FIELD AND LABORATORY EVALUATIONS
OF LIME SUSPENSIONS

by

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INTRODUCTION

The phasing out of the government lime subsidy program has caused a decrease in the amount of lime used in recent years. This trend, combined with the continued use of high rates of ammoniacal nitrogen (N) fertilizer, has resulted in a decline in soil pH levels that is approaching the critical level in some areas.

Interest in lime suspensions has developed primarily with suspension fertilizer dealers who have adapted existing mixing facilities and application equipment to accommodate lime suspensions. Lime suspensions were seen as an effective way to spread the depreciation costs of equipment over a greater number of acres during the slack fertilizer application periods. Interest in lime suspensions is also high in areas requiring lime that are lacking lime vending services.

Lime suspension technology involves the use of a finely divided lime material suspended by a fluid carrier with the aid of a suspending agent (usually attapulgite clay). Successful lime suspensions have been formulated with up to 70% solids by weight. The physical characteristic of the suspension and application equipment limitations have limited practical field applications to less than 1000 kg effective calcium carbonate (ECC)/ha. Kansas law defines ECC as the product of the purity and the fineness factor of the lime material. Fineness factor is determined by sieve analysis, with particles coarser than

8 mesh considered 0% effective, particles between 8 and 60 mesh considered 50% effective and particles finer than 60 mesh considered 100% effective.

The need for more information on this mode of lime application prompted establishment of field studies with these objectives:

1. To evaluate the effectiveness of fluid lime in field situations on soil pH, lime requirement, nutrient uptake and grain yield.
2. To compare the effectiveness of lime suspensions at various rates to coarse agricultural lime at the recommended rate.

The flexibility of suspension formulation allows liquid N fertilizer (urea-ammonium nitrate solution, UAN 28-0-0) to be considered as a carrier for lime suspensions. Savings of both fuel and time would be realized with a dual application on N and lime. This liming program could serve to stabilize soil pH by neutralizing the acidity produced with application of acid-producing N fertilizer. By-product lime sources suitable for lime suspension formulation such as cement plant stack dust may contain appreciable levels of calcium oxide (CaO), which exerts a strong influence on suspension pH and subsequent ammonia (NH_3) volatilization. Lime-UAN suspensions formulated with these lime sources has caused concern about possible NH_3 volatilization. To answer questions on NH_3 loss from lime-UAN suspensions before and after application to soil, laboratory studies were conducted with the following objectives:

1. To determine the effect of CaO content of lime on NH_3 volatilization during and following preparation of lime-UAN suspensions.

2. To evaluate NH_3 volatilization from lime-UAN suspensions following application to the soil surface.

In some reduced tillage systems, poor triazine herbicide performance has been observed and has been linked to low soil pH in the herbicide placement zone. As soil pH decreases, the triazine molecules become protonated, positively charged, and adsorbed by clay minerals. Soil adsorption lowers the herbicide concentration in the soil solution, forcing growers to increase herbicide rates to achieve satisfactory weed control.

The introduction of lime suspensions has created the possibility of applying herbicides with light rates of lime suspensions to help offset the acidity problem. Questions have arisen concerning lime-herbicide suspension compatibility and potential herbicide toxicity to seedlings. Toxicities could result from enhanced herbicide activity due to a higher pH in the herbicide placement zone following application of suspension lime. A higher pH results in fewer hydrogen ions (H^+) available to protonate neutral charged triazine molecules. Thus, more herbicide remains unadsorbed and available for plant uptake. A greenhouse study on lime-herbicide suspensions was initiated with the following objectives:

1. To evaluate lime-herbicide suspension compatibility.
2. To evaluate the potential herbicide toxicity to crop seedlings as a result of applying lime in conjunction with triazine herbicides.

REVIEW OF LITERATURE

Lime suspension formulation requires a finely divided lime material for acceptable suspension properties. Therefore, this literature summary will review alternative lime sources and particle size effects on lime reaction rate. The use of lime suspensions has created the option of combining liquid N fertilizer or herbicides with the lime suspension for simultaneous field application. As previously mentioned, the high-pH environment of lime suspensions may cause NH_3 volatilization from liquid N fertilizer or affect triazine herbicide toxicity. This literature summary will also review factors that influence NH_3 volatilization and triazine herbicide performance.

Lime Sources

Agricultural lime is any material containing calcium or magnesium that will neutralize soil acidity following its application to the soil. Early needs for lime were met by using several lime aources, including burned lime, hydrated lime, marl, or crushed limestone. Burned lime (calcium oxide) is prepared by heating limestone to drive off carbon dioxide. Hydrated lime (calcium hydroxide) is created by adding water to the burned lime. Both burned and hydrated lime are caustic, making them undesirable to handle. These materials are rarely used as agricultural lime sources due to their relatively high cost and the difficulty in spreading these materials (33).

Marl is a naturally occurring deposit, consisting of mixtures of amorphous calcium carbonate and clay or sand loosely cemented together. The high percentage of impurities and resulting high cost of transportation restrict the use of marl to areas near deposits (33).

A common source of agricultural lime is crushed limestone rock, which can be found in rock strata of varying thickness and at varying depths below the soil surface. The purity and fineness of grinding are the most important factors in determining the neutralizing value of limestone. The calcium (Ca) and magnesium (Mg) contents are inherent properties of limestone, but the fineness is controlled in the grinding process (33).

On a per unit weight basis, pure CaO will neutralize 1.79 times more acidity than pure calcium carbonate ($CaCO_3$), but the undesirable characteristics and high cost associated with CaO (burned lime) limit its use. Some comparisons have been made regarding the effectiveness of burned lime and finely divided limestone. Working with soil types representing extensive fertile areas of the United States, Kopeloff (24) found 200-mesh limestone as effective as burned lime on an equivalent basis for increasing crop yields and neutralizing soil acidity. Beacher and Merkle (2) measured the neutralizing values of ground limestone and hydrated lime by their reaction with 0.3 N acetic acid. With calcitic limestone the 200-mesh material was nearly as effective as the corresponding hydrate, while the 100- to 200-mesh limestone was definitely slower in reacting. White (47) showed that burned lime had a greater power for correcting soil acidity than 100-mesh limestone.

Other studies have measured the rate of solubilization of calcitic lime compared to dolomitic lime by determining the carbonates remaining in the soil after a specified interval following treatment. Morgan and Salter (35) concluded that the rate of solubility was dependent upon the relative percentages of magnesium and calcium carbonates in the lime sample. The six samples containing primarily calcitic limestone were the most effective in decreasing the lime requirement with the three dolomitic limestones producing slower reactions. Webster et al. (46) used H-saturated clay suspensions as a solvent for determining the neutralization of lime samples. Measurements made on equivalent-size particles showed that calcitic limestones had a faster rate of dissolution than dolomitic stones.

Effect of Particle Size

Limestone varies widely in crystalline structure, chemical composition, and various physical properties: porosity, hardness and specific gravity. Morgan and Salter (35) investigated the solubility of a series of limestones as affected by their physical properties. With particles similar in size to ground limestone, there was no apparent relationship between the rate of solubility in acid soils and any physical property of the rock material. However, the lime solubility rate of coarser particles is influenced by the Mg content. Consequently, the fineness factor is more important to dolomitic limestone efficiency than to calcitic limestone efficiency. White (47) demonstrated that the solubility differences between calcitic and dolomitic limestones were lessened as particle size decreased.

Lime is relatively insoluble in water, but can neutralize soil acidity only when in solution. As limestone particle size decreases, surface area increases per unit weight and neutralization occurs quicker. An agricultural lime criterion was suggested by Bear and Allen (3) based on particle size composition data furnished by complete sieve analysis. Their work dealt with the equal-reduction hypothesis, which suggested that the rate of particle diameter reduction was the same for all particle sizes, removing from each a shell of uniform thickness. The diameters of all particles were reduced by a constant amount, a, until the particle disappeared. The proportion (R) of the material in each size class remaining after the mean diameter (d) of all the particles in the size class had been reduced by a unit is $R = \left(\frac{d-a}{d}\right)^3$. However, the constant reduction amount, a, is not an absolute value and varies with the ability of the soil to decompose limestone. Schollenberger and Salter (40) further explored this equal-reduction hypothesis to produce a chart for evaluation of agricultural limestone. Their values for a were calculated from Ohio lime studies. Swartzendruber and Barber (42) suggested a modified rate equation to predict dissolution rate, which gave approximate dissolution rates if the initial particle sizes were not too small. Considerable deviation appeared for lime particles 40- to 80-mesh and finer.

Ideally, ground limestone should contain a particle size distribution that includes enough fine material for rapid correction of soil acidity, and also includes coarser material to furnish a continuing neutralization effect. Many researchers have tried to determine the ideal fineness for agricultural limestone to give maximum yields (12, 21, 24, 28, 32, 36, 46, 49). As fineness of pulverized limestone increased from 20- to 40-, 60- to 80-, 100- to 200-, and finer than 200-mesh, Kopeloff (24) observed a proportional increase in yield and total N content with crimson clover on several sandy loam and silt loam soils representing extensive fertile areas of the United States, along with a corresponding decrease in lime requirement. With pots cropped to barley, buckwheat and rape, the Sassafras sandy loam soil yielded highest with the 60- to 80-mesh limestone treatment. The 200-mesh treatment was inferior to the 60- to 80-mesh treatment due to the lime leaching below the root zone.

Similarly, Davis (12) observed that the 60- to 100-mesh grade limestone gave the largest overall 7-year average growth of Sudan grass. Lime grades coarser than 20-mesh were inferior to the finer grades in terms of crop growth. The results of this work suggested a fineness standard for Alabama of 100% through a 10-mesh sieve and 50% through a 60-mesh sieve. Similar work by Webster et al. (46) suggested that lime particles 30- to 40-mesh or finer have about equal effectiveness for correcting acidity in H-clay suspensions. Particle sizes of 8- to 20-mesh or coarser were very slow to react.

Working with uncropped Canfield silt loam in Ohio studies, Meyer and Volk (32) observed that particles coarser than 20-mesh were of little value in correcting soil acidity in pot cultures on a soil with a lime requirement of 3.5 tons per acre. Liming materials in the 20- to 60-mesh range gave a slow initial response, but approached the effectiveness of finer particles after 18 months. Particles finer than 100-mesh reacted quickly, but lost effectiveness after 18 months. Using three lime rates on an acid New York soil, Lyon (28) also noticed that particles finer than 200-mesh produced larger yields early, but the beneficial effect disappeared more rapidly. The 5- to 10-mesh material produced low yields and failed to show any improvement with time. The 10- to 25-mesh particles were superior to the 5- to 10-mesh, and were only slightly less productive than particles in the finer range.

Motto and Melsted (36) determined that limestone particles 10- to 28-mesh were generally only 14% as effective as particles finer than 100-mesh, while particles coarser than 10-mesh were of no value. Their work suggested that a large portion of commercial limestone be ground finer than 40-mesh. Investigations by Hoyert and Axley (21) suggested that ground limestone passing a 20- to 40-mesh sieve and containing enough finer material to give an immediate soil pH effect would be ideal. Whittaker and Chichilo (49) recommended that agricultural limestone specifications require that 50% pass a median sieve of the desired fineness and that 95% pass some coarser sieve to eliminate a large amount of coarse material.

The use of limestone suspensions produced from finely divided liming agents and water is a new concept on which no data are available. However, a considerable amount of literature is available that calls attention to the beneficial aspects of such a liming concept. The effect of small particle size on lime reaction rate has been discussed previously. A more uniform lime distribution pattern would be realized with the use of a suspension application. Dry bulk spreading, a widely accepted method of fertilizer and lime application, may result in a non-uniform application due to blowing of finely divided lime particles. Lutz et al. (27) monitored the effects of uneven lime applications on corn and soybeans. Corn yields were decreased where the highest rate of lime was applied due to a high soil pH-induced zinc deficiency.

Trials by Sawyer (39) indicate that limestone suspension formulation was possible for particle sizes ranging from 20- to 325-mesh. Sawyer further discussed the use of a suspending agent (attapulgite clay) to enhance the fluid state of the suspension and enable slurry formulation of up to 70% solids by weight. Trask (44) observed a more uniform field spread pattern with the use of limestone suspensions.

The use of limestone suspensions is most economically feasible when nearby commercial waste products can be utilized as the liming material. Cement plant stack dusts may contain appreciable amounts of potassium (K), but most are too low in K to have practical use as a K fertilizer, forcing most of their agricultural use as soil liming materials. Whittaker et al. (48) evaluated cement stack dusts as a lime material on alfalfa in greenhouse trials. Dust-limed cultures were superior to pulverized agricultural limestone with regard to alfalfa yield increase. Effects on soil pH, overliming, and crop Ca and K content were similar for both lime materials.

In a similar study, Carroll et al. (8) compared 21 stack dusts from different areas, types of cement-processing, and varying collection processes to two agricultural limestones, one pulverized and the other relatively coarse. Greenhouse results from two soils indicated soil pH values and alfalfa yields to be similar for both the dust and the pulverized limestone treatments, while pH values and yield were frequently lower on the coarse limestone treatments. On the average, the dusts supplied much more sulfur and K, nearly as much Ca, but much less Mg than agricultural limestones. The average $CaCO_3$ equivalent over all dusts was approximately 82%.

Effect of pH on Ammonia Volatilization

Questions on possible NH_3 volatilization from limestone suspensions using liquid N fertilizer as the carrier have been raised. A limited amount of research exists on pre-soil-contact NH_3 volatilization from sprinkler irrigation apparatus. Henderson et al. (19) investigated NH_3 loss from sprinkler jets and linked the severity of NH_3 volatilization to the pH of the water-fertilizer solution. Ammonia volatilization was dependent upon characteristics of both the irrigation water and the fertilizer materials. Addition of aqua ammonia to tap water with a pH of 8.3 increased the solution pH because of the basicity of the added NH_3. However, addition of other fertilizers decreased the solution pH through hydrolysis and the action of acidic materials remaining in the fertilizer. Factors having the greatest effect on NH_3 volatilization were (1) the pH and buffer capacity of the water, (2) the acidity of the fertilizer salt, and (3) the amount of fertilizer added to the water.

Doneen and Tanji (13) studied the effect of adding NH_3 to flowing irrigation water for the purpose of sealing cracks in concrete pipelines with precipitated lime. The amount of NH_3 required to precipitate crystalline lime with good adherence properties depended largely upon the buffering capacity of the solution, which was related to the bicarbonate content and pH.

Miyamoto et al. (34) investigated the addition of sulfuric acid (H_2SO_4) to irrigation water for the purpose of reducing NH_3 volatilization. Ammonia loss was reduced up to 50% when acid was simultaneously applied at rates equivalent to the NH_3 rate. The principal mechanism of reducing NH_3 loss by H_2SO_4 was the neutralization of hydroxyl ions (OH^-); consequently, the pH of the irrigation solution can serve as a guide for the need for H_2SO_4.

Pre-soil-contact NH_3 loss from ammoniated irrigation water was evaluated in detail by Bock (4). Bock developed a model to predict NH_3 loss based on NH_3 concentration, irrigation water quality, acid amendment and inhibition of NH_3-induced $CaCO_3$ precipitation. Ammonia loss was less than 5% with an initial ammoniated irrigation water pH of 8.0 or less, but NH_3 loss increased rapidly as initial pH increased above 8.0.

A considerable amount of research exists on NH_3 volatilization from surface-fertilized soils. Much of the work reveals a direct relationship between NH_3 loss and initial soil pH (9, 14, 15, 30). Working with chemisorbed NH_3 on fine textured soils with pH ranging from 4.5 to 7.1, Du Plessis and Kroontje (14) were able to support the following volatilization mechanism in soils:

$$NH_4^+ + OH^- \rightleftharpoons NH_3\uparrow + H_2O.$$

An increase in the OH^- content would favor a shift to the NH_3 which is subject to volatilization. Chao and Kroontje (9) noted a similar NH_3

loss trend on fine textured soils that was proportional to their original soil pH values. Martin and Chapman (30) measured very little NH_3 loss from ammonium sulfate and ammonium nitrate when applied to soil with a pH less than 7.2. However, ammonium hydroxide raised the surface pH of acid soils into the alkaline range and caused volatilization losses.

Fenn and Kissel (15) proposed that when ammonium (NH_4^+) compounds are applied to the surface of calcareous soils, they react with $CaCO_3$ to form ammonium carbonate and a calcium salt of varying solubility. Ammonium carbonate is an unstable compound and decomposes to form carbon dioxide and ammonium hydroxide. The formation of ammonium hydroxide caused an increase in pH at the surface and greater NH_3 losses.

Cation exchange capacity (CEC) is known to influence NH_3 volatilization from materials quickly yielding NH_3 upon decomposition. Martin and Chapman (30) found that NH_3 losses from ammonium hydroxide, urea and dried blood were greater on Ramona sandy loam with a pH of 6.7 and a relatively low CEC than on Meloland clay loam with a pH of 8.0 and high CEC. Increasing soil CEC resulted in greater NH_3 retention and a decrease in NH_3 volatilization. In work with surface-applied pelleted urea, Volk (45) suggested that soils having a CEC of less than 10 were especially prone to NH_3 volatilization.

At high rates of application, NH_3 accumulation is likely to occur at the site of placement until nitrification and diffusion take place. Under certain conditions, NH_3 volatilization may occur during soil drying. Fenn and Kissel (16) observed that increasing depths of NH_4^+

incorporation resulted in reduced NH_3 loss. A dry soil cover was more effective than a moist soil cover in reducing NH_3 losses due to prevention of water evaporation. Capillary water movement to the surface may carry NH_3 with it, thus facilitating NH_3 volatilization. Kresge and Satchell (25) observed the greatest NH_3 loss from urea when the soils were drying from a moisture content near field capacity. Apparently this moisture content provided enough moisture for urea hydrolysis and still allowed rapid soil drying. However, Martin and Chapman (30) concluded that moisture content of the soil had little effect on NH_3 losses except that water evaporation was necessary for appreciable NH_3 volatilization to occur.

Working with urea applied at 112 kg N/ha on bare soil, Volk (45) observed that relatively low moisture levels (2% soil moisture) produced greater than 40% N losses during a 7 day period on Lakeland fine sand, pH 5.6. Partial drying at higher moisture levels increased NH_3 loss on three of the four soils. However, NH_3 losses were small at low moisture levels, apparently due to insufficient moisture for urea hydrolysis and subsequent NH_3 volatilization. Chin and Kroontje (10) reported that urea-N loss through NH_3 volatilization proceeds rapidly and may immediately follow urea hydrolysis.

Kresge and Satchell (25) observed that urea topdressed on Coastal bermudagrass gave significantly lower losses than urea topdressed on bare soil, due to the bare soil drying rapidly following urea application. Similarly, Volk (45) reported that volatilization loss of N during a 7 day period following surface application of pelleted urea ranged from 17 to 59% for acid bare soils, and from 20 to 30% for four different grass sods.

Volk (45) found NH_3 evolution through urea hydrolysis to near completion in 7 days, if moisture and temperature were not limiting. A decrease in the rate of urea hydrolysis and NH_3 formation would increase the period of time during which rainfall could reduce NH_3 volatilization by leaching residual urea into the soil. The highest field losses would probably occur when initial moisture and temperature are sufficient to cause rapid and total hydrolysis of urea, followed by rapid drying of the soil.

Effect of Soil pH on Triazine Herbicide Performance

An extensive literature review has been written concerning the effect of soil pH on triazine herbicide performance (18). Triazine effectiveness is reduced by soil adsorption, which can be influenced by soil pH. Nearpass (37) observed that simazine (2-chloro-4,6-bis-(ethylamino)-s-triazine) adsorption by 18 acid soils increased with a decreasing soil pH, but this correlation was not statistically significant. Simazine adsorption did have a significant relationship to titratable acidity, due to formation of a protonated species of the chemically basic simazine molecule. The protonated herbicide molecule competes for available exchange sites on the soil colloid, resulting in a more strongly adsorbed compound than the unprotonated molecule. Nearpass (37) demonstrated the effect of soil pH on herbicide distribution in the soil profile by monitoring simazine adsorption in depth increments following lime application. With all four soils, raising the soil pH increased simazine penetration to the lower soil layer. Limed soil contained less exchangeable acidity and adsorbed less simazine as the wetting front percolated through the soil.

Bailey et al. (1) measured adsorption of triazine herbicides on montmorillonite clay adjusted to pH 3.35 and 6.80. Adsorption was greater on the highly acid H-montmorillonite compared to the near neutral sodium-montmorillonite. The major factors governing adsorption were the dissociation constant of the herbicide and the surface pH of the clay system. McGlamery and Slife (22) reported an inverse relationship between soil pH and atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) adsorption on a Drummer clay loam soil with the pH adjusted to five levels between 3.9 and 8.0 and further suggested that atrazine rates be adjusted according to soil pH.

Numerous researchers have also reported increased availability of triazines in soils with high pH, resulting in toxicity to crops. Colbert et al. (11) reported that adsorption of three triazines on three limed soils decreased as soil pH increased. Toxicity from GS-14254 (2-(sec-butylamino)-4-(ethylamino)-6-methoxy-s-triazine) reduced barley plant weights by 53% on Chehalis sandy loam, pH 5.2, after liming the soil to pH 7.0. Plant weight reduction corresponded closely with 48% more adsorption of GS-14254 on unlimed Chehalis sandy loam, pH 5.2, over the limed Chehalis sandy loam, pH 7.0. Triazine adsorption by soils with low organic matter content may be significantly altered by soil pH changes, thus affecting the amount of triazine herbicide remaining in the soil solution available for plant uptake.

In summary, finely divided lime materials used for formulation of lime suspensions can be expected to have a faster reaction rate than agricultural lime. Field studies were established to evaluate pH adjustment and yield effects of lime suspension materials and agricultural lime. Long-term objectives of these studies were to compare the effects of a heavy initial application of lime to annual applications at low rates similar to those used by commercial applicators. The literature shows NH_3 volatilization from N fertilizer to be strongly influenced by the pH of its surrounding medium which prompted establishment of a laboratory investigation to measure NH_3 volatilization both prior and following soil application of lime-UAN suspensions. Other work reviewed demonstrated the relationship between soil pH and triazine herbicide performance. Greenhouse trials were used to evaluate triazine herbicide toxicities on crops when herbicides were applied in conjunction with lime suspensions.

MATERIALS AND METHODS

Field studies were established to evaluate the rate of reaction of suspension lime at four rates along with the recommended rate of agricultural lime. The lime material used in 1977 at the Marion and Labette county sites was cement plant stack dust obtained from Lone Star Industries in Bonner Springs, Kansas. This material had an ECC rating of 78%. Lime material used in 1978 and 1979 was a finely divided (200 mesh) calcitic limestone processed in Weeping Water, Nebraska with an ECC rating of 93%. Laboratory evaluations measured NH_3 volatilization from a suspension of lime and UAN. Lime-herbicide suspension toxicity studies were conducted in greenhouse facilities at Kansas State University using corn, soybeans and grain sorghum as test crops to evaluate the effect of lime suspensions on herbicide activity. General information on the soils used for these studies and soil test data run by the Soil Testing Laboratory at Kansas State University are given in Table 1.

Field Evaluations

Corn Study. A simple lime rate study on corn (*Zea mays* L.) was conducted on a cooperator's field in Brown county over 2 years - 1977 and 1978 using a finely ground (200 mesh) calcitic limestone. A randomized complete block design with four treatments and three replications was used to compare lime rates. Lime rates were 0, 560, 1120

Table 1. GENERAL SOIL DESCRIPTION AND SOIL TYPE.

Investigation	Location	County	Soil Type	Cation Exchange Capacity (meq/100 g soil)	pH	Lime Requirement (kg ECC/ha)	ppm P	ppm K	ppm Ca	ppm Mg	Organic Matter (%)
Field Study	Chas. & Dean Reese Farm	Brown	Sharpsburg SiL Typic Argiudoll	16.0	5.2	3300	17	270	2710	540	2.6
" "	Edward R. Hein Farm	Marion	Not Classified	14.2	5.5	5600	30	256	2850	605	2.9
" "	Southeast Kansas Exp. Station	Labette	Parsons SiL Mollic Albaqualf	11.0	5.2	5600	15	115	1376	190	2.2
Laboratory NH_3 Volatilization		Brown	Grundy SiCL Aquic Argiudoll	19.5	5.8	4200	26	189	5710	1105	3.4
Laboratory NH_3 Volatilization		Labette	Parsons SiL Mollic Albaqualf	10.2	5.3	4500	3	45	1935	388	3.0
Greenhouse Lime-UAN-Herbicide Study		Riley	Muir SiL Pachic Haplustoll		5.8	4100					
Lime Rate-Herbicide Study in Greenhouse		Shawnee	Eudora L Fluventic Hapludoll	7.6	5.1	4200	45	300	928	143	1.0
Lime Rate-Herbicide Study in Greenhouse		Riley	Muir SiL Pachic Haplustoll	24.0	6.8	--	65	300	5327	632	4.6

and 3360 kg ECC/ha applied prior to spring tillage in 1977. Soil test results gave a 3360 kg ECC/ha lime requirement. The 560 and 1120 kg rates were repeated in the spring of 1978 to evaluate the effectiveness of small annual applications compared to the recommended lime rate in one application. All Brown county treatments were manually applied as a dry lime material and incorporated by disking.

Plot dimensions were 9.1 m by 9.1 m with a 4.6 m alley separating the replications. Since 1977, incorporation practices have included double disking and chiselling, followed by harrowing for seedbed preparation. The cooperator performed all tillage, planting, fertilizer and chemical applications on the plot site as part of the regular field operations. A blanket application of 112 kg N/ha as dry bulk fertilizer was broadcast over the plot area prior to planting in 1977. The plot area received 169 kg N/ha as anhydrous NH_3 prior to planting in 1978. Leaf tissue samples were taken at tassel stage in 1977. In 1978 leaf tissue samples were taken at the 8-leaf stage and post tassel stage. Soil samples were taken during the growing season following lime application to monitor soil pH and lime requirement with three samplings in 1977 and monthly sampling in 1978. Corn was hand harvested from 9.1 m of row and shelled with a mechanical sheller. Plot weights were recorded and grain samples were saved for moisture determination.

Grain Sorghum and Wheat Study. A lime suspension study was carried out on grain sorghum (Sorghum bicolor L.) on a cooperator's field in Marion county for 2 years - 1977 and 1978. Following the grain sorghum harvest in 1978, the field was double-cropped to wheat

(Triticum aestivum L.). A randomized complete block design with five treatments and four replications was used to compare lime rates and sources. Soil tests showed a lime requirement of 5600 kg ECC/ha. Lime suspension rates were 0, 560, 1120 and 5600 kg ECC/ha applied prior to spring tillage in 1977. A dry agricultural lime treatment (5600 kg ECC/ha) was included in this study for comparison. The 560 and 1120 kg rates were repeated prior to spring tillage in 1978 and following wheat harvest in 1979.

Plot dimensions were 9.1 m by 9.1 m with a 9.1 m alley separating the replications. Incorporation practices included double disking and chiselling, followed by harrowing for seedbed preparation. All tillage, planting, and chemical and fertilizer applications on the plot site were performed by the cooperator in conjunction with farming the surrounding area. The grain sorghum was fertilized each year with 95 kg N/ha as chisel applied anhydrous NH_3. Wheat fertility included a broadcast application of 18 kg P/ha as 18-46-0 prior to wheat planting. The wheat was topdressed in the spring of 1979 with 56 kg N/ha as UAN (28-0-0).

Grain sorghum leaf tissue samples were taken at boot stage in 1977. In 1978 leaf tissue samples were pulled at the 8-leaf stage and at heading. Soil samples were taken monthly during each growing season to monitor soil pH and lime requirement changes. Grain sorghum was hand harvested from 9.1 m of row and threshed with a mechanical thresher. Wheat was mechanically harvested with a modified model "E" Gleaner combine. Plot weights were recorded and grain samples were saved for moisture determination.

Soybean Study. A field evaluation of lime suspensions was conducted on soybeans (Glycine max L.) at the Southeast Kansas Branch Experiment Station in Labette county for 3 years - 1977, 1978 and 1979. Plot design, treatments and tillage practices were identical to the Marion county study. The two low rates of fluid lime were applied each spring. The site was located on an acid Parsons silt loam soil that was broken out of native sod for this study. The site received a dry broadcast application of 336 kg/ha of 6-24-24 fertilizer prior to planting in 1977. All lime treatments were incorporated by disking. Leaf tissue samples were taken prior to initial bloom stage in 1978 and 1979. The soil was periodically sampled to monitor soil pH and lime requirement changes. Plots were mechanically harvested with a combine and grain samples were saved for moisture determination.

Lime Suspension Formulation. Lime suspensions were formulated with the aid of a sparge-mixer drum with a capacity of 208 liters (55 gallons). Due to problems with lime settling during transportation to the field, the suspensions were purposely made as 25% solids, 75% fluid formulation by weight using water as the carrier and 1.5% attapulgite clay as the suspending agent as described by Sawyer (39). The clay was added to the water to form a pre-gel followed by the addition of the lime, yielding a final suspension weight of approximately 1.2 kg/liter (10 lb/gallon). The lime suspension batches were transferred to 208 liter (55 gallon) drums for transport to the field. Time lapse between formulation and field application ranged from 3 hours at the Marion county site to 24 hours at the Labette county site. Most of the lime had settled out after hauling, and compressed air and stirring rods were required to resuspend the lime at both sites. After the lime was resuspended, the suspension was transferred to the field applicator, a converted John Blue Model 80 Nitroshooter equipped with a ground-driven Dempster Model SND-2 pump. The applicator was fitted with one Spraying Systems Co. 1KSS300 nozzle which produced a uniform 4.6 m wide pattern equivalent to 560 kg ECC/ha. Higher rates were achieved by repeated applications. Conventional agricultural limestone (50% ECC) was manually applied to insure even distribution. All materials were incorporated by disking.

Laboratory Evaluations

Laboratory studies were conducted with lime-UAN suspensions to evaluate possible volatilization of NH_3 from the NH_4^+ fraction of the UAN solution. Different lime sources were evaluated for their effect on rate and magnitude of NH_3 loss from the suspension. Later studies measured NH_3 losses from lime-UAN suspensions following its application to the soil surface.

Suspension Ammonia Losses. A laboratory investigation was set up to determine the quantity of NH_3 lost immediately after preparing lime material-UAN suspensions. The laboratory apparatus consisted of Erlenmeyer flasks connected by Tygon tubing as shown in Figure 1. Incoming compressed air was first scrubbed with 0.1 $\underline{N}$ H_2SO_4 to remove any NH_3 that might be present. After being metered through manifold outlets at the rate of 40-50 flask air volumes per minute (approximately 7.5 liters per minute), this scrubbed air was bubbled through

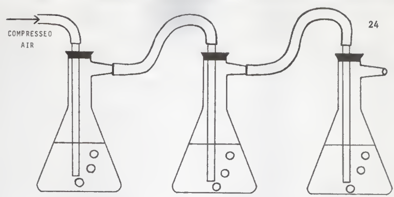


Figure 1. LABORATORY APPARATUS FOR TRAPPING AMMONIA LOST FROM LIME MATERIAL - UAN SUSPENSIONS

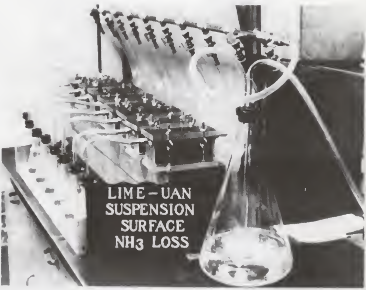


Figure 2. Laboratory apparatua for trapping ammonia lost from soil applied lime-UAN auspensions.

the suspensions carrying liberated NH_3 to the trap flask containing 200 ml of 1 N H_2SO_4. This high rate of air flow served as a sparging mechanism to aid in suspending the lime material. An air flow meter was used to adjust each manifold outlet valve to allow equal air flow through each valve.

The nine treatments evaluated consisted of four lime material suspensions formulated with and without UAN along with a check UAN treatment. The experiment was replicated three times. The four lime materials used were: 1) Finely ground (200-mesh) calcitic limestone, 2) Reagent grade $CaCO_3$, 3) Cement plant stack dust (containing 14% CaO), and 4) Reagent grade lime mixture composed of 50% CaO and 50% $CaCO_3$ by weight.

The lime material-UAN suspensions were formulated as follows:

1. 200 ml distilled-deionized water
2. 8 g attapulgite clay (suspending agent)
3. 100 g lime material
4. 100 g UAN

The lime-water-clay suspensions were mixed in individual flasks. The addition of the UAN was the final step of the suspension formulation. Lime was formulated on an equal weight basis with the UAN, regardless of the lime source or its ECC. Flasks containing the suspensions were immediately attached to the air sparge system after addition of UAN to the lime material-water suspensions. The acid trap flasks were exchanged for flasks containing fresh acid at periodic intervals during the 2 hour length of the trial.

The amount of NH_3 trapped was measured using a micro-Kjeldahl procedure similar to the method discussed by Bremner (6). A 5 ml aliquot of the acid containing trapped NH_3 was placed in a micro-Kjeldahl distillation flask. The distillation flasks were attached to the distillation unit and capped immediately following addition of 5 ml of 5 N sodium hydroxide solution. Thirty ml of distillate were collected in a 50 ml Erlenmeyer flask containing 5 ml of boric acid indicator solution. The sample was then titrated with 0.5 N H_2SO_4.

Ammonia losses were expressed as percentage of the NH_4^+-N fraction of the UAN lost. The actual NH_4^+ content of the UAN sample (7.59% or approximately one-fourth of the total UAN-N) was determined by micro-Kjeldahl steam distillation (7) and titration with 0.0048 N H_2SO_4.

Calcium oxide content of the cement plant stack dust was determined by developing a titration curve showing the relation between pH and milliequivalents (meq) of added H_2SO_4, as shown in Figure 3. One ml increments of 1 N H_2SO_4 were added to a series of Erlenmeyer flasks containing 1 g of stack dust suspended in 70 ml of distilled-deionized water. The flasks were lightly stoppered to allow carbon dioxide to escape. After periodic manual agitation over a 5 hour period, the suspension pH's were read and recorded. Titration curves were also developed in similar fashion for 0.5 g of the ground limestone (Figure 4) and a standard containing 9.3 and 10.0 meq of CaO and $CaCO_3$, respectively (Figure 5). The CaO content was determined on a meq basis by manually sketching the titration curves over computer-plotted data points.

Figure 3.

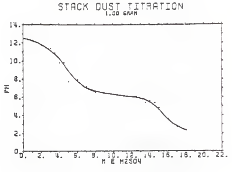


Figure 4.

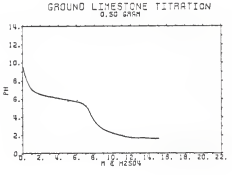
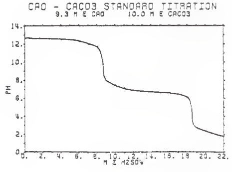


Figure 5.



A second laboratory study was initiated to evaluate the magnitude and rate of NH_3 volatilization from lime material-UAN suspensions as affected by the CaO content of the lime material. The lime material treatments used were formulated with reagent grade CaO and $CaCO_3$. Stack dust was also included as a treatment. The experiment was performed using the same methods and procedures as the original laboratory NH_3 loss study. The length of the trial was extended to 4 hours to obtain a more accurate NH_3 loss curve. The lime mixtures used in these trials were formulated on a weight basis to have the following percentages of $CaCO_3$ and CaO:

% $CaCO_3$	% CaO
100	0
95	5
90	10
85	15
75	25

Ammonia losses for this study were expressed as a percentage of the NH_4^+-N fraction of the UAN. The UAN sample used in this study contained 7.59% NH_4^+-N or approximately one-fourth of the total N in the solution.

Lime suspension pH determinations with and without UAN were replicated three times for each of the lime materials and blends used in the laboratory evaluations. All suspensions were formulated as a 1:1 solid to fluid by weight: 1) 2.5 g water or UAN, 2) 0.1 g attapulgite clay (suspending agent), 3) 2.4 g lime material. After mixing the suspension thoroughly, pH's were determined immediately.

Soil Applied Suspension Ammonia Losses. A third laboratory study was developed to evaluate NH_3 volatilization from lime-UAN suspensions following soil application. The laboratory apparatus was identical to the previous investigations with the exception of soil chambers replacing the lime-UAN suspension flasks. The soil chambers measured 5.1 cm x 15.2 cm x 5.1 cm and were constructed of plexiglass (Figure 2).

The four treatments consisted of UAN applications with and without lime applied to a Parsons silt loam and a Grundy silty clay loam described in Table 1. The lime source was a finely divided (200 mesh) calcitic limestone applied at a rate of 840 kg ECC/ha. The N rate was 112 kg N/ha. The lime-UAN treatments were formulated on a weight basis as 1:1 fluid to solids. The treatments were formulated as follows: 1) 0.38 ml distilled-deionized water, 2) 0.03 g attapulgite clay, 3) 0.25 ml UAN (0.31 g), 4) 0.66 g lime. Treatments without lime were formulated as follows: 1) 0.38 distilled-deionized water, 2) 0.03 g attapulgite clay, 3) 0.25 ml UAN (0.31 g).

Soil was prepared by drying in a forced air oven for 2 days at 30 C and grinding to pass an 8-mesh sieve. The soil was moistened to slightly less than field capacity that allowed the soil to remain workable. Then the soil was added to the chambers to a depth of 4.1 cm. Soil level in the chambers was immediately below the inlet and outlet ports of the chambers. The treatments were surface-applied to the soil in small drops. Petroleum jelly was applied to the chamber covers before closing to insure an airtight seal. The experiment was initiated immediately after the chambers were sealed and the air flow was started. The air flow rate was 15-20 chamber air volumes per minute. The trap flasks of acid were replaced at periodic intervals during the 17 days of the trial conducted at room temperature.

To prevent the soil surface from drying, a distilled-deionized water mist was lightly sprayed as needed to maintain a moist surface. This was accomplished by disconnecting the air flow from the chambers and removing the cover from each chamber long enough to moisten the soil. Care was taken to avoid over-watering and leaching of urea and NH_4^+-N. The trials were replicated two times.

The NH_3 trapped was distilled using the same micro-Kjeldahl method described for the previous experiments. The distillate was titrated with 0.0048 N H_2SO_4. Ammonia losses for this study were expressed as a percentage of the total N content of the UAN sample. The total N content of the UAN sample (27.46%) was analyzed using the micro-Kjeldahl method and 0.0048 N H_2SO_4 for titration, as described by Bremner and Keeney (7). Total N was the summation of 7.03% NH_4^+-N, 6.65% nitrite and nitrate-N and 13.78% urea-N. Urea-N was converted to NH_4^+-N for steam distillation by treating the sample directly with pH 8.0 potassium phosphate buffer and urease enzyme for 1 hour at 30 C as described by Keeney and Bremner (22).

Greenhouse Evaluations

Two greenhouse investigations were conducted with lime-herbicide suspensions on row crops to evaluate possible seedling toxicity from enhanced herbicide activity. Triazine herbicides were selected for evaluation due to their enhanced activity at high soil pH. The initial study utilized various lime-UAN-herbicide suspensions with two time of lime applications on corn, grain sorghum and soybeans to evaluate possible seedling toxicity from enhanced herbicide activity or free NH_3 in the seed zone. A second greenhouse investigation used soil types, lime rate, application method and herbicide treatment on grain sorghum and soybeans to evaluate seedling toxicity from enhanced herbicide activity.

Lime-UAN-Herbicide Suspension Evaluation. This study was designed with several herbicide combinations (triazine underlined) for each test crop to give a spectrum of lime-herbicide suspensions. Rates for each herbicide treatment were purposely high to allow evaluation of a high potential herbicide toxicity on a Muir silt loam soil (Table 1) for the test crops. Visual observations were made on herbicide compatibility with lime-UAN suspensions.

Grain sorghum herbicides and application rates:

1. Propazine (2-chloro-4,6-bis(isopropylamino)-s-triazine) at 2.7 kg ai/ha.
2. Terbutryn (2-(tert-butylamino)-4-(ethylamino)-6-methylthio)-s-triazine) at 2.2 kg ai/ha plus propazine at 0.9 kg ai/ha.
3. Terbutryn at 2.2 kg ai/ha plus atrazine at 0.9 kg ai/ha.
4. Propachlor (2-chloro-N-isopropylacetanilide) at 4.2 kg ai/ha plus atrazine at 1.8 kg ai/ha.

Corn herbicides and application rates:

1. Alachlor (2-chloro-2',6'-diethyl-N-(methoxymethyl)-acetanilide) at 2.8 kg ai/ha plus atrazine at 1.8 kg ai/ha.

2. Metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)-acetamide) at 2.8 kg ai/ha plus atrazine at 1.8 kg ai/ha.
3. EPTC (S-ethyl dipropylthiocarbamate) at 6.7 kg ai/ha plus R-25788 (plant protectant) (N,N-diallyl-2,2-dichloroacetamide) at 0.6 kg ai/ha plus atrazine at 1.8 kg ai/ha.
4. Butylate (S-ethyl diisobutylthiocarbamate) at 6.7 kg ai/ha plus R-25788 at 0.6 kg ai/ha plus atrazine at 1.8 kg ai/ha.
5. Cyanazine (2-((4-chloro-6-(ethylamino)-s-triazin-2-yl)-amino)-2-methyl-propionitrile) at 2.2 kg ai/ha plus butylate at 6.7 kg ai/ha plus R-25788 at 0.6 kg ai/ha.

Soybean herbicides and application rates:

1. Trifluralin (a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) at 1.1 kg ai/ha plus metribuzin (4-amino-6-tert-butyl-3-(methylthio)-as-triazine-5-(4H)-one) at 0.6 kg ai/ha.
2. Pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) at 1.4 kg ai/ha plus metribuzin at 0.6 kg ai/ha.
3. Alachlor at 2.8 kg ai/ha plus metribuzin at 0.6 kg ai/ha.
4. Metolachlor at 2.8 kg ai/ha plus metribuzin at 0.6 kg ai/ha.

In addition to the various herbicide combinations for each crop, the primary variable for this study was the time of lime application. Lime was applied either as a separate suspension 48 hours prior to the UAN-herbicide treatment (Lime Prior) or was applied with the UAN-herbicide treatment as a tank mix preplant (Lime Combination). Each treatment included UAN to evaluate possible seedling damage from free NH_3 in the seed zone. The N rate was held constant at 133 kg N/ha.

Lime was applied at the rate of 443 kg ECC/ha using a finely divided (200 mesh) calcitic limestone.

All studies were conducted in the greenhouse using plastic containers with perforated bottoms. The total dry soil weight per pot was 2 kg with treatment incorporation depth of 5 cm. It was determined that the top 5 cm of soil per pot weighed 743 g and this amount was weighed out into individual plastic bags to await treatment application and mixing. The remaining 1257 g of soil were added to each pot and watered to slightly less than field capacity.

All suspensions were formulated with the aid of an electric household blender, distilled-deionized water as the carrier and attapulgite clay added at 2% of the suspension weight as the suspending agent. Suspensions were formulated as follows to give a final volume of 150 mls:

1. 100 mls water-attapulgite-lime suspension
2. 10 mls herbicide-water dilution
3. 40 mls UAN-water dilution

The "Lime Prior" treatments were applied by incorporating the 100 mls of lime suspension thoroughly with the bagged soil 48 hours prior to incorporation of the 50 mls of UAN-herbicide mixture. This sequence allowed the lime to approach equilibrium with the soil prior to the UAN-herbicide application. The "Lime Combination" treatments were applied as a single suspension to the bagged soil at the same time the UAN-herbicide treatments were added to the "Lime Prior" series. The total 150 ml application brought the moisture content of the bagged soil up to slightly less than field capacity. This soil was returned to the pots and allowed to equilibrate 24 hours before planting. Immediately after planting, 300 mls of distilled-deionized water was added to each pot, bringing the soil moisture to field capacity. Soil moisture was maintained near field capacity for the duration of the experiment. All treatments were replicated three times. All pots were sampled to a depth of 5 cm for pH and lime requirement at 2 and 3 weeks after planting. Plants were harvested at 4 weeks for wet and dry weight determinations which were based on three plants per pot. Dry weights were taken after drying the plant material at 60 C for 3 days.

Lime Rate-Herbicide Suspension Evaluation. A second greenhouse study was initiated to evaluate possible seedling toxicity from enhanced herbicide activity on grain sorghum and soybeans following lime-herbicide suspension applications to the soil. All treatment formulation and incorporation procedures were identical to the previous greenhouse study.

Grain sorghum study. Herbicide rates were purposely high to allow evaluation of a high potential herbicide toxicity. The two herbicides and rates of application used were:

1. Propachlor at 4.2 kg ai/ha plus atrazine at 1.8 kg ai/ha.
2. Atrazine at 2.7 kg ai/ha.

Soil test results of the Eudora loam (Table 1) indicated a 15 cm depth lime requirement of approximately 4200 kg ECC/ha which corresponds to a 1400 kg ECC/ha lime requirement for a 5 cm depth. The 1700 kg rate was used to insure soil pH adjustment to near neutral. The 850 kg rate was more realistic to field application of lime suspensions. Lime rates and application techniques for the experiment were as follows:

1. Prior 1700. Lime was applied as a suspension to the bagged soil at the rate of 1700 kg ECC/ha 1 week prior to the herbicide application to allow time for soil equilibration.
2. Tank 1700. Lime was applied at the rate of 1700 kg ECC/ha with the herbicide as a tank mix preplant.
3. Tank 850. Lime was applied at the 850 kg ECC/ha rate with the herbicide as a tank mix preplant.
4. No lime. Soil received herbicide only.

The grain sorghum study also included two methods of application: surface or incorporated.

Soybean study. Lime rates and application techniques were identical to those described for the grain sorghum study. The herbicide variables were as follows:

1. Trifluralin at 1.1 kg ai/ha plus metribuzin at 0.6 kg ai/ha.
2. Alachlor at 2.8 kg ai/ha plus metribuzin at 0.6 kg ai/ha.

Trifluralin and alachlor require soil incorporation to be effective, thus all lime-herbicide treatments were incorporated. A soil variable was introduced using Eudora loam of the grain sorghum study and Muir silt loam with a near neutral pH (Table 1).

All treatments were replicated three times. All pots were sampled to a depth of 5 cm for pH and lime requirement each week for 3 weeks. Soil moisture was maintained at slightly less than field capacity with distilled-deionized water. Plants were harvested at 5 weeks for dry weight determinations, which were taken after drying the plant material at 60 C for 3 days.

Soil and Plant Analyses

Soils. Soil samples were dried within 2 days of sampling in a forced air oven at 30 C. After drying, the samples were ground to pass a 20-mesh sieve and stored at room temperature. Soils were analyzed for pH according to procedures used in the North Central Region (38). Soil pH was determined by using a glass electrode pH meter on a 1:1 paste composed of soil and distilled-deionized water. Lime requirement was determined by use of the SMP buffer method which correlates the decrease in pH of the buffer solution with the amount of lime required (41).

Soil phosphorus was determined by a 1:10 Bray-P1 extraction (38). Exchangeable cations were extracted with 1 N ammonium acetate solution with a 1:10 extraction ratio. Calcium and magnesium extracts were diluted 1:20 with 1% lanthanum oxide solution and were analyzed by atomic absorption, and potassium was determined by flame emission according to North Central Region procedures (38). Organic matter was determined by a modified Walkley-Black procedure in which the samples were analyzed colorimetrically as described by Graham (17). Soil cation exchange capacity was determined with a technique similar to the procedure described by Bower et al. (5). Since all soils tested were non alkaline, barium chloride was used as the saturating cation. With the aid of suction funnels, the samples were washed repeatedly five times with methanol to remove excess barium, followed by five ammonium acetate washings to extract exchangeable barium, which was then determined by flame emission.

Plant Tissue. Leaf tissue samples were dried at 60 C for 5 days. Dried samples were ground through a Udy rotary-abrasion cyclone mill and approximately 7 g of sample were stored in sealed plastic vials. All samples were redried for 24 hours at 65 C prior to actual analysis. Nitrogen, phosphorus and potassium analyses followed a sulfuric digest described by Linder and Harley (26). Nitrogen determination was based on a colorimetric procedure for a Technicon Auto-Analyzer (43) on which an emerald-green color was formed by the reaction of ammonia, sodium salicylate, sodium nitroprusside and sodium hypochlorite in a buffered alkaline medium at a pH of 12.8-13.0. The ammonia-salicylate complex was read at 660 nm. Phosphorus determination was also based on a colorimetric procedure for a Technicon Auto-Analyzer (43) in which a blue color was formed by the reaction of orthphosphate, molybdate and antimony ions followed by reduction with ascorbic acid at an acidic pH. The phosphomolybdenum complex was read at 660 nm. Potassium was determined by flame photometry after diluting the sulfuric digest 1:10 with distilled-deionized water.

Plant tissue was prepared for Ca and Mg determination by digestion of 0.5 g of plant material with 7.5 ml of a 1:1 mixture of nitric acid and perchloric acid. These digests were then diluted 1:20 with 1% lanthanum oxide solution and analyzed for Ca and Mg by atomic absorption spectrophotometry.

Grain Analysis

Grain samples were ground through a Udy cyclone mill and approximately 10 g were stored in plastic vials and saved for analysis. Nitrogen in the grain was determined by the same procedure outlined for N in plant tissue. Wheat grain crude protein was calculated by multiplying the percent total grain N by a factor of 5.7. The grain sorghum factor for N conversion to protein was 6.25.

Calcium Carbonate Equivalence of Lime Materials

Calcium carbonate equivalence of lime materials was determined by procedures outlined by the A.O.A.C. (20). A 0.1 g lime sample was boiled gently for 5 minutes in 50 ml of 0.1 N hydrochloric acid. Calcium carbonate equivalence was calculated after determining the amount of unreacted hydrochloric acid by titrating with 0.1 N sodium hydroxide.

Statistical Analysis Procedures

The 1977 field data were analyzed by the General Analysis of Variance (GANOVA) system. All succeeding data were analyzed by the Statistical Analysis System (SAS) developed by North Carolina State University. All graphs were produced at the computing center at Kansas State University using a Calcomp plotter and plotting program developed by Kemp et al. (23).

RESULTS AND DISCUSSION

The field, laboratory and greenhouse studies are discussed in separate sections. In the field studies lime suspensions at various rates were evaluated for their effect on soil pH, lime requirement, grain yield and nutrient uptake. In the laboratory studies, the CaO content of lime suspensions was evaluated for its effect on NH_3 volatilization where UAN fertilizer was used as the suspending agent. Ammonia volatilization from the soil also was studied where lime-UAN suspensions were applied. In the greenhouse studies an evaluation was made of the effect of herbicides applied in combination with lime suspensions on possible seedling toxicities.

Field Evaluations

Corn Study. Soil pH and lime requirement was monitored through the 1977 and 1978 growing seasons and showed little change due to lime application rate compared to the control (Table 2 and Appendix Figures 1 and 2). Soil samples were taken in two depth increments in July of 1978 to look at lime incorporation and pH results (Figure 6 and Appendix Table 1). Results showed that generally lime application increased soil pH in the 8-15 cm zone from a 5.1 pH in the control plots. Prior to 1977 soil tests indicated a very acid soil at this site. The field was moldboard plowed prior to establishment of this study, which may have been a contributing factor to the lower pH in

Table 2. EFFECT OF SUSPENSION GRADE LIME RATES ON SOIL pH AND LIME REQUIREMENT OVER TWO YEARS - 1977 AND 1978 IN BROWN COUNTY.

Lime Rate (kg ECC/ha)	Sampling Dates 1977 3-30	1977 6-21	1977 10-20	1978 4-7	1978 5-19	1978 6-13	1978 7-5	1978 8-14	1978 9-28
	pH								
Control	5.3	5.5	5.5	5.8	5.6	5.7	5.3	5.9	5.8
560	5.3	5.1	5.5	5.4	5.6	5.6	5.4	5.9	5.5
1120	5.3	5.2	5.5	5.5	5.6	5.7	5.4	5.8	5.6
3360	5.4	5.6	5.6	5.4	5.4	5.4	5.5	5.8	5.4
$LSD_{.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Lime Requirement, kg ECC/ha								
Control	6500	8200	8200	4800	5600	5900	6400	5400	5000
560	6900	9100	8400	7500	5900	6900	6600	3900	6500
1120	6900	9900	8200	6500	4900	6200	5900	5300	5000
3360	6900	6400	6500	6900	5600	6700	6600	6200	6700
$LSD_{.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

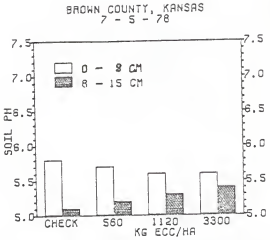


Figure 6. Effect of suspension grade lime rates on soil pH from two depths of sampling, Brown county, 1978.

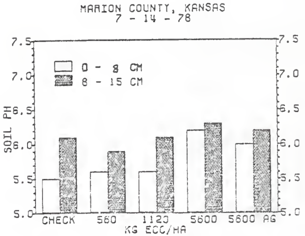


Figure 7. Effect of lime suspension rates and agricultural lime on soil pH from two depths of sampling, Marion county, 1978.

the deeper half of the plow layer. This difference was less with the higher lime rates. Tillage practices at this site after plowing included disking and chiselling, which do not mix the soil in the plow layer as thoroughly or as deep as conventional moldboard plowing.

Yield results from this site increased with lime rate (Table 3) but were not significant at the 5% probability level due to variability between the three replications. Nutrient uptake was relatively constant at normal levels for corn and was not affected by lime rate.

Soil P levels were in the medium range and were not significantly affected by lime rate (Table 4). Soil tests showed high K levels which were not changed by lime application. The ground limestone contained 0.13% K, which did not contribute an appreciable amount of K at the 3360 kg ECC/ha rate. Lime Mg content was 0.64% (23 kg Mg/ha application at the 3360 kg lime rate), which did not significantly change soil Mg levels. Calcium content of the lime was 33.5%, which resulted in a 1210 kg Ca/ha application at the high lime rate. Soil test results did not reflect any significant changes in the Ca level following lime application.

Grain Sorghum and Wheat Study. Soil pH and lime requirement samples were collected in 1977, 1978 and 1979 following establishment of a lime suspension study on a cooperator's field in Marion county. The 5600 kg rate as a lime suspension increased soil pH and reduced the lime requirement compared to all other treatments within one week following application (Table 5 and Appendix Figures 3 and 4) due to the small particle size and rapid reaction with the soil. By the

Table 3. EFFECT OF SUSPENSION GRADE LIME RATES ON CORN GRAIN YIELD AND PLANT NUTRIENT CONTENT OVER TWO YEARS - 1977 AND 1978 IN BROWN COUNTY.

Lime Rate (kg ECC/ha)	Grain Yield (kg/ha)	Tissue Composition: 8-Leaf Stage %N	%P	%K	%Ca	%Mg	Tassel Stage %N	%P	%K	%Ca	%Mg
1977											
Control	5645						2.95	.23	2.06	.30	.17
560	6196						3.00	.25	2.06	.44	.25
1120	7211						3.01	.25	2.13	.40	.22
3360	7264						2.97	.26	2.01	.37	.20
$LSD_{.05}$	NS						NS	NS	NS	NS	NS
1978											
Control	6962	3.72	.29	3.38	.24	.18	2.60	.21	2.15	.40	.30
560	8420	3.86	.30	3.24	.26	.21	2.55	.21	2.22	.32	.25
1120	7715	3.66	.27	3.35	.22	.18	2.76	.22	2.23	.39	.29
3360	7997	3.87	.30	3.26	.29	.21	2.44	.19	2.06	.41	.35
$LSD_{.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4. EFFECT OF SUSPENSION GRADE LIME RATES ON SOIL LEVELS OF P, K, Ca AND Mg OVER TWO YEARS - 1977 AND 1978 IN BROWN COUNTY.

Lime Rate (kg ECC/ha)		Sampling Dates 1977 3-30	1977 10-20	1978 4-7	1978 5-19	1978 8-14	1978 9-29
				Available P, ppm			
Control		15	20	18	12	12	18
560		16	15	12	13	13	18
1120		12	13	15	12	10	14
3360		16	25	13	19	14	15
	$LSD_{.05}$	NS	NS	NS	NS	NS	NS
				Exchangeable K, ppm			
Control		255	298	282	280	260	265
560		270	298	252	264	263	297
1120		264	312	277	257	251	258
3360		242	290	258	255	250	265
	$LSD_{.05}$	NS	NS	NS	NS	NS	NS
				Extractable Ca, ppm			
Control		2836			2837	2601	
560		2622			2757	2440	
1120		2676			3101	2323	
3360		2895			3386	2322	
	$LSD_{.05}$	NS			NS	NS	
				Extractable Mg, ppm			
Control		643			540	502	
560		611			566	481	
1120		606			586	467	
3360		676			706	484	
	$LSD_{.05}$	NS			NS	NS	

Table 5. EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOIL pH AND LIME REQUIREMENT OVER THREE YEARS - 1977, 1978 AND 1979 IN MARION COUNTY.

	Sampling Dates						
Lime Rate				1977			
(kg ECC/ha)	12-21-76	3-15	3-22	3-28	5-13	6-16	10-13
	pH						
Control	5.5	5.4	5.4	5.4	5.4	5.3	5.6
560	5.4	5.4	5.4	5.3	5.4	5.2	5.5
1120	5.5	5.4	5.4	5.4	5.5	5.4	5.6
5600	5.6	6.0	6.2	6.0	6.3	6.6	6.2
5600 Ag Lime	5.6	5.6	5.6	5.4	5.6	5.8	6.0
$LSD_{.05}$	NS	0.3	0.4	0.4	0.5	0.3	0.4
	Lime Requirement, kg ECC/ha						
Control	5000	5900	2900	6600	7400	5300	4300
560	5200	6600	4200	6400	7600	6400	4200
1120	4500	5700	3800	5200	7300	4500	3900
5600	5200	3100	2200	3400	2200	1800	1500
5600 Ag Lime	5500	5900	3800	5900	5700	3400	3200
$LSD_{.05}$	NS	1500	1300	NS	3500	1800	NS

Table 5. (cont.) EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOIL pH AND LIME REQUIREMENT OVER THREE YEARS - 1977, 1978 AND 1979 IN MARION COUNTY.

Lime Rate (kg ECC/ha)	Sampling Dates 1978 5-5	5-29	6-23	7-14	7-28	8-25	9-15	1979 5-17	8-21
	pH								
Control	5.8	6.0	5.4	5.7	5.6	5.9	5.4	5.8	6.0
560	5.8	5.9	5.6	5.7	5.6	5.8	5.3	5.7	6.0
1120	5.9	6.1	5.6	5.8	5.8	5.9	5.4	5.7	6.1
5600	6.4	6.4	6.1	6.2	6.2	6.4	6.3	6.0	6.4
5600 Ag Lime	6.1	6.2	5.8	6.1	6.2	6.2	5.8	5.9	6.5
$LSD_{.05}$	0.3	0.3	0.4	0.3	0.2	0.3	0.2	NS	0.4
	Lime Requirement, kg ECC/ha								
Control	3900	3400	5200	3800	5000	3500	5300	3800	2800
560	3900	3800	4500	4500	5300	3200	5600	4600	3600
1120	3900	2900	3500	3400	4200	3200	5000	4300	2800
5600	1400	2000	2400	2200	2100	1000	2100	3500	1800
5600 Ag Lime	3400	3600	3400	2700	3100	2400	3100	3600	1300
$LSD_{.05}$	NS	NS	1600	1500	1800	1500	1500	NS	NS

June 1977 sampling, the agricultural lime treatment had significantly raised the soil pH above the pH observed with the low rates of lime. Since October 1977 both 5600 kg lime treatments (fluid and agricultural lime) have resulted in soil pH's that generally were not different at the .05 level of probability. Agricultural lime reaction time was slower due to the coarser particle size. The 560 and 1120 kg rates did not significantly raise the soil pH or lower the lime requirement from the control treatments.

Soil sampling in two depth increments are shown in Figure 7 and Appendix Table 1. These samples showed that an acidity gradient exists within the top 15 cm with the soil pH in the 0-8 cm zone of the check plots 0.6 pH units less than in the 8-15 cm zone pH. The lower lime rates produced smaller pH adjustments than the highest lime rate with most of the change in pH coming in the 0-8 cm increment.

Lime treatments did not significantly affect grain yield or nutrient uptake and no lime benefit trends were evident (Table 6). Check plot soil pH was near 5.5, which is generally not considered acid enough to show a lime response on grain sorghum in situations where the subsoil is not acidic. Grain sorghum yields were reduced in 1978 by drought conditions and an infestation of chinch bugs. Following the grain sorghum harvest in 1978, the field was double-cropped to wheat under dry planting conditions. Favorable growing conditions in the spring of 1979 were responsible for the excellent yields that were harvested. No differences due to treatment were evident in grain yield or protein data.

Table 6. EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON GRAIN SORGHUM GRAIN YIELD AND PLANT NUTRIENT CONTENT IN 1977 AND 1978 AND WHEAT YIELD IN 1979 IN MARION COUNTY.

Lime Rate (kg ECC/ha)	Grain Yield (kg/ha)	Grain %Protein	8-Leaf Stage %N	8-Leaf Stage %P	8-Leaf Stage %K	8-Leaf Stage %Ca	8-Leaf Stage %Mg	Boot Stage %N	Boot Stage %P	Boot Stage %K	Boot Stage %Ca	Boot Stage %Mg
	1977 Grain Sorghum											
Control	4731	10.1						3.02	.29	1.63	.32	.28
560	4570	10.0						2.93	.29	1.68	.31	.24
1120	4193	9.9						2.95	.29	1.69	.26	.24
5600	4845	10.0						2.98	.28	1.64	.28	.26
5600 Ag Lime	4442	10.0						3.07	.29	1.65	.32	.28
$LSD_{.05}$	NS	NS						NS	NS	NS	NS	NS
	1978 Grain Sorghum											
Control	2460		3.17	.25	1.75	.26	.26	2.64	.23	1.54	.35	.24
560	2097		3.27	.28	1.84	.27	.26	2.55	.21	1.61	.33	.24
1120	2412		3.22	.28	1.72	.28	.28	2.68	.22	1.64	.36	.25
5600	2117		3.20	.26	1.70	.28	.27	2.56	.22	1.57	.30	.23
5600 Ag Lime	2171		3.23	.27	1.65	.28	.28	2.62	.21	1.54	.33	.24
$LSD_{.05}$	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	1979 Wheat											
Control	3589	13.2										
560	3421	13.0										
1120	3562	12.7										
5600	3549	12.6										
5600 Ag Lime	3582	12.3										
$LSD_{.05}$	NS	NS										

Soil test values for P, K, Ca and Mg (Table 7) were not significantly affected by lime treatment. The 1977 treatments used as the lime source cement plant stack dust, which contained 3.65% total K, 26.0% Ca and 1.43% Mg. The 5600 kg ECC/ha rate applied 262 kg K, 1867 kg Ca and 103 kg Mg/ha. Soil nutrient levels were relatively high at this site and significant soil test increases may have been obscured by variability. Soil P tests were generally in the high range and were not affected by lime application.

Soybean Study. Soil pH results from the soybean study located at the Southeast Branch Experiment Station in Labette county are shown graphically in Appendix Figures 5, 6 and 7 for 1977, 1978 and 1979, respectively. Similar to the Marion county study in 1977, the 5600 kg fluid treatment gave a rapid significant initial pH increase (Table 8). Agricultural lime reaction was slower, but by August 1977 the agricultural lime soil pH had increased to a level that was not different statistically from the soil pH with the 5600 kg fluid treatment. The soil pH from both lime sources at the 5600 kg/ha rate continued equal through 1978 and 1979 (Table 9). The annual 560 and 1120 kg treatments gave pH increases proportional to the rate applied with each application. Following the second annual application in 1978, the soil pH with the 1120 kg rate was consistently higher than the control pH at the 5% level of significance.

In July 1978 the plots were sampled in two depth increments to determine if a pH gradient existed in the plow layer. On the check plot the pH was nearly equal in the two depths showing a uniform need

Table 7. EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOIL LEVELS OF P, K, Ca AND Mg OVER THREE YEARS - 1977, 1978 AND 1979 IN MARION COUNTY.

Lime Rate (kg ECC/ha)	1977 10-13	1978 5-5	1978 7-28	1979 5-17
		Available P, ppm		
Control	31	20	42	39
560	35	21	42	38
1120	30	22	46	31
5600	27	24	37	29
5600 Ag Lime	25	22	40	30
$LSD_{.05}$	NS	NS	NS	NS
		Exchangeable K, ppm		
Control	225	280	271	210
560	218	251	268	220
1120	220	258	270	196
5600	229	300	285	204
5600 Ag Lime	188	250	245	180
$LSD_{.05}$	NS	NS	NS	NS
		Extractable Ca, ppm		
Control	2829		2926	
560	2782		2716	
1120	2857		2850	
5600	2982		3188	
5600 Ag Lime	2910		3081	
$LSD_{.05}$	NS		NS	
		Extractable Mg, ppm		
Control	615		565	
560	587		521	
1120	606		542	
5600	617		538	
5600 Ag Lime	609		517	
$LSD_{.05}$	NS		NS	

Table 8. EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOIL pH AND LIME REQUIREMENT IN 1977 IN LABETTE COUNTY.

Lime Rate (kg ECC/ha)	Sampling Dates 1977													
	3-17	3-23	3-30	4-7	4-22	5-5	7-6	7-21	8-2	8-22	8-31	9-20	10-6	10-25
	pH													
Control	5.1	5.0	5.1	5.0	5.1	5.2	5.4	5.1	5.4	5.4	5.4	5.4	5.3	5.3
560	5.4	5.0	5.2	5.2	5.4	5.2	5.4	5.3	5.3	5.6	5.5	5.4	5.4	5.5
1120	5.8	5.2	5.5	5.4	5.6	5.5	5.6	5.5	5.5	5.7	5.6	5.5	5.6	5.5
5600	6.1	5.8	6.3	5.9	6.1	5.9	6.7	6.5	6.4	6.5	6.0	6.4	6.3	6.5
5600 Ag Lime	5.7	5.2	5.5	5.4	5.7	5.5	6.2	6.0	5.8	6.2	6.3	6.0	6.3	6.0
$LSD_{.05}$	0.4	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.6	0.2	0.4	0.5	0.2	0.5
	Lime Requirement, kg ECC/ha													
Control	5600	5600	6400	5900	4500	4800	4500	5000	3100	3100	2800	4500	4200	5000
560	4200	5300	5600	5300	3600	3900	3900	4800	3200	2700	2800	4200	3400	3900
1120	3200	4500	5200	3900	3500	3500	3600	3800	2900	2200	2500	3500	2900	3400
5600	2100	2800	1400	2700	2100	2100	1000	1000	600	700	1500	1300	1400	600
5600 Ag Lime	3200	4200	4900	3900	3800	3600	2200	2400	2000	1400	1100	2000	1500	2200
$LSD_{.05}$	1400	900	1400	1000	1000	1200	1000	1000	1100	700	1000	900	800	1200

Table 9. EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOIL pH AND LIME REQUIREMENT OVER TWO YEARS - 1978 AND 1979 IN LABETTE COUNTY.

Lime Rate (kg ECC/ha)	Sampling Dates 1978 4-25	5-11	5-26	6-16	7-1	7-18	9-5	10-3
	pH							
Control	5.5	5.5	5.4	5.5	5.4	5.6	5.4	5.4
560	5.8	5.7	5.6	5.7	5.6	5.8	5.6	5.7
1120	5.8	5.9	5.8	5.8	5.8	6.0	5.9	6.0
5600	6.2	6.2	6.2	6.2	6.1	6.4	6.2	6.4
5600 Ag Lime	6.5	6.2	6.2	6.1	6.1	6.3	6.3	6.3
$LSD_{.05}$	0.3	0.3	0.3	0.2	0.3	0.2	0.3	0.3
	Lime Requirement, kg ECC/ha							
Control	4500	4200	4200	2500	3900	3300	4200	4100
560	3600	3600	3200	2800	3500	2600	3600	3500
1120	3200	3600	3200	2000	2900	2200	2500	2400
5600	2400	2200	2100	1100	2100	1100	1700	1300
5600 Ag Lime	1000	2100	2100	1100	2000	1100	1500	1300
$LSD_{.05}$	1000	900	1200	700	900	600	900	1000

Table 9. (cont.) EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOIL pH AND LIME REQUIREMENT OVER TWO YEARS - 1978 AND 1979 IN LABETTE COUNTY.

Lime Rate (kg ECC/ha)	Sampling Dates 1979 3-15	4-5	4-30	6-1	7-12	8-1	8-17
	pH						
Control	5.6	5.6	5.5	5.7	5.8	5.8	5.7
560	5.8	5.8	5.6	6.0	6.0	5.2	5.9
1120	6.2	6.3	5.9	6.2	6.2	6.4	6.2
5600	6.6	6.6	6.1	6.6	6.6	6.8	6.6
5600 Ag Lime	6.8	6.6	6.1	6.5	6.6	6.9	6.6
$LSD_{.05}$	0.3	0.3	0.2	0.4	0.2	0.2	0.2
	Lime Requirement, kg ECC/ha						
Control	3200	3800	3400	2800	2000	2400	3400
560	2700	3100	3100	2400	1400	1500	2500
1120	1700	1500	2500	1500	1300	1100	2000
5600	600	--	2100	300	100	300	400
5600 Ag Lime	--	--	2100	600	--	--	--
$LSD_{.05}$	700	900	500	1100	400	600	700

for lime in the 15 cm depth used for determining lime rate (Figure 8 and Appendix Table 1). With each increasing rate of lime, a higher pH in the 0-8 cm zone was observed than with the 8-15 cm zone. This difference may be due to the tillage method which includes disking and chiselling and may be insufficient for thorough plow layer mixing of the lime. These differences were consistent with the August 1979 sample that was taken in a similar manner (Figure 9 and Appendix Table 1). The highest lime rate was fairly effective in increasing the 8-15 cm pH.

Lime treatment did not significantly affect nutrient uptake or grain yield (Table 10). A slight soybean yield increase with lime rate was observed each year; however, these differences were not statistically significant. Visual height and color differences were observed among soybean plants early in the 1979 growing season. However, this difference was negligible by mid-summer.

Soil samples were analyzed for P and K to determine the effect of lime treatments (Table 11). Soil P levels were not affected, but soil exchangeable K was significantly increased by the 5600 kg fluid treatment in 1977. The stack dust lime source included 3.65% K, which resulted in a significant soil K increase. The Mg application rate through stack dust was 92 kg/ha and gave significantly higher soil Mg levels on one date in 1977 (Table 12). Soil Ca levels were significantly increased by lime application on at least one sampling date each year. Soil nutrient increases were not surprising due to the low native fertility of this soil and the amount of nutrients applied. The soil

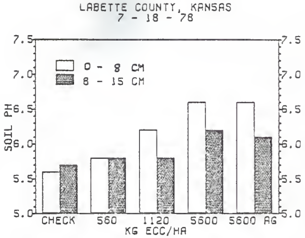


Figure 8. Effect of lime suspension rates and agricultural lime on soil pH from two depths of sampling, Labette county, 1978.

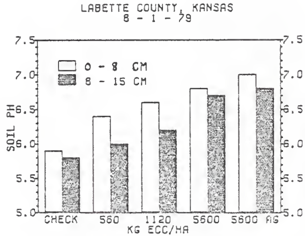


Figure 9. Effect of lime suspension rates and agricultural lime on soil pH from two depths of sampling, Labette county, 1979.

Table 10. EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOYBEAN PLANT NUTRIENT CONTENT IN 1978 AND 1979 AND GRAIN YIELD OVER THREE YEARS - 1977, 1978 AND 1979 IN LABETTE COUNTY.

Lime Rate (kg ECC/ha)	Grain Yield (kg/ha)	Tissue Composition				
		%N	%P	%K	%Ca	%Mg
1977						
Control	1781					
560	1740					
1120	1942					
5600	1927					
5600 Ag Lime	2117					
$LSD_{.05}$	NS					
1978						
Control	1290	4.93	.34	2.39	1.05	.38
560	1364	4.76	.34	2.56	1.12	.38
1120	1384	4.73	.35	2.63	1.05	.38
5600	1485	4.88	.36	2.62	1.06	.38
5600 Ag Lime	1425	4.87	.36	2.36	1.09	.39
$LSD_{.05}$	NS	NS	NS	NS	NS	NS
1979						
Control	2016	4.92	.44	2.18	.83	.34
560	2171	4.92	.43	2.23	.92	.34
1120	2178	5.05	.43	2.07	.94	.36
5600	2171	5.25	.48	2.16	.84	.34
5600 Ag Lime	2204	5.32	.45	1.93	1.00	.39
$LSD_{.05}$	NS	NS	NS	NS	NS	NS

Table 11. EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOIL LEVELS OF P AND K OVER THREE YEARS - 1977, 1978 AND 1979 IN LABETTE COUNTY.

Lime Rate	Sampling Dates											
	1977								1978		1979	
(kg ECC/ha)	7-6	7-21	8-2	8-22	8-31	9-20	10-6	10-25	4-25	9-5	3-15	6-1
	Available P, ppm											
Control	15	17	16	12	12	12	12	10	11	19	16	19
560	15	15	16	14	14	13	12	13	10	20	18	20
1120	14	14	14	14	12	12	12	11	11	24	17	20
5600	15	15	19	18	13	16	15	13	12	21	20	24
5600 Ag Lime	13	15	19	13	15	14	13	12	12	23	18	22
$LSD_{.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Exchangeable K, ppm											
Control	97	98	117	100	101	108	111	111	94	121	120	106
560	109	94	129	113	113	128	125	132	91	133	158	125
1120	109	102	125	122	120	122	129	123	94	132	122	123
5600	147	110	161	154	135	160	140	163	105	140	165	149
5600 Ag Lime	96	93	116	99	103	117	122	121	93	129	129	120
$LSD_{.05}$	50	NS	NS	36	NS	28	NS	34	NS	NS	NS	NS

Table 12. EFFECT OF LIME SUSPENSION RATES AND AGRICULTURAL LIME ON SOIL LEVELS OF Ca AND Mg OVER THREE YEARS - 1977, 1978 AND 1979 IN LABETTE COUNTY.

Lime Rate (kg ECC/ha)	Sampling Dates 1977 7-6	1977 7-21	1977 8-2	1977 8-22	1977 8-31	1978 9-5	1979 6-1
			Extractable Ca, ppm				
Control	1376	1552	1540	1339	1379	1376	1944
560	1516	1445	1538	1442	1545	1518	2442
1120	2290	1702	1486	1942	1604	1586	2209
5600	2451	1702	1904	1923	1695	1818	2766
5600 Ag Lime	1914	1387	1698	1908	1844	1790	2586
$LSD_{.05}$	311	NS	NS	NS	NS	111	258
			Extractable Mg, ppm				
Control	180	183	222	206	215	178	267
560	194	169	239	216	229	183	296
1120	280	194	212	250	220	185	232
5600	206	184	225	222	209	200	283
5600 Ag Lime	186	190	219	209	214	180	234
$LSD_{.05}$	30	NS	NS	NS	NS	NS	NS

nutrient increases observed were partially diminished by the blanket application of 6-24-24 fertilizer in 1977.

The results of this study indicate that lime suspensions will react in a similar manner to conventional agricultural lime with regard to soil pH change. Lime application rate for lime suspensions will be the same as for conventional agricultural lime to give equal soil pH changes. The finely divided lime used in lime suspensions allows a quicker soil reaction, but low rates of lime (560-1120 kg ECC/ha) will require repeated applications to raise the soil pH.

Laboratory Evaluations

Suspension Ammonia Losses. Results from the initial suspension NH_3 loss study are given in Figure 10 and Appendix Table 2. The results are expressed as the accumulative NH_3-N loss from the NH_4^+ fraction of the UAN sample. The UAN used in the study contained 7.59% N as NH_4^+. A 100 percent NH_3-N loss would be approximately one-fourth of the total N content of UAN (28-0-0). No NH_3 volatilization was detected from the lime-UAN suspensions of reagent grade $CaCO_3$ (0% CaO) and ground limestone. However, considerable NH_3-N loss was found with the two suspensions using lime sources containing CaO. Ammonia-N loss from the 50% CaO-lime suspension occurred at a faster initial rate and after 2 hours the loss was more than double the loss from the stack dust (14% CaO) suspension. The slope of the loss curves at 2 hours indicated that accumulative losses would have been greater with more time. This study showed that NH_3 loss could occur, but did not show how much CaO could be present before loss of NH_3 was substantial.

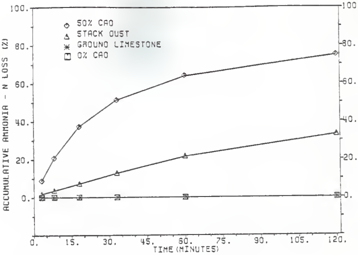


Figure 10. Effect of lime source on ammonia volatilization from lime-UAN suspensions.

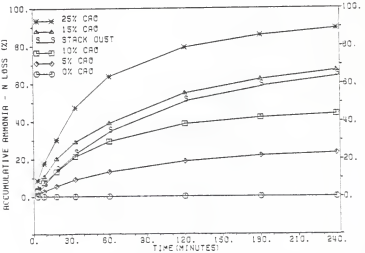


Figure 11. Effect of lime calcium oxide content on ammonia volatilization from lime-UAN suspensions.

To evaluate the relationship between lime-CaO content and magnitude of NH_3-N loss from lime-UAN suspensions, a second laboratory evaluation was established. Ammonia volatilization would be likely with a lime source containing appreciable amounts of CaO and may be explained by these reactions:

1. $CaO + H_2O \rightleftharpoons Ca^{++} + 2\ OH^-$ (12.5 pH)
2. $NH_4^+ + OH^- \rightleftharpoons NH_3\uparrow + H_2O$

The amount of CaO in suspension dictates the suspension pH, which is a major factor in NH_3 volatilization. Lime-material - water pH's for all CaO-containing lime sources are relatively constant at approximately 12.2 (Table 13) compared to 8.9 for pure $CaCO_3$ (0% CaO). When these lime sources were suspended with UAN, an increase in pH was found as the percent CaO increased. This relationship supports the mechanism suggested above for NH_3 volatilization. Lime-UAN suspension pH's for the 100% $CaCO_3$ lime material and the ground limestone were each 6.5. Ammonia volatilization would not be expected at this relatively acid pH. The stack dust-UAN suspension pH fell between the lime-UAN suspension pH's for the 10 and 15% CaO lime sources, agreeing well with a previous laboratory CaO determination for this stack dust sample of 14%.

Five reagent grade CaO-lime mixtures composed of increasing ratios of CaO:$CaCO_3$ were used to formulate lime-UAN suspensions to evaluate NH_3-N volatilization. Stack dust was included as a lime source. Initial rates of loss and total losses showed a direct relationship to the CaO content (Figure 11 and Appendix Table 3). Ammonia-N loss

Table 13. EFFECT OF LIME CALCIUM OXIDE CONTENT ON SUSPENSION pH.

Lime Material		Lime Material + Water	Lime Material + UAN
% CaO	% $CaCO_3$	Suspension pH	
50	50	12.3	11.6
25	75	12.2	11.3
15	85	12.2	9.6
14	(Stack Dust)	12.4	9.3
10	90	12.3	9.2
5	95	12.2	8.7
0	100	8.9	6.5
Ground Limestone		8.6	6.5
UAN + Water	6.4 pH		
UAN Only	6.3 pH		

rates declined with time and by the end of the 4 hours were very slow. Losses ranged from no loss with the 100% $CaCO_3$ source to nearly 90% NH_3-N loss with the 25% CaO material. Accumulative NH_3-N loss from the stack dust (14% CaO) suspension was slightly less than the 15% CaO lime suspension through the course of the trial indicating a commercially available suspendable lime source containing CaO reacted as expected when compared to reagent grade materials.

Due to air sparging limitations with the apparatus, a considerable amount of lime material settled out of suspension in each flask during the trial and physically prevented unexposed material from chemically reacting with the suspension. This may have lowered total losses and rates of loss compared to the more efficient air sparge systems in commercial operations; however, the data show that CaO-containing lime should not be used for lime suspensions made with UAN.

The CaO content of each lime-UAN suspension in the second NH_3 loss study was used to compare the potential chemically equivalent NH_3-N losses to actual loss (Figure 12 and Appendix Table 4). Equivalent NH_3-N losses were calculated by assuming that a given number of CaO meq would cause volatilization of an equal number of meq of N as NH_3. These losses were expressed as a percentage of the total NH_3-N initially present in each suspension. The 132% NH_3-N loss predicted for the 25% CaO lime suspension was not possible, but showed the potential loss of NH_3-N had the number of N meq as NH_3 been equal to or greater than the number of CaO meq. Actual losses shown in the figure were the total NH_3-N losses measured after 4 hours. Ammonia-N

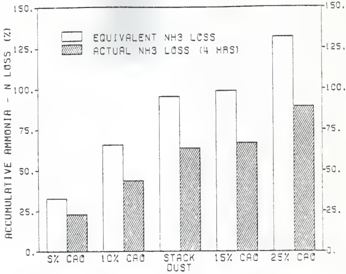


Figure 12. Comparison of calcium oxide-equivalent ammonia losses and actual ammonia volatilization losses from lime-UAN suspensions with variable calcium oxide contents.

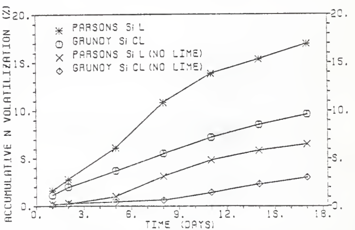


Figure 13. Effect of soil type and the presence of lime on ammonia volatilization from soil applied lime-UAN suspensions.

losses might have been greater if more of the lime material had stayed in suspension and reacted to influence the suspension pH.

These studies indicate that lime materials containing appreciable amounts of CaO can be expected to cause substantial NH_3 volatilization during and following preparation of a lime-UAN suspension. Initial rates of loss and total losses were directly proportional to the CaO content of the lime material.

Soil Applied Suspension Ammonia Losses. A third laboratory study was performed to evaluate N volatilization from the soil surface following application of lime-UAN suspensions. To prevent NH_3 volatilization prior to soil application, ground limestone was used as the lime source. Two soil types with different CEC's were used to evaluate the effect of CEC on NH_3 losses. The Grundy silty clay loam and the Parsons silt loam had CEC's of 19.5 and 10.2 me/100 g, respectively.

Greater initial and total N losses over the 17 days were measured from lime-UAN treatments compared to UAN without lime on both soils (Figure 13 and Appendix Table 5). Volatilization losses were reported as percent of the total N present in each treatment and could include possible NH_3 losses during urea hydrolysis. Based on the previous laboratory study with this lime source, no NH_3 losses were expected from the lime-UAN suspension (pH 6.5). However, NH_3 volatilization would be more likely following soil application and the subsequent increase in soil pH from hydrolysis of urea. The lime-UAN treatment and its high pH environment at the soil surface would be more conducive to NH_3 losses than the UAN treatments without lime.

With the soil moisture content near field capacity, sufficient moisture was present for urea hydrolysis to occur. Chin and Kroontje (10) reported that urea-N loss through NH_3 volatilization may immediately follow urea hydrolysis.

Cation exchange capacity influenced NH_3 volatilization regardless of the presence of lime. Identical suspensions applied to both soils resulted in greater volatilization losses from the Parsons soil (CEC of 10.2) compared to the Grundy soil (CEC of 19.5). This agrees well with the findings of Volk (45), who suggested that soils having a CEC of 10 or less were especially susceptible to NH_3 volatilization.

Soil organic matter is similar to soil clays with regard to effect on NH_3 retention. Soil organic matter content was 3.0 and 3.4% for the Parsons and Grundy soil, respectively. Since the Grundy organic matter level was only 13% greater than the Parsons organic matter level, it was not considered to be a contributing factor to the NH_3 loss differences found in this study.

Even though some air humidifying effect was achieved with the acid scrub flask, the soil surface in each chamber was subject to a small degree of drying between water mist applications. Other researchers (16, 25, 32) have noted that partial drying, especially at high soil moisture levels, was conducive to NH_3 volatilization.

The results of this study indicate that the presence of a $CaCO_3$ lime source was a contributing factor to NH_3 volatilization from surface applied lime-UAN suspensions. Soil CEC had a negative relationship to

NH_3 volatilization from surface applied treatments. Based on previous research, soil surface drying may have facilitated NH_3 volatilization in this study. Due to the favorable NH_3 volatilization conditions present in the laboratory study, losses observed in a field situation would probably be less.

Greenhouse Evaluations

Lime-UAN-Herbicide Suspension Evaluation. This preliminary greenhouse study was intended to be a broad spectrum evaluation to look at lime-UAN-herbicide suspension compatibility and effects of herbicide toxicity on seedlings. Several herbicide treatments were added to lime-UAN suspensions for application on grain sorghum, corn and soybeans.

Grain sorghum study. As a result of applying the lime in combination with the UAN-herbicide mixture to the soil as a suspension (Lime Combination) as compared to the lime applied 48 hours before the UAN-herbicide application (Lime Prior), grain sorghum dry matter weights were significantly higher (Table 14). There was concern that the lime-UAN combination might produce enough free NH_3 to cause seedling injury; however, this data would indicate that free NH_3 did not hinder seedling growth when lime was applied with UAN solution. The Lime Combination method also produced a significantly higher soil pH and lower lime requirement at the first sampling date 2 weeks after application. However, this difference disappeared by the second sampling a week later. Lime reaction differences were not expected since field data indicate this finely ground lime material reacts rapidly following

Table 14. EFFECT OF LIME-UAN-HERBICIDE SUSPENSIONS ON GRAIN SORGHUM GROWTH, SOIL pH AND LIME REQUIREMENT.

	pH		Lime Requirement kg ECC/ha		Dry Weight
	Week		Week		
Treatment	2	3	2	3	g/pot
Lime Prior Application					
Propazine	5.8	5.8	4100	4100	1.5
Terbutryn + Propazine	5.8	5.9	3700	4100	1.5
Terbutryn + Atrazine	5.9	5.8	4100	4100	1.7
Propachlor + Atrazine	5.8	5.9	4500	3900	1.3
Lime Combination Application					
Propazine	5.9	5.8	3100	4100	1.9
Terbutryn + Propazine	6.0	5.9	2600	3600	2.2
Terbutryn + Atrazine	5.9	5.9	3100	3600	2.1
Propachlor + Atrazine	6.0	5.8	3400	4300	1.8
$LSD_{.05}$	0.1	NS	800	NS	NS*
Mean Values:					
Time of Lime Application					
Lime Prior	5.8	5.8	4100	4000	1.5
Lime Combination	6.0	5.8	3100	3900	2.0
$LSD_{.05}$	0.1	NS	300	NS	0.3
Herbicide Variables					
Propazine	5.9	5.8	3600	4100	1.7
Terbutryn + Propazine	5.9	5.9	3100	3800	1.8
Terbutryn + Atrazine	5.9	5.9	3600	3800	1.9
Propachlor + Atrazine	5.9	5.8	3900	4100	1.6
$LSD_{.05}$	NS	NS	500	NS	NS

* Significant at the .07 level.

soil application. Time between lime application and sampling should have been sufficient for the lime reaction to near completion.

Corn study. Corn seedling weights were not significantly affected by time of lime application or herbicide treatment (Table 15). Soil pH was increased significantly and lime requirement decreased with the Lime Combination application method on the first sampling date; however, the change was quite small and probably of little agronomic significance.

Soybean study. Soybean plant weights were not significantly affected by time of lime application or herbicide treatment (Table 16). The Lime Combination method again produced a significantly lower lime requirement on the first sampling date which disappeared by the second sampling. Because all treatments were incorporated to a depth of 5 cm rather than the recommended 15 cm, the rate on the 5 cm depth would correspond to three times the applied rate of 443 kg ECC/ha or 1329 kg ECC/ha.

The results of this study indicate that lime-UAN suspensions pose no compatibility problems when combined with these herbicides. Lime requirement and pH changes were relatively small and did not continue to the second sampling. Applying lime together with a herbicide-UAN mixture does not appear to cause greater seedling damage when compared to soil limed prior to the herbicide-UAN application. No seedling damage from free NH_3 was observed with the lime-UAN-herbicide suspension treatments. The results of this study were inconclusive and prompted establishment of a second greenhouse study.

Table 15. EFFECT OF LIME-UAN-HERBICIDE SUSPENSIONS ON CORN GROWTH, SOIL pH AND LIME REQUIREMENT.

	pH		Lime Requirement kg ECC/ha		Dry Weight
	Week		Week		
Treatment	2	3	2	3	g/pot
Lime Prior Application					
Atrazine + Alachlor	6.1	5.9	3000	4100	2.8
Atrazine + Metolachlor	5.9	5.9	3700	4100	2.5
Atrazine + EPTC*	5.8	5.9	3700	3900	2.6
Atrazine + Butylate*	5.8	6.0	3700	4100	2.8
Cyanazine + Butylate*	5.9	5.9	3400	4100	2.6
Lime Combination Application					
Atrazine + Alachlor	6.1	5.9	3000	4100	2.5
Atrazine + Metolachlor	6.0	5.9	3100	4300	3.1
Atrazine + EPTC*	5.9	5.9	3100	4300	2.5
Atrazine + Butylate*	6.0	5.8	3100	4100	2.5
Cyanazine + Butylate*	5.9	5.8	3000	3700	2.1
$LSD_{.05}$	0.1	NS	NS	NS	NS
Mean Values:					
Time of Lime Application					
Lime Prior	5.9	5.9	3500	4000	2.6
Lime Combination	6.0	5.9	3100	4100	2.5
$LSD_{.05}$	0.1	NS	300	NS	NS
Herbicide Variables					
Atrazine + Alachlor	6.1	5.9	3000	4100	2.6
Atrazine + Metolachlor	5.9	5.9	3500	4200	2.8
Atrazine + EPTC*	5.8	5.9	3500	4100	2.5
Atrazine + Butylate*	5.9	5.9	3500	4100	2.6
Cyanazine + Butylate*	5.9	5.9	3200	3900	2.4
$LSD_{.05}$	0.1	NS	NS	NS	NS

* Herbicide includes R-25788 (plant protectant).

Table 16. EFFECT OF LIME-UAN-HERBICIDE SUSPENSIONS ON SOYBEAN GROWTH, SOIL pH AND LIME REQUIREMENT.

	pH		Lime Requirement kg ECC/ha		Dry Weight
	Week		Week		
Treatment	2	3	2	3	g/pot
Lime Prior Application					
Metribuzin + Trifluralin	5.8	6.0	3700	4500	1.7
Metribuzin + Pendimethalin	5.8	5.9	4500	4100	2.0
Metribuzin + Alachlor	5.9	5.9	3700	3700	1.7
Metribuzin + Metolachlor	6.0	5.9	3900	4100	1.5
Lime Combination Application					
Metribuzin + Trifluralin	5.9	5.8	3200	4100	1.6
Metribuzin + Pendimethalin	5.8	5.9	4100	4100	1.6
Metribuzin + Alachlor	6.0	5.9	2600	4100	1.6
Metribuzin + Metolachlor	5.9	5.9	3100	3900	1.6
$LSD_{.05}$	NS	NS	NS	NS	NS
Mean Values:					
Time of Lime Application					
Lime Prior	5.9	5.9	4000	4100	1.7
Lime Combination	5.9	5.9	3300	4000	1.6
$LSD_{.05}$	NS	NS	634	NS	NS
Herbicide Variables					
Metribuzin + Trifluralin	5.9	5.9	3500	4300	1.7
Metribuzin + Pendimethalin	5.8	5.9	4300	4100	1.8
Metribuzin + Alachlor	6.0	5.9	3100	3900	1.6
Metribuzin + Metolachlor	5.9	5.9	3600	4000	1.5
$LSD_{.05}$	NS	NS	NS	NS	NS

Lime Rate-Herbicide Suspension Evaluation

Grain sorghum study. The soil pH, lime requirement and plant dry weight data from the grain sorghum study are presented in Table 17. The surface applied lime-herbicide suspensions produced significantly higher plant weights than the incorporated treatments. This difference may be due to a smaller quantity of herbicide present in the root zone with the surface application. Soil applied triazines rely primarily on root absorption for plant uptake. The greater concentration of triazine present in the root zone of the incorporated treatments could have inhibited seedling growth enough to show this difference. No significant plant weight differences were noted due to herbicide or to lime treatment. The lime treatment applied 1 week prior to the atrazine application (Prior 1700) did not result in any plant weight or visual differences from the lime-herbicide tank mix treatments.

Soil pH was significantly raised and lime requirement significantly lowered in proportion to the quantity of lime applied at all sampling dates. Lime treatments averaged across application and herbicide variables indicate that the Prior 1700 treatment produced a higher soil pH and lower lime requirement than the Tank 1700 treatment. This difference may be due to a 1 week longer incubation period for the Prior 1700 treatment, although the finely ground lime material was expected to react rapidly with the soil. When averaged across the herbicide and lime variables, the incorporated treatments produced a higher soil pH and a lower lime requirement than the surface applied treatments. This difference may have been caused by a more uniform lime distribution in the soil with the incorporated treatments. The

Table 17. EFFECT OF LIME-HERBICIDE SUSPENSIONS ON GRAIN SORGHUM GROWTH, SOIL pH AND LIME REQUIREMENT.

	pH			Lime Requirement kg ECC/ha			Dry Weight
	Week			Week			
Treatment	1	2	3	1	2	3	g/pot
Surface Application							
Propachlor + Atrazine							
Prior 1700	6.1	6.1	6.0	2100	2100	2500	0.16
Tank 1700	6.0	6.1	5.6	2800	2200	3700	0.14
Tank 850	5.9	5.6	5.8	2500	2600	2000	0.17
No Lime	5.1	5.2	5.2	4500	3900	4300	0.13
Atrazine							
Prior 1700	6.4	5.8	6.0	1100	2500	2600	0.17
Tank 1700	6.3	6.2	6.1	1500	1700	2600	0.17
Tank 850	6.0	5.8	5.8	2500	2200	2800	0.16
No Lime	5.1	5.3	5.2	3700	3000	4100	0.14
Incorporated							
Propachlor + Atrazine							
Prior 1700	6.7	6.7	6.7	—	—	—	0.13
Tank 1700	6.3	6.3	6.3	1700	900	2100	0.13
Tank 850	5.8	6.0	5.9	2500	2000	2200	0.12
No Lime	5.1	5.1	5.1	4800	3700	5600	0.12
Atrazine							
Prior 1700	6.6	6.7	6.6	—	—	—	0.10
Tank 1700	6.5	6.4	6.5	—	1300	600	0.13
Tank 850	6.0	5.9	5.8	2000	2100	2500	0.12
No Lime	5.2	5.3	5.2	3900	3100	4500	0.16
No Lime - No Herbicide	5.1	5.2	5.2	4100	3100	3700	0.17
$LSD_{.05}$	0.3	0.2	0.3	1200	900	1200	0.04

Table 17. (Cont.) EFFECT OF LIME-HERBICIDE SUSPENSIONS ON GRAIN SORGHUM GROWTH, SOIL pH AND LIME REQUIREMENT.

	pH			Lime Requirement kg ECC/ha			Dry Weight
	Week			Week			
Mean Values	1	2	3	1	2	3	g/pot
Application Variables							
Surface	5.9	5.8	5.7	2600	2500	3100	0.15
Incorporated	6.0	6.0	6.0	2100	1600	2100	0.13
$LSD_{.05}$	0.1	0.1	0.1	400	300	400	0.01
Herbicide Variables							
Propachlor + Atrazine	5.9	5.9	5.8	2600	2100	2800	0.14
Atrazine	6.0	5.9	5.9	1800	2000	2500	0.14
$LSD_{.05}$	0.1	NS	NS	400	NS	NS	NS
Lime Variables							
Prior 1700	6.4	6.3	6.3	800	1100	1200	0.14
Tank 1700	6.3	6.2	6.1	1500	1600	2200	0.14
Tank 850	5.9	5.8	5.8	2400	2200	2400	0.14
No Lime	5.1	5.2	5.2	4300	3500	4600	0.14
$LSD_{.05}$	0.2	0.1	0.1	600	400	600	NS

lime distribution with the surface applied treatments was variable as seen in the pH and lime requirement data. A considerable amount of soil in this 5 cm sampling zone did not come in contact with lime, causing a smaller overall pH adjustment.

A statistically significant interaction between the lime treatments and method of incorporation was found for soil pH and lime requirement on the three sampling dates. As the lime rate increased, a greater change in pH and lime requirement was observed with the incorporated treatments than with the surface-applied treatments. Lime requires thorough mixing with the soil to achieve maximum efficiency and the effect of poor incorporation is more evident with the higher lime rates.

Significantly higher soil pH and lower lime requirement was noted with atrazine compared to the propachlor-atrazine combination on the first sampling date when averaged over the application and lime variables. This difference was small and no apparent reason was seen for this difference.

Soybean study. The soil pH, lime requirement and plant weight data from the soybean trial are given in Table 18 reported by soil type. Soybeans grown on the Eudora loam had significantly lower dry weights than soybeans grown on the Muir silt loam. The lighter plant weights on the Eudora soil were the result of reduced plant vigor and the loss of leaves. The Eudora soil, being coarser textured and having only 1% organic matter, was more susceptible than the Muir soil (4.6% organic matter) to the high rate of herbicide applied. This difference

Table 18. EFFECT OF LIME-HERBICIDE SUSPENSIONS ON SOYBEAN GROWTH, SOIL pH AND LIME REQUIREMENT.

Treatment	pH Week 1	pH Week 2	pH Week 3	Lime Requirement kg ECC/ha Week 1	Lime Requirement kg ECC/ha Week 2	Lime Requirement kg ECC/ha Week 3	Dry Weight g/pot
Muir Silt Loam							
Trifluralin + Metribuzin							
Prior 1700	7.3	7.1	7.2	--	--	--	2.35
Tank 1700	7.2	7.1	7.1	--	--	--	2.02
Tank 850	7.2	7.0	7.0	--	--	--	2.17
No Lime	6.8	6.8	6.7	--	--	--	1.64
Alachlor + Metribuzin							
Prior 1700	7.4	7.1	7.2	--	--	--	1.76
Tank 1700	7.3	7.2	7.1	--	--	--	2.13
Tank 850	7.3	7.1	7.0	--	--	--	2.34
No Lime	6.8	6.8	6.8	--	--	--	2.01
No Lime - No Herbicide	6.8	6.7	6.6	--	--	--	2.28
Eudora Loam							
Trifluralin + Metribuzin							
Prior 1700	6.8	6.5	6.8	800	800	--	0.66
Tank 1700	6.4	6.2	6.3	900	1500	2000	0.95
Tank 850	5.9	5.7	6.0	1900	2000	2800	0.46
No Lime	5.2	5.1	5.1	3700	3400	5600	0.81
Alachlor + Metribuzin							
Prior 1700	6.4	6.5	6.8	300	300	--	0.66
Tank 1700	6.4	6.3	6.5	1100	1100	600	0.57
Tank 850	6.0	5.5	6.0	2000	2000	2800	0.57
No Lime	5.2	5.1	5.1	3100	4500	4800	0.62
No Lime - No Herbicide	5.1	5.0	5.2	3700	4500	5600	1.27
$LSD_{.05}$	0.2	0.2	0.2	800	400	600	0.47

Table 18. (Cont.) EFFECT OF LIME-HERBICIDE SUSPENSIONS ON SOYBEAN GROWTH, SOIL pH AND LIME REQUIREMENT.

Mean Values	pH Week 1	pH Week 2	pH Week 3	Lime Requirement kg ECC/ha Week 1	Week 2	Week 3	Dry Weight g/pot
Soil Type							
Muir	7.2	7.0	7.0	--	--	--	2.05
Eudora	6.0	5.9	6.1	1800	1900	2400	0.66
$LSD_{.05}$	0.1	0.1	0.1	300	200	200	0.17
Muir Soil Means							
Herbicide Variables							
Trifluralin + Metribuzin	7.1	7.0	7.0	--	--	--	2.03
Alachlor + Metribuzin	7.2	7.0	7.0	--	--	--	2.06
$LSD_{.05}$	NS	NS	NS	--	--	--	NS
Lime Variables							
Prior 1700	7.4	7.1	7.2	--	--	--	2.06
Tank 1700	7.2	7.2	7.1	--	--	--	2.08
Tank 850	7.2	7.0	7.0	--	--	--	2.22
No Lime	6.8	6.8	6.8	--	--	--	1.83
$LSD_{.05}$	0.1	0.1	0.1	--	--	--	NS
Eudora Soil Means							
Herbicide Variables							
Trifluralin + Metribuzin	6.0	5.9	6.0	1800	1900	2600	0.72
Alachlor + Metribuzin	6.0	5.8	6.1	1700	2100	2000	0.60
$LSD_{.05}$	NS	NS	NS	NS	NS	300	NS
Lime Variables							
Prior 1700	6.4	6.5	6.8	600	600	--	0.66
Tank 1700	6.4	6.2	6.4	1000	1300	1300	0.76
Tank 850	6.0	5.6	6.0	2000	2300	2800	0.51
No Lime	5.2	5.1	5.1	3500	3900	5200	0.72
$LSD_{.05}$	0.2	0.1	0.2	900	400	500	NS

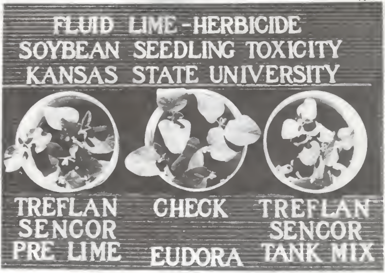
occurred regardless of the time of lime application (1700 kg ECC/ha) as shown in Figure 14. The level of organic matter in the Muir soil was sufficient to prevent herbicide toxicity to soybeans at the application rates used.

Soil organic matter attracts positively-charged particles in a manner similar to clay minerals. Low organic matter soils are more susceptible to enhanced herbicide activity due to less adsorption capacity. Crop injury from metribuzin has been reported most frequently on soil having less than 1% organic matter and/or a soil pH greater than 7.5. Triazine damage is apparent first on the soybean seedlings in the form of leaf chlorosis and subsequently as leaf abscission. Herbicide damage was consistent across all four lime-incorporation treatments, suggesting the low soil organic matter as a primary factor in the damage observed. The alachlor plus metribuzin combination showed slightly more visible seedling injury and produced lower plant weights than the trifluralin plus metribuzin treatments, but the difference was not statistically significant. No weight or visual differences between herbicide treatments with the high lime rate (1700 kg ECC/ha) occurred on the Muir soil (Figure 15).

Soil pH was raised significantly on each soil type with lime application as compared to the no lime application. Soil pH increase was proportional to the lime rate applied, as observed in the grain sorghum study. The Prior 1700 lime treatments averaged across the herbicide variables gave a higher pH than the Tank 1700 lime treatments even though each was incorporated to the same depth. These results

Figure 14. Visual effects of lime-herbicide suspensions on Eudora loam with soybeans. Pre Lime vs. Check vs. Tank Mix.

Figure 15. Visual effects of lime-herbicide suspensions on Muir silt loam with soybeans. Tank Mix vs. Check vs. Pre Lime.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SOYBEAN SEEDLING TOXICITY
KANSAS STATE UNIVERSITY
TREFLAN
SENCOR
PRE LIME
CHECK
EUDORA
TREFLAN
SENCOR
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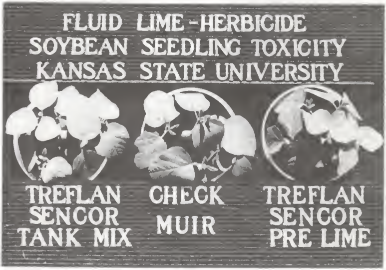
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KANSAS STATE UNIVERSITY
TREFLAN
SENCOR
TANK MIX
CHECK
MUIR
TREFLAN
SENCOR
PRE LIME

agree with the grain sorghum study and could have been caused by a week longer incubation period for the Prior 1700 treatments.

Because all incorporated treatments for both the grain sorghum and the soybean studies were mixed only to a depth of 5 cm, the applied rates of 850 and 1700 kg ECC/ha were equivalent to three times the 15 cm incorporation depth rates. Rapid initial lime reaction with the soil resulted in little soil pH and lime requirement change.

The results of the grain sorghum and soybean studies indicate that the lime-herbicide suspensions tested pose no compatibility problems. Applying lime in conjunction with triazines does not appear to enhance herbicide activity to the level of causing toxicity to seedlings. No observations were possible on weed control effectiveness.

SUMMARY AND CONCLUSIONS

Lime suspension application resulted in a more rapid pH increase and lime requirement decrease initially than conventional agricultural lime when applied at the rates determined by soil tests. Suspension lime applied at 560 and 1120 kg ECC/ha was insufficient to significantly raise soil pH initially, but repeated annual applications of these low rates produced significant soil pH increases over the 3 year period of the field studies in Labette and Marion counties. The small particle size of lime suspension materials enables a rapid soil reaction with pH change limited in magnitude to the amount of ECC applied. Total lime requirements when using lime suspensions were similar to those for conventional agricultural lime expressed as ECC.

Lime rate and source did not significantly change yields or tissue composition of field crops. Soil K, Ca and Mg levels at the Labette county site were significantly increased on many sampling dates by the 5600 kg ECC/ha lime suspension application, which utilized cement plant stack dust as the lime source. Approximately 3.65% K, 26.0% Ca and 1.43% Mg were present in the stack dust, and with the low native levels of these elements present in the newly broken sod, a significant increase was measured.

A possible advantage for the lime suspension technique is the flexibility involved with lime suspension combinations. Fuel and time savings are attractive advantages when utilizing liquid N fertilizer as the lime suspension carrier. However, lime sources such as stack dust that contain appreciable amounts of CaO create a high pH environment that may cause volatilization of NH_3 during and following formulation of a lime-UAN suspension. Losses of close to 90% of the NH_4^+ fraction of the UAN were measured in the lab study in a 4 hour period when a lime-UAN system was sparged with air. Ammonia volatilization from soil surface applied lime-UAN suspensions was enhanced by the presence of a $CaCO_3$ lime source and a low soil cation exchange capacity. These losses would have been reduced considerably by incorporation. Annual lime-UAN suspension applications followed by incorporation may be an effective way to offset acidity created by ammoniacal N sources and maintain soil pH at a relatively constant level.

Another lime suspension option involves the addition of herbicides to allow lime-herbicide application. No compatibility problems were noted when specific herbicides were combined with lime suspensions for the greenhouse studies. Phytotoxicity of herbicides applied with lime suspensions was no greater than phytotoxicity of herbicides applied 1 week following lime application. Lime-herbicide suspensions may be useful in reduced tillage systems where low soil pH's have developed in the herbicide placement zone and have restricted herbicide performance. More work is needed with lime-herbicide suspensions to evaluate crop seedling toxicities and weed control effectiveness.

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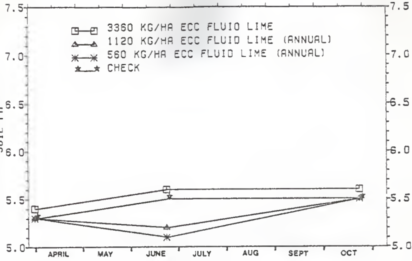
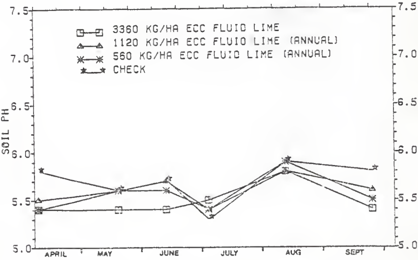
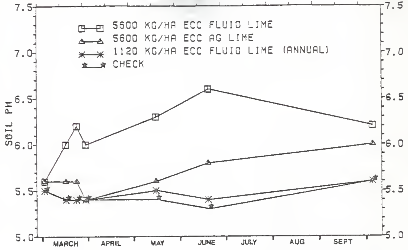
APPENDIX



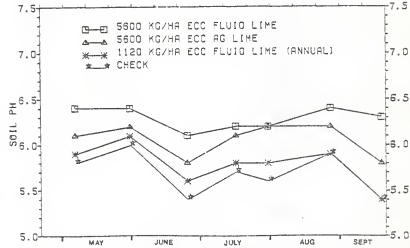
Appendix Figure 1. Effect of suspension grade lime rates on soil pH, Brown county, 1977.



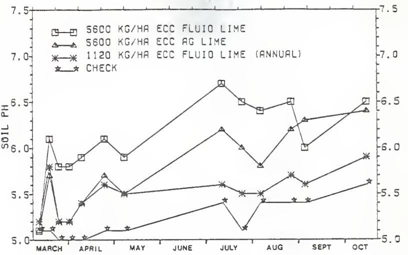
Appendix Figure 2. Effect of suspension grade lime rates on soil pH, Brown county, 1978.



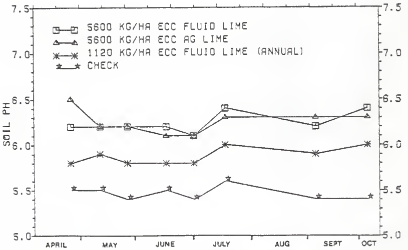
Appendix Figure 3. Effect of lime suspension rates and agricultural lime on soil pH, Marion county, 1977.



Appendix Figure 4. Effect of lime suspension rates and agricultural lime on soil pH, Marion county, 1978.

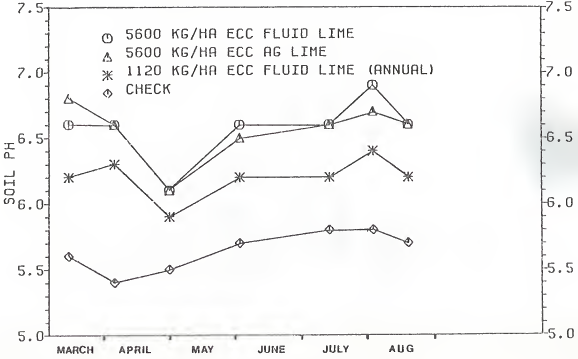


Appendix Figure 5. Effect of lime suspension rates and agricultural lime on soil pH, Labette county, 1977.



Appendix Figure 6. Effect of lime suspension rates and agricultural lime on soil pH, Labette county, 1978.

Appendix Figure 7. Effect of lime suspension rates and agricultural lime on soil pH, Labette county, 1979.



Appendix Table 1. SOIL pH AND LIME REQUIREMENTS ON TWO SAMPLING DEPTHS AT THE THREE LIME RATE AND SOURCE STUDIES.

Lime Rate (kg ECC/ha)	Soil pH 0-8	Soil pH 8-15	Lime Requirement kg ECC/ha 0-8	Lime Requirement kg ECC/ha 8-15
		Depth, cm		
Brown County, 7-5-78				
Control	5.8	5.1	3000	9700
560	5.7	5.2	4100	9000
1120	5.6	5.3	4500	7500
3360	5.6	5.4	3700	5000
Marion County, 7-14-78				
Control	5.5	6.1	4700	2900
560	5.6	5.9	5000	4000
1120	5.6	6.1	4300	2700
5600	6.2	6.3	2500	2000
5600 Ag Lime	6.0	6.2	2900	2500
Labette County, 7-18-78				
Control	5.6	5.7	3500	3100
560	5.8	5.8	2500	2700
1120	6.2	5.8	1700	2800
5600	6.6	6.2	200	2000
5600 Ag Lime	6.6	6.1	200	2000
Labette County, 8-1-79				
Control	5.9	5.8	2100	2700
560	6.4	6.0	1400	2100
1120	6.6	6.2	400	1700
5600	6.8	6.7	--	600
5600 Ag Lime	7.0	6.8	--	--

Appendix Table 2. EFFECT OF LIME SOURCE ON AMMONIA VOLATILIZATION FROM LIME-UAN SUSPENSIONS.

	Time, minutes					
Lime Source	3	8	18	33	60	120
	-------Accumulative Ammonia-N Loss, %-------					
0% CaO - 100% $CaCO_3$	0.0	0.0	0.0	0.0	0.0	0.0
Ground Limestone	0.0	0.0	0.0	0.0	0.0	0.0
Stack Dust (14% CaO)	1.8	3.7	7.4	12.9	21.8	33.2
50% CaO - 50% $CaCO_3$	8.8	20.7	37.3	51.3	64.2	74.9

Appendix Table 3. EFFECT OF LIME CALCIUM OXIDE CONTENT ON AMMONIA VOLATILIZATION FROM LIME-UAN SUSPENSIONS.

Lime Source		Time, minutes							
		3	8	18	33	60	120	180	240
% CaO	% $CaCO_3$								
0	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	95	1.4	2.8	5.5	9.1	13.3	18.8	21.8	23.2
10	90	3.3	7.5	13.3	21.3	29.4	38.6	41.9	43.8
14	(Stack Dust)	2.4	5.6	13.5	22.3	34.2	50.2	58.2	63.7
15	85	4.7	10.6	20.1	29.0	39.0	54.8	62.2	66.9
25	75	8.5	17.7	30.1	47.2	63.8	79.2	85.6	89.2

Appendix Table 4. COMPARISON OF CALCIUM OXIDE-EQUIVALENT AMMONIA LOSSES AND ACTUAL AMMONIA VOLATILIZATION LOSSES FROM LIME-UAN SUSPENSIONS WITH VARIABLE CALCIUM OXIDE CONTENTS.

Lime Source		Actual Loss- 4 Hours	CaO-Equivalent Loss
% CaO	% $CaCO_3$	---Accumulative Ammonia-N Loss, %---	
0	100	0.0	0.0
5	95	23.2	32.9
10	90	43.8	65.9
14	(Stack Dust)	63.7	95.3
15	85	66.9	98.8
25	75	89.2	131.8

Appendix Table 5. EFFECT OF SOIL TYPE AND THE PRESENCE OF LIME ON AMMONIA VOLATILIZATION FROM SOIL APPLIED LIME-UAN SUSPENSIONS.

	Time, days						
Soil Type	1	2	5	8	11	14	17
	------Accumulative N Volatilization, %------						
Parsons SiL	1.6	2.8	6.1	10.8	13.8	15.3	16.9
Grundy SiCL	1.1	2.0	3.7	5.5	7.2	8.5	9.6
Parsons SiL (No Lime)	0.2	0.3	1.0	3.1	4.8	5.8	6.5
Grundy SiCL (No Lime)	0.1	0.2	0.4	0.6	1.4	2.3	3.0

FIELD AND LABORATORY EVALUATIONS

OF LIME SUSPENSIONS

by

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Lime suspension technology involves lime application utilizing various lime sources having a much finer particle size than conventional agricultural lime. Lime suspension formulation requires a finely divided lime material for acceptable suspension properties.

Field studies were conducted in 1977, 1978 and 1979 to evaluate lime suspensions on row crops and wheat. Different lime suspension rates were compared for their effect on soil pH and lime requirement, and yield and nutrient uptake of the test crops - corn, grain sorghum, soybeans and wheat. The treatments examined in the corn study were four lime rates ranging from 0 to 3360 kg ECC/ha using a finely divided calcitic lime source. Treatments evaluated in the other two field studies were four suspension lime rates - 0 to 5600 kg ECC/ha - in addition to an agricultural lime source at the 5600 kg rate. The 560 and 1120 kg rates were repeated annually at each site, while the 5600 kg rate was applied only in 1977. The lime source for all studies was cement plant stack dust in 1977 and finely ground calcitic limestone for the 560 and 1120 kg treatments in 1978 and 1979.

The finely divided lime of the lime suspensions produced a much faster soil pH increase and lime requirement decrease than agricultural lime when both were applied at a rate determined by soil test analysis. Soil pH and lime requirement changes with agricultural lime were slower but approached the level produced by the fluid lime treatment by the second season. Low rates of fluid lime produced smaller changes in soil pH and lime requirement.

There was no significant effect of lime treatment on crop yields or plant tissue composition for Ca, Mg or K. Soil levels of Ca, Mg and K showed a significant increase on several sampling dates at one site due to the Ca, Mg and K contained in cement plant stack dust used as the lime source.

Ammonia volatilization was measured in the laboratory from lime-UAN suspensions formulated with lime sources containing calcium oxide. Rates of loss and total ammonia losses were directly proportional to the calcium oxide content of the lime material and ranged up to approximately 90% of the ammonium fraction of the UAN. Ammonia volatilization from the soil surface was also evaluated following application of lime-UAN suspensions. Ammonia volatilization was increased with the presence of lime with the UAN and was lower on the Grundy soil compared to the Parsons soil with a lower cation exchange capacity. Up to 17% of total nitrogen was lost with the lime-UAN treatments on the Parsons silt loam with a cation exchange capacity of 10.2.

Greenhouse studies evaluated possible toxicity from enhanced herbicide activity following application of lime-herbicide suspensions compared to separate applications on corn, grain sorghum and soybeans. Lime applied in conjunction with the triazine herbicides tested did not enhance herbicide activity to the level of causing seedling toxicities.