resist the alkalinity produced as urea hydrolysis proceeds. Consequently, a rapid increase in pH is seen, followed by rapid NH_3 loss.

Actual measurement of these conditions were only approximated in this study. The zone of the soil in which these reactions occur is very small. The actual depth affected near the surface depends on the application rate and the amount of soil. (As influenced by bulk density.) The measurements of soil surface pH which were taken in this study almost surely measured

a portion of the soil which was not included in these reactions, reducing the pH measurement accuracy, and thus indicating a lower than actual pH at the soil surface. A method of continuously measuring soil pH, without disturbing the soil, at depth increments of 2 or 3 mm, would be very helpful in understanding these processes.

Control of the soil water potential is another factor which was only approximated in this study. Substantial loss of soil moisture was experienced from the chambers on a daily basis. This resulted in drying, to some extent, of the layer at the soil surface where urea hydrolysis was occurring. Variation of the soil water potential will also cause variation in actual concentrations of NH_4OH and NH_3 , although the relative concentrations would be unaffected. The extent to which these fluctuations affect NH_3 loss in this study are unknown.

LITERATURE CITED

1. Avminelech, Y., and M. Laher. 1977. Ammonia volatilization from soils: Equilibrium considerations. Soil Sci. Soc. Amer. J. 41:1080-84.
2. Bremner, J. M., and R. L. Mulvaney. 1978. Urease activity in soils in "Soil Enzymes" edited by R. G. Burns. Publ. by Academic Press, London.
3. Chao, T., and W. Kroontje. 1964. Relationships between ammonia volatilization, ammonia concentration and water evaporation. Soil Sci. Soc. Amer. Proc. 28:393-395.
4. Chesnin, L. and N. Shafer. 1953. Foliage applications of urea solutions to grain and forage crops. Agron. J. 45:576.
5. Chin, W., and W. Kroontje. 1963. Urea hydrolysis and subsequent loss of ammonia. Soil Sci. Soc. Amer. Proc. 27:316-318.
6. Coleman, N. T. and G. W. Thomas. 1964. Buffer curves of acid clays as affected by the presence of ferric iron and aluminum. Soil Sci. Soc. Amer. Proc. 28:187-190.
7. Cook, R. L. and C. E. Millar. 1936. The effect of spring applications of soluble nitrogen fertilizers on the yields of wheat on heavy soils. Mich. Ag. Exp. Quar. B. v.18:182-92.
8. Deluane, R. D., and W. H. Patrick, Jr. 1970. Urea conversion to ammonia in waterlogged soils. Soil Sci. Soc. Amer. Proc. 34:603-607.
9. Douglas, L. A., and J. M. Bremner. 1970. Extraction and colorimetric determination of urea in soils. Soil Sci. Soc. Amer. Proc. 34:859-862.
10. DuPlessis, M. C. F., and W. Kroontje. 1964. The relationship between pH and ammonia equilibria in soil. Soil Sci. Soc. Amer. Proc. 28:7514.
11. Ernst, J. W., and H. F. Massey. 1960. The effects of several factors on volatilization of ammonia formed from urea in the soil. Soil Sci. Soc. Amer. Proc. 24:87-90.

12. Faurie, G., and R. Bardin. 1979. Volatilization of Ammonia: I. Influence of the nature of soil and nitrogen compounds. *Ann. Agron.* 30(4):363-85.
13. Fenn, L. B., and D. E. Kissel. 1973. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: I. General theory. *Soil Sci. Soc. Amer. Proc.* 37:855-59.
14. Fenn, L. B., and D. E. Kissel. 1974. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: II. Effects of temperature and rate of ammonium nitrogen application. *Soil Sci. Soc. Amer. Proc.* 38:606-610.
15. Fenn, L. B., and D. E. Kissel. 1975. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: IV. Effect of calcium carbonate content. *Soil Sci. Soc. Amer. Proc.* 39:631-633.
16. Fenn, L. B., and D. E. Kissel. 1976. The influence of cation exchange capacity and depth of incorporation of ammonia volatilization from ammonium compounds applied to calcareous soils. *Soil Sci. Soc. Amer. J.* 40:394-398.
17. Fenn, L. B., and R. Escarzaga. 1976. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: V: Soil water content and method of nitrogen application. *Soil Sci. Soc. Amer. J.* 40:537-541.
18. Finney, K. F., J. W. Meyer, F. W. Smith and H. C. Fryer. 1957. Effect of foliar spraying of Pawnee wheat with urea solutions on yield, protein content and protein quality. *Agron. J.* 49:341-7.
19. Fisher, W. B., and W. L. Parks. 1958. Influence of soil temperature on urea hydrolysis and subsequent nitrification. *Soil Sci. Soc. Amer. Proc.* 22:247-248.
20. Frank, W. 1967. Mechanisms of foliar penetration of solutions. *Ann. Rev. Plant Phys.* 18:281-300.
21. Gardner, H. W. 1950. The effect of nitrogen topdressings on the yield and protein content of winter wheat. *J. Ministry of Ag., Great Britain.* 57:1-8.
22. Garcia, R. L., and J. J. Hanway. 1976. Foliar fertilization of soybeans during the seed-filling period. *Agron. J.* 68:653-57.
23. Gasser, J. K. R. 1964. Some factors affecting losses of ammonia from urea and ammonium sulphate applied to soils. *J. Soil Sci.* 15(2):258-272.
24. Gibson, T. 1930. The decomposition of urea in soils. *J. Agric. Sci.* 20:549-558.

25. Gould, W. D., F. D. Cook and G. R. Webster. 1973. *Pl. Soil* 38:393.
26. Hargett, N. L., and J. T. Berry. 1980. Fertilizer summary data - 1980. TVA ISSN:0146.1850. Publ. National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama 35660.
27. Hargrove, W. L., D. E. Kissel and L. B. Fenn. 1977. Field measurements of ammonia volatilization from surface applications of ammonium salts to a calcareous soil. *Agron. J.* 69:473-476.
28. Hargrove, W. L., and D. E. Kissel. 1979. Ammonia volatilization from surface applications of urea in the field and laboratory. *Soil Sci. Soc. Amer. J.* 43:359-363.
29. Helwig, J. T., and K. A. Council (ed.) 1979. SAS Users Guide - 1979 Edition. SAS Institute, North Carolina.
30. Hiltbold, A. E., and F. Adams. 1960. Effect of nitrogen volatilization on soil acidity changes due to applied nitrogen. *Soil Sci. Soc. Amer. Proc.* 53:45-47.
31. Hoare, J. P., and K. J. Laidler. 1950. The molecular kinetics of the urea-urease system. II. The inhibition by products. *J. Amer. Chem. Soc.* 72:2487-2489.
32. Jackson, M. L. 1970. Soil Chemical Analysis. Prentice Hall, Inc. 6th printing by the author, Dept. of Soil Science, University of Wisconsin, Madison, Wisconsin 53706.
33. Jewitt, T. N. 1942. Loss of ammonia from ammonium sulfate applied to alkaline soils. *Soil Sci.* 54:401-09.
34. Keeney, D. R., and J. M. Bremner. 1967. Determination and isotope-ratio analysis of different forms of nitrogen in soils: 7. Urea. *Soil Sci. Soc. Amer. Proc.* 31:317-321.
35. Kissel, D. E., H. L. Brewer and G. F. Arkin. 1977. Design and test of a field sampler for ammonia volatilization. *Soil Sci. Soc. Amer. J.* 41:1133-1138.
36. Kresge, C. B., and D. P. Satchell. 1959. Gaseous loss of ammonia from nitrogen fertilizers applied to soils. *Agron. J.* 52:104-107.
37. Lewis, A. H., J. Proctor and D. Trevains. 1938. The effect of time and rate of application of nitrogen fertilizers on the yield of wheat. *J. Ag. Sci.* 28:618-29.
38. Linder, R. G., and C. P. Harley. 1942. A rapid method for the determination of ammonium, nitrate and nitrite. *Anal. Chim. Acta.* 32:485-495.

39. Linskens, H. F. 1966. Relief of leaf structures (German) *Planta* 68:1-14.
40. Lyster, S., P. O'Toole and M. A. Morgan. 1979. Losses of ammonia from urea and ammonium nitrate treated soils in Fert. Abstr. 14 (7) July 81, from "Faculty of General Agric. Res. Report, 1978-1979." Dublin, Ireland: Univ. College, p. 61.
41. Martin, J. P., and H. D. Chapman. 1951. Volatilization of ammonia from surface-fertilized soils. *Soil Sci.* 71:25-34.
42. Matocha, J. E. 1976. Ammonia volatilization and nitrogen utilization from sulfur-coated ureas and conventional nitrogen fertilizers. *Soil Sci. Soc. Amer. J.* 40:597-601.
43. Mederski, H. J., and G. W. Volk. 1956. Foliar fertilization of field crops. *Ohio Agric. Exp. Stn. Res. Circ.* 35.
44. Meyer, R. D., R. A. Olson, and H. F. Rhoades. 1961. Ammonia losses from fertilized Nebraska soils. *Agron. J.* 53:241-244.
45. Meyers, R. J. K. 1974. Soil processes affecting nitrogenous fertilizers from "Fertilizers and the Environment," edited by D. R. Leece, publ. by the Australian Institute of Agricultural Science.
46. Mitsui, S., K. Ozaki, and M. Moriyama. 1954. The volatilization of ammonia transformed from urea. *Chem. Abstr.* 48:11702 (*J. Sci. Soil Manure, Japan* 25:17-19, 1954).
47. Moe, P. G. 1967. Nitrogen losses from urea as affected by altering soil urease activity. *Soil Sci. Soc. Amer. Proc.* 31:380-382.
48. Neumann, P. M. 1979. Rapid evaluation of foliar fertilizer-induced damage: N,P,K, and S on corn. *Agron. J.* 71:598-602.
49. Nowakowski, T. Z. 1961. The effect of different nitrogenous fertilizers, applied as solids or solutions, on the yield and nitrate-N content of established grass and newly sown ryegrass. *J. Ag. Sci.* 56:287-92.
50. Overrein, L. N. and P. G. Moe. 1967. Factors affecting urea hydrolysis and ammonia volatilization in soil. *Soil Sci Soc. Amer. Proc.* 31:57-61.
51. Overrein, L. N. 1968. Lysimeter studies on tracer nitrogen in forest soil: I. Nitrogen losses by leaching and volatilization after addition of urea-¹⁵N. *Soil Sci.* 106:280-290.
52. Parker, M. B., and F. C. Boswell. 1980. Foliage injury, nutrient intake and yield of soybeans as influenced by foliar fertilization. *Agron. J.* 72:110-13.

53. Petit, N. M., A. R. J. Smith, R. B. Freedman and R. G. Burns. 1976. Soil Urease: Activity, stability and kinetic properties. Soil Biol. Biochem. 8:479-484.
54. Pooviah, B. W., and A. Leopold. 1976. Effects of inorganic salts on tissue permeability. Plant Physiol. 58:182-185.
55. Prasad, M. 1976. Gaseous loss of ammonia from sulfur-coated urea, ammonium sulfate and urea applied to calcareous soil (pH 7.3). Soil Sci. Soc. Amer. J. 40:130-134.
56. Ryan, J., D. Curtin and I. Safi. 1981. Ammonia volatilization as influenced by calcium carbonate particle size and iron oxides. Soil Sci. Soc. Amer. J. 45:338-341.
57. Simpson, D. M. H., and S. W. Melsted. 1962. Gaseous ammonia losses from urea solutions applied as a foliar spray to various grass sods. Soil Sci. Soc. Amer. Proc. 26:186-189.
58. Simpson, D. M. H., and S. W. Melsted. 1963. Urea hydrolysis and transformation in some Illinois soils. Soil Sci. Soc. Amer. Proc. 27:48-50.
59. Steenbjerg, F. 1947. Ammonia loss from nitrogen-containing commercial fertilizers when applied to topsoil. Chem. Abstr. 41:4878. (Tids. Plant Eval. 48:516-43, 1944).
60. Syme, P. S. 1938. Making the most of top-dressing in New Zealand. J. Ag. 57:195-196.
61. Technicon Industrial Systems. 1977. Industrial method No. 334-74 W/B+, pp. 1-7, Individual/Simultaneous determination of nitrogen and/or phosphorus in BD acid digests. Tarryton, N.Y.
62. Thorne, G. N. 1957. Application of an April top-dressing of nitrogen to winter wheat in a spray with 2,4-Dichlorophenoxyacetic acid. J. Ag. Sci. 48:266-72.
63. Tisdale, S. L., and W. L. Nelson. 1975. Soil Fertility and Fertilizers. Publ. MacMillan Publishing Co., Inc. New York, N.Y.
64. Trickey, N. G., and G. E. Smith. 1955. Losses of nitrogen from solution materials. Soil Sci. Soc. Amer. Proc. 19:222-224.
65. Vasilas, B. L., J. O. Legg, and D. C. Wolf. 1980. Foliar fertilization of soybeans: Absorption and translocation of ¹⁵N-labeled urea. Agron. J. 72:271-275.
66. Vlek, P. L. G., and J. M. Stumpe. 1978. Effect of solution chemistry and environmental conditions on ammonia volatilization losses from aqueous systems. Soil Sci. Soc. Amer. J. 42:416-21.

67. Volk, G. M. 1959. Volatile loss of ammonia following surface application of urea to turf or bare soils. *Agron. J.* 51:746-749.
68. Volk, G. M. 1961. Gaseous loss of ammonia from surface applied nitrogenous fertilizers. *J. Agric. Food Chem.* 9:280-283.
69. Wittwer, S. H., and F. G. Teubner. 1959. Foliar absorption of mineral nutrients. *Ann. Rev. Plant Physiol.* 10:13-32.
70. Wittwer, S. H., M. J. Bukovac, and H. B. Tukey. 1963. Advances in foliar feeding of plant nutrients, p. 429-455, in M. H. McVickar, G. L. Bridger and L. B. Nelson (eds.) Fertilizer Technology and Usage. Am. Soc. of Agron., Madison, Wis.
71. Woodcock, J. W., and A. V. F. Mallo. 1938. Top-dressing wheat with nitrogen. New Zealand. *J. Ag.* 57:113-114.
72. Yamada, Y., S. H. Wittwer, and M. J. Bukovac. 1964. Penetration of ions through isolated cuticles. *Plant Phys.* 39:28-32.
73. Yamada, Y., H. P. Rasmussen, M. J. Bukovac and S. H. Wittwer. 1966. Binding sites for inorganic ions and urea on isolated cuticular membrane surfaces. *Amer. J. Bot.* 53:170-172.
74. Zantua, M. I., and J. M. Bremner. 1975. Comparison of methods of assaying urease activity in soils. *Soil Biol. Biochem.* 7:291-295.
75. Zantua, M. I., and J. M. Bremner. 1976. Production and persistence of urease activity in soils. *Soil Biol. Biochem.* 8:369-374.

VITA

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APPENDIX

SITE OF 1980, 1981 WHEAT STUDIES

RILEY COUNTY, NORTH AGRONOMY FARM

Smolan Silt Loam

The Smolan series consists of deep, gently sloping and sloping soils on high terraces and uplands near the valleys of the Kansas and Republican Rivers. These soils formed in loess.

In a representative profile the surface layer is dark-gray silt loam about 8 inches thick. The subsoil is 43 inches thick. The upper 9 inches of the subsoil is brown silty clay loam that is hard when dry and is friable when moist. The next 19 inches is reddish-brown heavy silty clay loam that is very hard when dry and is firm when moist. The lower 15 inches is brown silty clay. The substratum is light-brown silty clay loam.

Smolan soils are moderately well drained to well drained. They have slow permeability.

Representative profile of Smolan silt loam, 4 to 8 percent slopes, 1,930 feet west and 710 feet north of the southeast corner of sec. 10, T. 10 S., R. 7 E., in native grass:

Al-0 to 8 inches, dark-gray (10 YR 4/1) silt loam, very dark gray (10 YR 3/1) when moist; moderate, fine granular structure; slightly hard when dry, very friable when moist; abundant roots; few worm casts; slightly acid; clear, smooth boundary.

B1-8 to 17 inches, brown (7.5 YR 4/2) silty clay loam, dark brown (7.5 YR 3/2) when moist; moderate, very fine, subangular blocky

structure; hard when dry, friable when moist; common roots; few worm casts; medium acid; clear, smooth boundary.

B2lt-17 to 28 inches, reddish-brown (5 YR 4/2) heavy silty clay loam, dark reddish brown (5 YR 3/3) when moist; moderate, fine, blocky structure; very hard when dry, firm when moist; common roots; few black stains of iron and manganese; medium acid; gradual, smooth boundary.

B2t-28 to 36 inches, reddish-brown (5 YR 5/4) heavy silty clay loam, reddish brown (5 YR 4/4) when moist; moderate, medium, blocky structure; very hard when dry, firm when moist; few roots; few fine concretions of iron and manganese; medium acid; gradual, smooth boundary.

B3-36 to 51 inches, brown (7.5 YR 5/4) silty clay loam, dark brown (7.5 YR 4/4) when moist; weak, fine, blocky structure; very hard when dry, firm when moist; few roots; few fine concretions of iron and manganese; slightly acid; diffuse boundary.

C-51 to 60 inches, light-brown (7.5 YR 6/4) silty clay loam, brown (7.5 YR 5/4) when moist; few, fine, faint mottles; weak blocky structure; hard when dry, firm when moist; common, fine, black concretions of iron and manganese; neutral.

The solum ranges from 38 inches to more than 60 inches in thickness. When dry, the A1 horizon ranges from dark gray to brown in color. The B2t horizon ranges from dark grayish brown or brown in the upper layers to reddish brown or light reddish brown in the lower layers. The B2t horizon is heavy silty clay loam or light silty clay. Depth to a horizon that contains more than 40 percent clay is greater than 14 inches. Smolan soils are medium acid to neutral in the A horizon and in the B horizons.

In the mapping unit Smolan silty clay loam, 4 to 8 percent slopes, eroded, most areas have layers with a chroma of 4 within 20 inches of the surface. This is nearer the surface than is within the range defined for the series, but this difference does not alter the usefulness or behavior of the soil.

Smolan soils are mapped near Geary and Wymore soils and are on similar landscapes. Smolan soils have a more clayey B horizon than the Geary soils, and they have a redder colored and less clayey B horizon than the Wymore soils.

SITE OF 1981 FESCUE STUDY
RILEY COUNTY, NORTH AGRONOMY FARM

Wymore Silty Clay Loam

The Wymore series consists of deep, nearly level to sloping soils on uplands. These soils formed in loess.

In a representative profile the surface layer is dark-gray silty clay loam about 13 inches thick. The subsoil is about 26 inches thick. It is dark grayish-brown silty clay in the upper part, grayish-brown silty clay in the middle part, and grayish-brown silty clay loam in the lower part. In the upper and middle parts it is very hard when dry and is firm when moist. The lower part is hard when dry and is firm when moist. The substratum is light brownish-gray silty clay loam to a depth of about 58 inches. Below this is silty clay loam.

Wymore soils are well drained to moderately well drained. Their subsoils are slowly permeable.

Representative profile of Wymore silty clay loam, 1 to 4 percent slopes, 2,640 feet north and 270 feet west of the southeast corner of sec. 14, T. 8 S., R. 5 E., in native grass:

A1-0 to 7 inches, dark-gray (10 YR 4/1) light silty clay loam, black (10 YR 2/1) when moist; weak, medium, granular structure; slightly hard when dry, friable when moist; common roots; few worm casts; slightly acid; clear, smooth boundary.

A3-7 to 13 inches, dark-gray (10 YR 4/1) silty clay loam, very dark grayish brown (10 YR 3/2) when moist; weak, fine, subangular blocky and granular structure; hard when dry, friable when moist; common very fine roots; few worm casts; medium acid; clear, smooth boundary.

B2lt-13 to 24 inches, dark grayish-brown (10 YR 4/2) silty clay, very dark grayish brown (10 YR 3/2) when moist; moderate, fine and medium, blocky structure; very hard when dry, firm when moist; few very fine roots; few, small, black concretions of iron and manganese; neutral; clear, smooth boundary.

B22t-24 to 33 inches, grayish-brown (10 YR 5/2) silty clay, dark grayish brown (10 YR 4/2) when moist; few, fine distinct mottles of yellowish red (5 YR 5/8); moderate, fine and medium, blocky structure; very hard when dry, firm when moist; few very fine roots; few concretions and coatings of iron and manganese; neutral; clear, smooth boundary.

B3ca-33 to 39 inches, grayish-brown (10 YR 5/2) heavy silty clay loam, dark grayish brown (10 YR 4/2) when moist; common, fine, distinct mottles of yellowish red (5 YR 5/8); moderate, fine and medium, blocky structure; hard when dry, firm when moist; few very fine roots; few concretions of carbonate; mildly alkaline; clear, smooth boundary.

C-39 to 58 inches, light brownish-gray (10 YR 6/2) silty clay loam, grayish brown (10 YR 5/2) when moist; common, medium, distinct mottles of yellowish red (5 YR 5/8); weak, medium and coarse, blocky structure; hard when dry, friable when moist; mildly alkaline; gradual, smooth boundary.

Ab-58 to 64 inches, brown (7.5 YR 5/2) silty clay loam, dark brown (7.5 YR 4/2) when moist; common, medium, distinct mottles of yellowish red (5 YR 5/8); massive; hard when dry, friable when moist; mildly alkaline.

The solum ranges from 36 to 50 inches in thickness. Depth to a silty clay horizon ranges from 7 to 15 inches. When dry, the A horizon ranges from dark gray to dark grayish brown. The B horizons range from 19 to 36 inches in combined thickness. When dry, they are dark grayish brown to grayish brown in the upper part and grayish brown to brown in the lower part. The C horizon commonly is light brownish gray, but in some places it is grayish brown, pale brown, or brown. Wymore soils are medium acid or slightly acid in the A horizons, slightly acid or neutral in the B2 horizon, and neutral or mildly alkaline in the B3 and C horizons. Carbonate concretions are below a depth of 25 inches in some places.

Wymore soils are on landscapes that are similar to those of the Dwight, Irwin, Smolan, and Mayberry soils. Wymore soils have a less clayey C horizon than the Dwight and Irwin soils; they have B and C horizons that are not so red as those of the Smolan soils, and they do not have the glacial pebbles that are characteristic of the Mayberry soils.

SITE OF 1980 BERMUDAGRASS STUDY

SALINE COUNTY, JOHN CARLIN FARM

Elmo Silt Loams

Elmo silt loams are deep, friable, reddish-brown soils of the upland. They have granular surface layers. They occur principally in the south-central and eastern parts of the county. Development has taken place in deep, uniformly silty, moderately fine textured parent materials, which are a mixture of windblown silts and outwash from Cretaceous shales and sandstones. The beds of parent material are normally more than 6 feet thick. They sometimes overlay coarse strata of waterworn channery material, but normally they are underlain by Cretaceous or Permian bedrock.

Profile description for Elmo silt loams:

- 0 to 6 inches, brown (7.5 YR 4/2, dry) or dark-brown (7.5 YR 3/2, moist) silt loam; slightly hard when dry, very friable when moist; moderate fine crumb structure; nearly neutral in reaction.
- 6 to 25 inches, reddish-brown (5 YR 4/2, dry) or dark reddish-brown (5 YR 3/3, moist) silty clay; hard when dry, friable when moist; weak to moderately developed medium to fine subangular blocky structure; nearly neutral in reaction.
- 25 to 30 inches, reddish-brown (5 YR 5/4, dry) or (5 YR 4/4, moist) silty clay loam; hard when dry, friable when moist; moderate fine subangular blocky structure; nearly neutral in reaction.
- 30 to 60 inches, yellowish-red (5 YR 4/6, dry) or reddish-brown (5 YR 4/4, moist) silty clay loam; hard when dry, friable when

moist; massive to very weak coarse subangular blocky structure; neutral to slightly alkaline in reaction; contains a few small fragments of ironstone and sandstone.

Elmo silt loam soils are well drained. In most areas surface runoff is medium. Some water is lost, but there is good penetration of moisture. Permeability is moderate to moderately rapid, and underdrainage is free. These soils have a large water-storing capacity, and much of this water is available to plants.

Elmo silt loam soils are productive and suited to most crops grown in the county. They are best used for small grains, but row crops are profitably grown on them. Most crops yield better on these soils when phosphate is applied. Where these soils have been eroded, or managed less carefully, crops may require additional nitrogen early in spring.

Elmo silt loams have good qualities of tilth. Their moderately resistant surface soil and upper subsoil are easily tilled. Conventional machinery can be used on them throughout a wide range of moisture content.

FLUID SOURCES -- pH's USED IN FIELD STUDIES

Material	pH
31-0-0 UAN Suspension	7.9
31-0-0 UAN Solution	8.1
28-0-0 UAN Solution	6.5
24-8-0 Suspension	6.5
28-0-0-2S Suran	6.8
H ₂ O + 1.5% Clay	8.0

SURFACE APPLICATION OF
NITROGENOUS FERTILIZERS

by

RICHARD BEVAN FERGUSON
B.S., Friends University, 1976

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

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MASTER OF SCIENCE

Department of Agronomy

Kansas State University

Manhattan, Kansas

1981

ABSTRACT

Surface application of nitrogen fertilizers is becoming more common as reduced tillage and other intensive management practices increase in usage. Fertilizer use efficiency in maximizing crop response is very important in these practices. Two factors affecting fertilizer efficiency are: crop injury (leaf burn) caused by application of fluid fertilizers to established crops, and ammonia volatilization from fertilizers applied to the soil surface.

Field studies were conducted in 1980 and 1981, comparing fluid fertilizers surface-applied to established crops of winter wheat, bermudagrass and fescue. The nitrogen sources primarily under comparison were a UAN suspension, designed for use as a base product in making N-P-K suspensions, and a UAN clear solution. Also compared in the studies were a 24-8-0 suspension and a 28-0-0-2S clear solution. Time and rate of application and spray droplet size were other factors considered.

The UAN suspension caused significantly greater leaf burn than did the other sources. Leaf burn had no effect on yield for any of the sources. There was no leaf burn when the spray was applied early; higher rates and fine droplet size both tended to increase leaf burn. Yield increased with higher application rates, and was higher for the early application dates.

Laboratory studies were carried out to measure the amounts of NH_3 volatilized from surface-applied urea on two soils; a Smolan silt loam,

and a Smolan silt loam in which the buffering capacity was increased by the addition of hydroxy-aluminum polymers. The soils were placed in chambers and finely ground urea was applied to the soil surface at 56 and 224 kg N/ha. Evolved NH_3 was collected in a 1 N H_2SO_4 trap. Periodic soil samples were taken from the chambers and analyzed for urea and ammonium nitrogen. Also, periodic measurements of the soil surface pH were taken.

The native soil was found to have total NH_3 losses over twice those of the amended soil at both fertilizer rates. Losses at the 224 kg N/ha rate were 42.1% of the total applied urea nitrogen for the native Smolan, and 18.4% for the amended Smolan. Losses at the 56 kg N/ha rate were similar. Soil surface pH's of the amended soil remained at a lower level than the soil surface pH's of the native Smolan soil.