THE EFFECT OF BANDED AND DISPERSED LIME MATERIALS AND LIME SUSPENSIONS ON CROP YIELD AND SOIL ACIDITY

By

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CHAPTER I

INTRODUCTION

Neutralizing acid soils in Oklahoma by the use of liming materials has benefitted both the farmer and people since statehood. Much of the area in our state falls under climatic conditions which favor leaching of basic cations from the soil. Likewise the increased use of ammonium fertilizers which react in the soil to produce hydrogen ions has enhanced the decline of pH in all areas of the state under agricultural production.

The original intent of this study was to investigate the effect of fluid lime suspensions applied in the tillering stage of winter wheat. Later the scope was expanded to view banding lime and a heretofore unresearched possibility of applying lime as a dispersed band in the soil.

CHAPTER II

LITERATURE REVIEW

On a treatise concerning basic aspects of liming Follett and Murphy (1979) reported that the effectiveness of a liming material is based on its ability to produce calcium and magnesium ions which replace hydrogen ions on adsorptive sites. Three topics stand out in discussing this topic which will be reviewed, that is (1) liming materials (2) particle size and purity and (3) application methods.

Liming Materials

Barber (1967) defines liming materials as a substance whose calcium or magnesium content is capable of neutralizing soil acidity. He states that early settlers used marl, a natural deposit of amorphous calcium carbonate lightly cemented to clay or sand (Meyers et al., 1937) for this purpose. From 1880 to 1902 experiment stations investigated this source along with burned lime and gas lime (Hopkins and Readhimer, 1907; Latta, 1885; Patterson, 1906) as crushed agriculture limestone was not readily available. Barber also adds quick lime, hydrated lime, limestone (calcitic and dolomitic), shells and byproducts such as slag as lime sources.

Burned lime is heat treated calcium carbonate (Meyers et al., 1937). Although the calcium oxide has 1.79 times the neutralizing value of calcium carbonate on a molecular weight basis Kopeloff (1917) found the actual soil effects to become similar as particle size decreased. Beacher and Merkle (1949) measured the neutralizing values of calcium oxide and calcium carbonate in a 0.03 N solution of acetic acid and found both substances to be equally effective when the lime was 200 mesh. They determined 100-200 mesh lime particles to be much slower in neutralizing acidity than 200 mesh or greater.

Cement stack dust has also been used as a liming agent (Winter, 1979) but as is the case with marl these agents are usually not economically feasible outside of close proximity to a source due to their low percentage calcium content which increases transportation costs.

Concerning limestone materials, Webster et al. (1953) investigated the correlation of physical properties of limestone verses dissolution in the soil. He found no relationship in the rate of dissolution and porosity, hardness or specific gravity of particular limestones, but did find calcitic limestones to dissolute faster than dolomitic limestones in a hydrogen saturated clay suspension. Morgan and Salter (1923) found six samples of calcitic limestone to be more soluble than three dolomitic samples regarding relative rates of dissolution. Skinner et al. (1959) found that in an acid solution calcite would react in 30-90 seconds while the dolomite reacted over a period of several minutes. White (1917) noticed that as particle size gets smaller, the importance of calcium or magnesium concentration decreases.

In Oklahoma the effectiveness of liming materials are measured by their ECCE which includes both calcium carbonate concentration (or equivalent) and the fineness factor of the particular material (Baker, 1973).

Particle Size

Limestone dissolves slowly in water (Winter, 1979). This makes it necessary to have large surface areas of liming material in order for lime particles to dissolve. The relationship between particle size and rate of dissolution based on the equal-diameter reduction hypothesis has been intensively studied (Kriege, 1929; Bear and Allen, 1932; Salter and Schollenberger, 1940; Schollenberger and Salter, 1943; Schollenberger and Whittaker, 1962). The hypothesis states that particle dissolution occurs at a constant rate diametrically regardless of particle size. For example if particle A has N diameter and particle B has 2N diameter then particle B will require twice the amount of time to dissolve under the same environmental circumstances as particle A.

Swartzendruber and Barber (1965) presented a mathematical model in validating this hypothesis. Two presuppositions were made: (1) initial limestone particles were uniform in size, density and composition and (2) the role of dissolution was proportional to surface area. The equation for this assumption (2) is:

$$dm/dt = KS$$

where

M = Mass of dissolved limestone

T = Time Zero upon Soil Mixing

S = Surface area of lime

K = proportionality constant

From this equation they showed that

$$u = 1 - (1-ct)^3$$

where

$u = m_1/m$ = fractional mass dissolved

(m_1 = initial mass,

m = dissolved mass)

$c = 2K/pD$

(p = density, D = initial diameter)

Rearranging the equation to graph the cube root of mass remaining over time, Swartzendruber and Barber plotted the results in Figure 1 (Barber, 1967).

Rates of dissolution have been measured by many workers (Bear and Allen, 1932; Dawson et al., 1939; Elphick, 1955; Greiner, 1950; Shaw, 1960;). Using the equation by Elphick (1955) (Figure 2.) the range that these workers established began with particles dissoluting at 0.07 micrometers per week (McIntyre and Shaw, 1930) and extend to a rate of 12.20

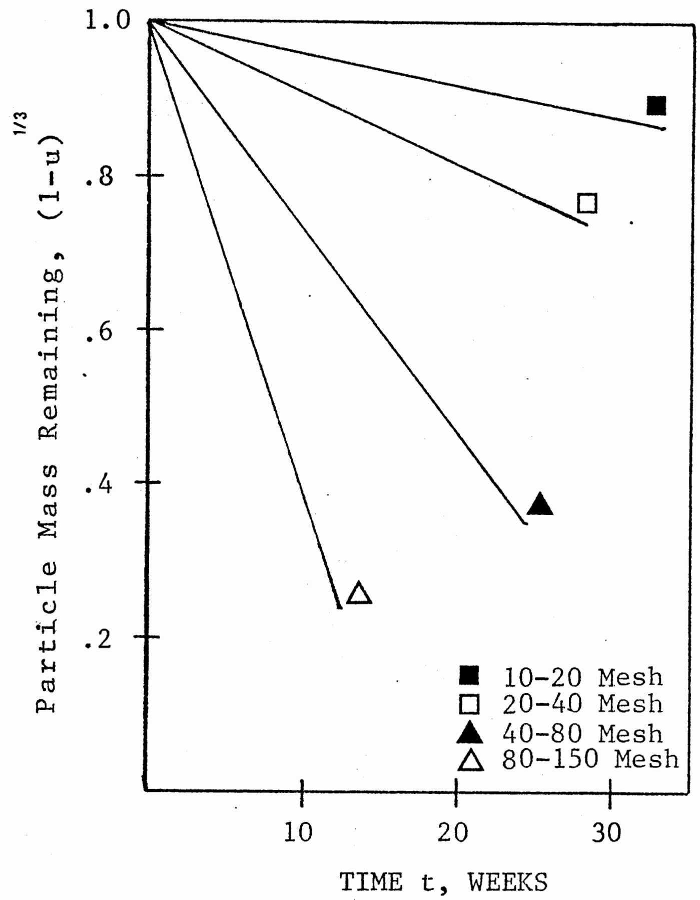

Figure 1. Effect of Time on the Dissolution of Lime Particles

$$\Delta = \frac{D\ 1 - \left(\frac{M - M}{M}\right)^{1/3}}{t}$$

Figure 2. Elphick's Equation for Measuring the Rate of Diameter Reduction of Lime Particles

micrometers per week as recorded by Morgan and Salter (1923). The measured particles varied in size and composition of calcite or dolomite. The soil texture also varied greatly.

The effect of particle size has been measured experimentally on both pH and crop yield. Motto and Melstead (1960) found that 10-28 mesh limestone was only 14% as effective in neutralizing pH as those particles measuring less than 100 mesh in three different acid soils. Hoyert and Axley (1952) conducted experiments using three limestone materials at two different rates. The lower rate of lime showed the finer lime to raise pH higher than the more coarse material. Many others have verified this correlation (Hoyert and Axley, 1952; Motto and Melstead, 1960; Rost and Fieger, 1927).

In greenhouse pot studies Meyer and Volk (1952) found particle size affected crop yield of alfalfa and soybeans. As particle size diminished from 5-8 mesh to less than 100, an increase of yield corresponded. Both calcitic and dolomitic limestones had the same effect, however, the calcitic effect was noticeably larger on alfalfa. Beacher el al. (1952) observed increased yield with finer divided materials on alfalfa and crimson clover.

Much field research has been conducted linking limestone particle size to crop yield (Albrecht, 1946; Crowther and Walker 1952; Davis, 1951; Firkins and Pierre, 1944; Love et al., 1960; Volk et al., 1952). Richards

(1958) showed alfalfa yields increasing as limestone fineness increased from 45 to 98 mesh. Volk et al.(1952), experimenting with alfalfa-timothy earlier had observed the same increase of yield as particle size decreased. Wiancho et al. (1929) growing corn, wheat and hay on silt loam also established a positive correlation between fine mesh and yield in all three crops.

Distribution and Application

Albrecht (1946) and Linsley (1954) among others who advanced the idea that larger particles of limestone created islands of neutrality in a soil which would serve to provide needed calcium or magnesium. Accompanying this postulation was the idea that the acid soil between these zones would readily supply micronutrients. Barber (1967) raised the question that aluminum, iron and manganese might also be furnished in toxic quantities from the low pH areas. This is a key consideration when thinking in terms of banding lime or partially treating a layer of the soil.

De Wit (1953) promoted applying nitrogen, phosphorous and potassium fertilizers by placing them as bands in the soil. Banding of fertilizers have been shown to be capable of crop-yields equal to broadcasting and in some cases with less fertilizer. Barber (1967) reports lime banding operations with seedlings of legume crops but warns that favorable soil must be encountered as roots penetrate downward. Otherwise this is a poor substitute. DeTurk

(1938) reports that calcium diffused through a soil 0.6 cm after 260 days and 1.7 cm after 528 days. This would disallow a calcium band to be expected to form a neutralized zone much larger than the band itself in a single growing season. It is also noted that the nutrient density in a soil volume accompanying a lime band would not be as great as the nutrient density of de Wit's bands. Furthermore, conditions are favorable in a large portion of the soil for uptake of toxic quantities of aluminum, iron and manganese

Lathwell and Peech (1965) limed soils to a 7.5 cm depth at 1120 - 2240 kilograms per hectare and found a superior effect on alfalfa yield when compared to the same rate to a 15.0 cm depth. The question of toxicity is raised here as the roots would certainly be expected to exceed 7.5 cm. At higher rates (4480-8960 kg/ha) depth of liming showed no effect. Therefore, a case for partial zone liming may be raised but is largely unresearched.

In Oklahoma limestone is traditionally broadcast over the soil and then incorporated (Baker, 1973). Hulbert and Menzel (1953) broadcast radioactive phosphorous on a soil and investigated the thoroughness of different mixing mechanisms. In other experiments they used sorghum seed pellets to study the effect of tillage methods. They found that (1) tilling twice with a rotary tiller came close to homogeneous mixing (2) plowing put most of the material at the bottom of the plow layer (3) split applications before and after plowing gave fair vertical distribution but poor horizontal distribution and (4) cultivators, harrows or discs only mixed the material into the surface 5 - 7.5 cm. Due to poor mixing Walker (1952) found 2 to 3 times as much limestone needed in the field to give the same effect as mixing in the greenhouse.

Lime applications in the form of slurries is a relatively new method of application. An originator in this field, E. W. Sawyer (1976) formulated suspensions of lime which ranged in particle size from 20 to 325 mesh. He found that he could suspend up to 70% solid material by weight using attapulgite clay as a suspension agent. At Kansas State University, Winters et al. (1978) conducted research on lime suspensions with a mixed suspension of 30% solids, 70% water and 1.5% attapulgite clay. Later Winters (1979) reported in his work that continuing agitation was necessary to keep lime from settling out.

Alley and Bertsch (Winter et al., 1980) said that small amounts of lime suspension can produce rapid change of pH, but that the change is small when compared to conventional applications of agriculture limestone. This agrees with earlier findings by Follet and Murphy (1979). Alley and Bertsch (Winter et al., 1980) also report on their work in Virginia that corn, wheat and soybeans showed no significant difference of yield between suspension and conventional lime applications. It is noted that their work was done with a high grade of dry lime.

The Kansas results are similar to those of Virginia. Winters et al.(1979) applied lime suspension at 560, 1120 and 5600 kilograms per hectare and one treatment of 5600 kilograms ECC dry limestone per hectare. At 5600 kilograms ECC the lime suspension produced a quicker pH response with the difference becoming more slight as the season progressed when compared to the equal rate of dry agriculture limestone. There was no significant effect on yield with any of the crops (see also Kissel, 1978).

Trask (1976) noted a more uniform distribution pattern of lime with the suspension than broadcast agriculture limestone. Sawyer (1980) notes lime suspensions aid in the ability to adjust to a narrow pH range for crops which are pH sensitive (ie. where a pH maximum and minimum for optimum growth is desired).

Whitney (1979) lists the general observations on lime suspensions at this time (1) the soil chemical reactions are exactly the same for fluid lime as agriculture limestone (2) the smaller particle size reacts quicker to raise pH than agriculture limestone with the difference becoming unnoticed by the first years end (3) applications of low ECC rates in relation to recommended liming rate will have limited effect (4) the transportation costs of fine lime to regions without agriculture limestone source may make its use economically attractive (5) costs of both sources need to be considered (6) annual maintenance programs may utilize suspensions such as in reduced tillage operations and (7) lime suspensions of calcium or magnesium carbonate may be used compatibly with nitrogen solutions but calcium magnesium carbonate should be used to avoid volatilization of ammonia in high pH solutions.

Winters (1979) also conducted research on the compatibility of lime suspension with herbicides. Special note is made of the triazines where pH dependent performance is observed.

CHAPTER III

MATERIALS AND METHODS

Four experiments were established to study the effect of liming materials and placement methods on crop yield and soil pH. All liming materials and methods were evaluated under field and greenhouse conditions.

Field Experiment of Lime Suspension on Winter Wheat

In the spring of 1979 an experiment was established to study effect of surface application of lime suspensions and solid agriculture limestone on yield of TAM 101 hard red winter wheat (*Triticum aestivum* L.) and soil pH. The lime applications were made in the tillering stage of growth.

A randomized complete block design was used having five treatments (Table I). The treatments were replicated four times. Two test sites were selected on the basis of their known low pH and uniform field composition covering the test area.

Test one was performed on a Tabler silt loam, classified as a fine, mixed, thermic, Vertic Paleustolls. The site is located approximately three miles west of

TABLE I

SURFACE APPLIED LIME TREATMENTS ON WINTER WHEAT IN THE TILLERING STAGE IN FIELD EXPERIMENTS AT CLEO SPRINGS AND GARBER OKLAHOMA (1979)

Source	Effective Calcium Carbonate Equivalent (kg/ha)
Control	None
Suspension	1120
Suspension	2240
Suspension	4480
Solid	4480

Garber, Oklahoma (33-23n-4w). This study was harvested June 20, 1979. Test two was conducted on a Pratt loamy fine sand, which is classified as a sandy, mixed, thermic, psammentic Haplustalfs. The site is situated approximately three miles north of Cleo Springs, Oklahoma (30-23n-11w). This study was harvested June 21, 1979.

Soil samples were collected from each individual plot and analyzed in the Oklahoma Soil Test Laboratory at Stillwater, Oklahoma for pH, buffer index, nitrate nitrogen, phosphorous and potassium. Table II contains initial pH data of the experimental plots. Complete data is listed in Appendix Table XVII. Each plot measured 7.62 x 15.24 meters. Only the center 3.05 meters were harvested for yield to remove any border effect.

The lime suspensions were applied using a Tote solution applicator. Some difficulty was encountered in keeping the calcium carbonate material in suspension using a mixture of 74% water, 25% lime (200 mesh, 100% ECCE) and 1% attapulgite clay. The solid agriculture limestone was applied with a Barber spreader. Each site received nitrogen, phosphorous and potassium applications based on soil tests.

Soil samples were taken before harvesting to determine treatment effect on pH. The objective was to take soil samples at 2.5 cm increments to a depth of 17.5 cm. This was accomplished by sinking a probe to this depth in the soil and then cutting the cylindrical slice into 2.5 cm sections.

TABLE II

INITIAL SOIL PH AND BUFFER INDEX OF EXPERIMENTAL BLOCKS USED FOR FLUID LIME SUSPENSION FIELD EXPERIMENTS ON WINTER WHEAT (1979)

Source	pH	BI
Cleo Springs		
Control	5.20	7.1
Suspension	5.12	7.1
Suspension	5.15	7.2
Suspension	5.07	7.1
Solid	5.12	7.1
Garber		
Control	4.83	6.7
Suspension	4.77	6.6
Suspension	4.77	6.5
Suspension	4.75	6.5
Solid	4.90	6.5

These sections were placed in sacks which designated which sample (treatment-rep-depth) was contained in the sack. The soils were then oven dried and tested for pH using a 1:1 soil to water ratio.

The grain was harvested using an Allis-Chalmers Model A Gleaner. Data was recorded for grain yield.

Both yield and pH data were analyzed using the SAS computer programming service (Service, 1972). Analysis of variance and Duncan's new multiple range test (Steele and Torrie, 1960) for significance were performed.

Field Experiment of Lime Placement on Grain Sorghum

On July 7th and 8th of 1980 a field experiment was established to determine the effect of banding lime on yield of grain sorghum and soil pH. A randomized complete block design was used having 15 treatments with four replications (Sorghum bicolor L.) (Table III). The test was performed on a Pratt loamy fine sand. This site was selected both for its known low pH and light sandy soil which is ideal for showing treatment effect of liming methods.

Soil samples were collected prior to plot work for each replicated area. The samples were analyzed at the Oklahoma Soil Testing Laboratory for pH, buffer index, nitrate nitrogen, phosphorous and potassium. The four replicated areas pH measured 6.5, 4.6, 5.2 and 4.7. According to

TABLE III

RATES AND METHODS OF LIME APPLICATION
APPLIED TO A PRATT LOAMY FINE SAND
IN A FIELD EXPERIMENT CROPPED
TO HYBRID GRAIN SORGHUM,
CLEO SPRINGS, 1980

Source	ECCE(kg/ha)	Method of Application
Control	None	
Powder	6720	Broadcast/Disc
Pellet	6720	Broadcast/Disc
Powder	2240	Band
Powder	4480	Band
Powder	6720	Band
Powder	2240	Disced-Band
Powder	4480	Disced-Band
Powder	6720	Disced-Band
Pellet	2240	Band
Pellet	4480	Band
Pellet	6720	Band
Pellet	2240	Disced-Band
Pellet	4480	Disced-Band
Pellet	6720	Disced-Band

recommendations the test area received a uniform application of 14-14-46 kg/ha N-P-K, respectively, with a Barber spreader.

The crop rows were laid out on 91.44 cm centers. Each plot contained two rows, 3.05 meters long.

Two liming materials were used for treatments: (1) a finely divided powdery lime, 200 mesh and 100% ECCE and (2) a pellet material with 95.7% ECCE.

Broadcast treatments were established by hand dispersing liming material based on a rate of 3360 kg/ha and treatments were incorporated with a tandem disc. Banding operations were established by constructing an approximate 15 cm furrow with a lister plow centered on the crop row. Pre-measured amounts of lime corresponding to 3360 kg/ha were hand distributed in the furrow. The furrow was then leveled with soil to form a uniform surface. The dispersed bands were established in the same manner as the bands and then disced twice with a tandem disc.

A 90 day hybrid grain sorghum (Sorghum bicolor L.) was planted at a rate of two seeds per 10 cm. The intent was to thin the crop after a stand was established if necessary. Seeds were placed approximately 5 cm above banded lime so that sorghum roots would penetrate the band. Water was brought into the field to irrigate the crop rows and promote germination in the dry seed bed. The intention was to encourage plant roots to reach subsoil moisture.

Greenhouse Experiment of Lime Placement on Sorghum

On March 11, 1980, a controlled environmental research laboratory experiment was established to determine the effect of banded lime treatments on crop yield of hard red winter wheat and soil pH. Florescent lights containing titanium burst in the control box affecting treatments by forming titanium hydroxide in the soil, which raised surface pH. Due to accumulated error the wheat was harvested for dry matter yield and recorded. The variablility of yield was extremely high and the data is not reported.

On October 2, 1980, the same soil containers were translocated to the greenhouse and planted to SG-10 90 day hybrid grain sorghum (Sorghum bicolor L.) to study the effect of banded lime treatments on grain yield.

A randomized complete block design was used having 14 treatments and replicated three times (Table IV). The surface soil of a Shallaberger fine sandy loam (mixed, thermic, Udic Argiustoll) was transported from western Oklahoma. This soil was selected for its known low pH and sandy texture which is ideal for showing treatment effect of calcium carbonate.

A soil sample was taken from the translocated soil and analyzed for pH, buffer index, nitrate nitrogen, phosphorous and potassium by the OSU soil lab. According to soil tests 123 kg/ha N was incorporated into the entire soil. All

TABLE IV

RATES AND METHODS OF LIME APPLIED TO A SHALLABERGER FINE SANDY LOAM CROPPED TO HYBRID GRAIN SORGHUM IN A GREENHOUSE EXPERIMENT (1980-1981)

ECCE(kg/ha)	Method/Zone of Placement
Control	
2688	Dispersed/ 0-30 cm
896	Dispersed/ 0-10 cm
1782	Dispersed/ 0-10 cm
2688	Dispersed/ 0-10 cm
896	Dispersed/10-20 cm
1782	Dispersed/10-20 cm
2688	Dispersed/10-20 cm
896	Dispersed/20-30 cm
1782	Dispersed/20-30 cm
2688	Dispersed/20-30 cm
896	Band
1782	Band
2688	Band

initial fertilizer and lime applications were incorporated into the soil by mixing the substance with the sandy soil in an electric cement mixer. An additional 56 kg/ha N was added to the soil surface May 16, 1980. The materials were weighed out beforehand to be mixed at rates prescribed by soil test or in the case of lime, according to treatment specifications in Table IV.

Wooden boxes were constructed from 0.94 cm thick plywood to serve as soil containers. Each box contained three experimental plots measuring 30 cm long, 10 cm wide and 30 cm deep. The boxes were constructed by nailing sides and bottom boards together to form a 30 x 30 x 30 cm box and then nailing two equally spaced partitions inside the box to make 10 cm wide plots. Holes were drilled at the bottom of each box for drainage and each plot within each wooden box was lined with a plastic bag to prevent any unnecessary contamination.

Treated soil was hand placed into the wooden containers according to treatment specifications. Dispersed band treatments were established by mixing the indicated amount of lime with the soil in the mixer and then packed into the 10 cm zone prescribed in Table IV. Banded applications were established by furrowing an approximate 5 cm crevice along the center of the 30 cm plot length and hand placing the indicated amount of lime. The lime was then covered to form a uniform surface.

Sorghum seed was planted at a rate of 16 seeds per plot or 16 seeds per 30 cm row. After a stand was established each plot was thinned to eight plants. In a few cases it was necessary to plant extra seed to meet the specified number of eight plants per plot.

The entire experiment was treated twice for greenbugs which visibly damaged plant growth in about 1/5 of the experiment. The experiment was sprayed with Malathion first and a second time later when greenbugs reappeared with Diazinon.

The sorghum was harvested in the dough stage on February 13, 1981. At this point it was determined the experiment was not getting sufficient sunlight to enhance maturity.

Plants were separated into heads, stems, leaves, crowns and roots. The plants were oven dried and the dry matter yield of each plant part was recorded. After grinding, .2 g of the plant tissue was mixed with 5 ml of 69% nitric and 2 ml of 70-72% perchloric acid. These were set overnight and heated in a block digestor at 100 C for 90 minutes; then at 175 C for 60 minutes; then at 230-270 C for 30 minutes. The remaining approximate 0.5 ml solution was diluted to 50 ml with water after cooling.

Aluminum and manganese concentrations were determined in this solution using an atomic absorption spectrophotometer. After extracting 8 ml of this solution and adding 2 ml of 1% lanthimum chloride solution calcium and magnesium were also determined using an atomic absorption spectrophotometer.

Soil samples were taken from the containers in each 10 cm depth increment. These samples were oven dried and tested using a 1:1 soil to water ratio for pH. The pH was measured with an Orion Research Microprocessor Inonalyzer/901.

A decision was made to examine the aluminum, calcium, magnesium and manganese availability dependence on pH. Samples were selected between pH values of 4.10 and 7.40 from the soils used for this experiment. From these samples 25 g of soil was extracted and placed in a 500 ml flask. An addition of 250 ml of ammonium acetic acid, adjusted to a pH of 4.8 (by acetic acid) was added and then shaken for 5 minutes. The mixture was allowed to set overnight. The soil and solution was then passed through a Buechner funnel using Whatman No. 42 filter paper with slight suction. After the liquid solution had passed through the filter leaving the soil on top, 50 ml of 4.8 ammonium acetic acid was washed through the soil to ensure the removal of cations. This allowed approximately 300 ml of solution to be collected. From this 300 ml solution 12.5 ml were extracted and diluted to 50 ml with water. This dilution was then analyzed by atomic absorption spectrophotometry for aluminum and manganese. For calcium and magnesium concentrations, 8 ml of the solution was mixed with 2 ml of a 1% lanthimum chloride solution and then determined.

All complete sets of data underwent analysis of variance through the SAS computer service (Service, 1972) at Oklahoma State University. Incomplete data sets were analyzed using the general linear models procedure. Duncan's new multiple range test (Steel and Torrie, 1960) for significance was performed on each data set. All atomic absorption work was performed with a Perkin Elmer 403 Atomic Absorption Spectophotometer.

Greenhouse Equilbrium Study

On September 25, 1980, a greenhouse study was established to study the reactive behavior of lime in the soil under different application methods. The experiment was designed to study the effect of calcium carbonate from three different material sources on the pH of a soil under three simulated field application methods.

A complete radomized block design was used having eight treatments (Table V) with three replications. A sandy soil (Pratt series) was obtained from western Oklahoma. This soil was chosen based on its known low pH (5.2) and light sandy texture which qualified its ideal use as a medium for tracing calcium carbonate movement by detecting a change of pH.

TABLE V

LIME TREATMENTS APPLIED TO A PRATT LOAMY FINE SAND IN A GREENHOUSE EQUILIBRIUM STUDY (1980-1981)

Source	ECCE(kg/ha)	Placement
Control	None	
Ag-lime	5600	Band
Pellet	5600	Band
Powder	5600	Band
Ag-lime	5600	Disc
Powder	5600	Disc
Pellet	5600	Disc
Suspension	5600	Surface

Three lime materials were used: (1) a fine powdery, 200 mesh, 100% ECCE material, (2) a pelleted granular lime, 95.7% ECCE and (3) a crushed agricultural limestone, 44% ECCE. All lime applications in the experiment were applied at a rate of 2800 kilograms per hectare.

Broadcast-disc field applications were simulated by mixing pre-measured amounts of lime material (corresponding to liming rate) with the soil and then packed into a plastic lined 3.8 liter can. The containers were immersed with water initially and watered sparingly later. Soil samples were taken at approximate 15 day intervals.

Banded operations were constructed by filling a 15 cm sunken table with soil. The table was sectioned into plots measuring 110 cm long by 30 cm wide by 15 cm deep. Each plot was lined with plastic to avoid contamination. The lime bands were placed by furrowing an approximate 5 cm crevice down the center of the 110 cm length of each plot. Pre-measured amounts of lime corresponding to 2800 kg/ha were hand distributed along the length of the crevice and overlaid with plastic line before filling with soil to ensure location of the center of the band for sampling purposes. One side of the plot had a vertical face from which samples were taken.

The banded experimental plots were watered at sampling dates by soaking the surface with water; however, thorough penetration of the plot did not occur.

A plexiglass die (Figure 3) was constructed for sampling purposes. The die was made by cutting a plexiglass sheet slightly less than 30 cm wide and approximately 18 cm high. A center hole was drilled from which the plastic line would be placed through to locate the center of the band. Three horizontal holes and two vertical holes were drilled at 2.5 cm increments either side and up and down from the center hole. When sampling, soil would be extracted from these holes with a scoopula and placed in sacks identified by treatment, replication and location. This sampling occured at approximate 15 day intervals for 102 days.

The soil samples were oven dried and tested for pH using a 1:1 soil to water ratio. The pH was measured using an Orion Research Microprocessor Ionalyzer/901 to the nearest .01 pH unit for all samples except those taken on December 18 which were measured to the .05 pH unit with an Orion Research Model 701a/Digital Ionalyzer.

The lime suspension treatments were simulated by treating the surface of plots with the same dimensions as those of the banded treatment plots with a slurry application at an ECCE rate of 2800 kg/ha. The solution was prepared by mixing the powdered 200 mesh material with water and pouring over the surface of the plot area. Agricultural limestone and pellet lime materials were not used in this treatment. The watering schedule followed that used on banded treatments. Samples were collected by taking soil

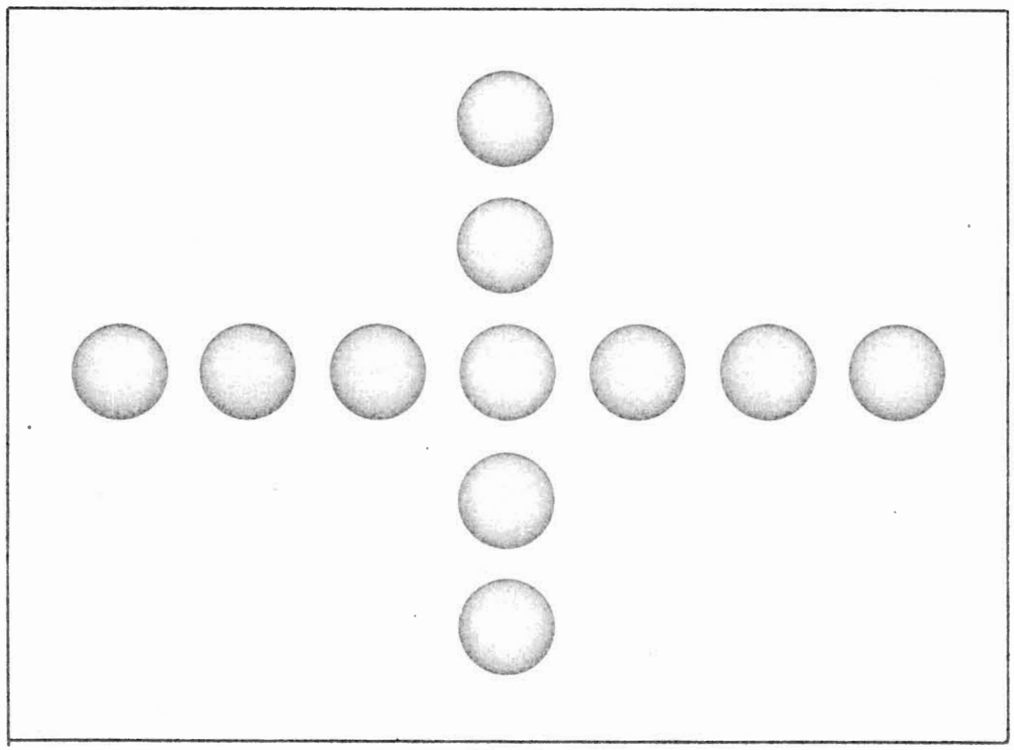

Figure 3. Plexiglas Die Used to Sample Band Applications of Lime Materials in a Greenhouse Equilibrium Study

from the surface 2.5 cm and at 2.5 cm intervals downward to a depth of 15 cm.

The soil samples were oven dried and measured for pH using a 1:1 soil to water ratio. Machines employed were the same as those in banded and lime suspension operations.

The data was processed using the SAS computer programming service (Service, 1972) and Duncan's new multiple range test (Steel and Torrie, 1960) for significance. The general linear models procedure was used to determine significant variations. The General Linear Models procedure was also used to calculate the least significant difference of Figure 8 in the liming materials experiment.

CHAPTER IV

RESULTS AND DISCUSSION

Soil pH and crop yield as affected by liming materials and practices are discussed from the data obtained.

Field Experiment of Lime Suspension on Winter Wheat

Lime suspension was applied to hard red winter wheat in the tillering stage on the field surface at two locations.

No significant difference occurred in the grain yield between treatments at the 5% level (Table VI) at either location. Figure 4 indicates the lack of response to surface application of lime materials on grain yield. Kansas State University workers (Winter et al., 1978) found no significant effect on grain yield after incorporation into the soil between lime suspensions and solid agriculture limestone. It is noticeable in our study that no toxic effect to grain yield resulted from direct applications of heavy amounts of calcium onto winter wheat in the tillering stage. Complete yield data for the lime suspension experiment is listed in the the Appendix (Table XVII).

TABLE VI

EFFECT OF SURFACE APPLIED LIME MATERIALS ON YIELD OF WHEAT GRAIN GROWN UNDER FIELD CONDITIONS IN WESTERN OKLAHOMA (1979)

Source	ECCE kg/ha	Yield, kg/ha
Cleo Springs		
Control	0	2813
Suspension	1120	2878
Suspension	2240	2725
Suspension	4480	2571
Solid	4480	2773
Garber		
Control	0	2795
Suspension	1120	3054
Suspension	2240	3037
Suspension	4480	3015
Solid	4480	2922

†All values represent means of four replications

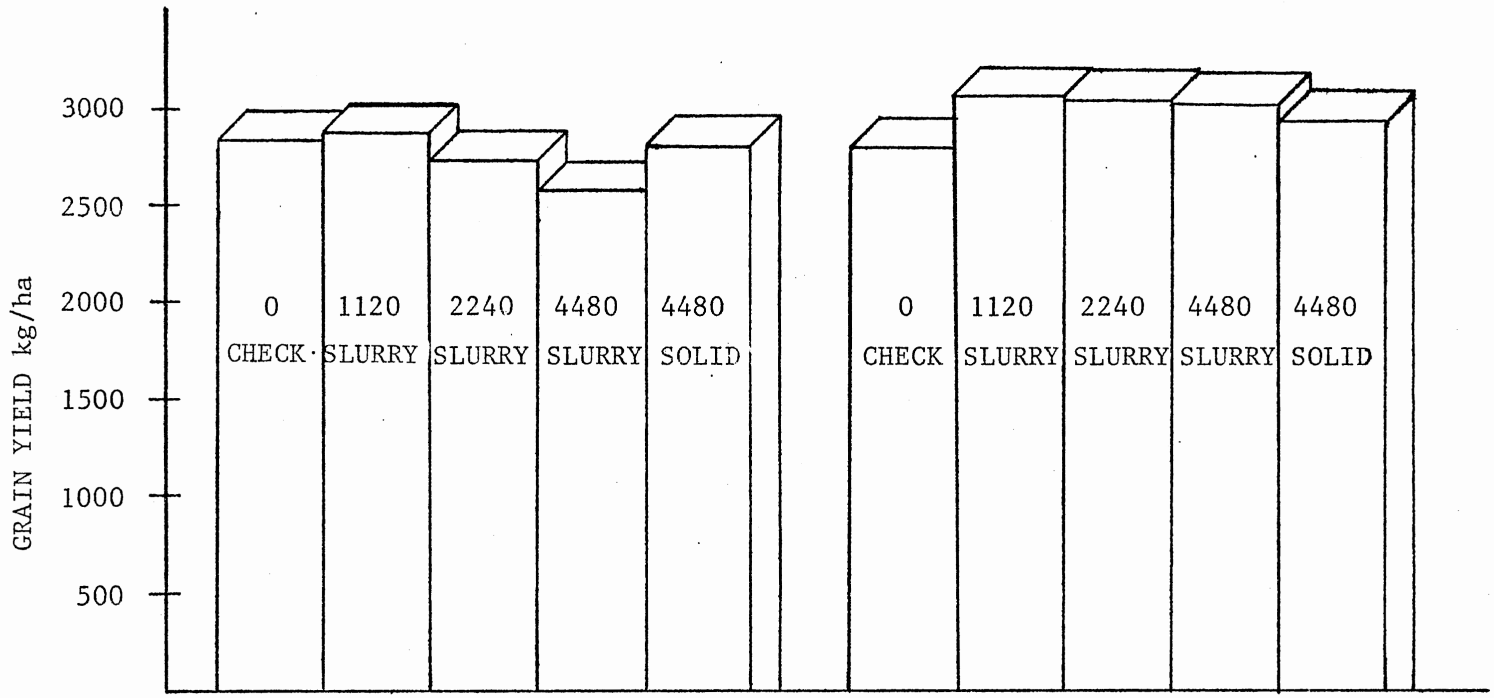

Figure 4. Effect of Surface Applied Lime Materials on Field of Wheat Grain Grown Under Field Conditions in Western Oklahoma

Soil sampling of the field sites (Table VII) revealed that lime did not penetrate the soil sufficiently to produce a significant difference in pH. No method for detecting how much liming materials may have washed off after application was employed. Complete pH data by 2.5 cm increments are listed in the Appendix (Tables XIX and XX).

Field Experiment of Lime Placement on Sorghum

Due to drought conditions this experiment failed and was not harvested.

Greenhouse Experiment of Lime Placement on Sorghum

The greenhouse study revealed a significant difference in root development with lime banding operations being inferior to broadcast-disc simulations and in most cases inferior to the 10 cm zone treatments (Table VIII and IX). Figure 5 shows the effect of banded and broadcast-disc lime placement on root development. This effect is not visible on dry matter yield of forage at the 5% level. In many treatments where 2/3 to full treatments were applied in 10 cm zones the yields equaled treatments where the entire 30 cm was fully treated. Figure 6 illustrates the effect of lime placement on root and forage yield. Complete yield data is listed in the Appendix(Tables XXI and XXII).

TABLE VII

EFFECT OF SURFACE APPLIED LIME MATERIALS ON SOIL PH AT 2.5 CM INCREMENTS IN THE SURFACE LAYER OF TWO FIELD EXPERIMENTS (1979)

Source	ECCE (kg/ha)	IPH#	DEPTH, CM†						
			0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0	15.0-17.5
Cleo/Spgs									
Control	0	5.20	6.19	5.20	4.91	4.61	4.57	4.72	4.70
Suspension	1120	5.13	5.66	4.94	4.65	4.81	4.63	4.69	4.78
Suspension	2240	5.15	5.81	5.05	4.99	4.75	4.59	4.71	4.75
Suspension	4480	5.08	6.31	5.39	4.95	4.80	4.84	4.91	4.78
Solid	4480	5.13	6.73	5.58	4.84	4.78	4.60	4.71	7.74
Garber									
Control	0	4.83	4.58	4.41	4.25	3.94	4.56	4.74	5.20
Suspension	1120	4.78	4.55	4.25	4.31	4.25	4.40	4.58	5.15
Suspension	2240	4.78	4.90	4.64	4.41	4.48	4.48	4.81	4.98
Suspension	4480	4.75	5.09	4.46	4.48	4.51	4.68	4.84	5.35
Solid	4480	4.80	5.06	4.41	4.31	4.48	4.50	4.68	5.21

†All values represent means of four replications
#IPH = initial pH

TABLE VIII

EFFECT OF ZONE LIME PLACEMENT IN A SHALLABERGER FINE SANDY LOAM ON DRY MATTER YIELD OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (1980-1981)

			Yield (g/8 plants)					
Trt.	ECCE(kg/ha)	Placement	Heads	Stems	Leaves	Crowns	Roots	Tops
1	0	Control	3.03	2.03	6.12	0.77	5.75c	11.96a
2	2688	Broadcast/disc	2.26	2.41	8.15	1.01	9.88a	13.83a
3	896	0-10 cm	1.81	2.28	6.63	1.24	8.06abc	11.96a
4	1782	0-10 cm	2.40	2.13	6.69	1.44	8.42abc	12.66a
5	2688	0-10 cm	3.38	3.48	8.87	1.34	8.71ab	17.07a
6	896	10-20 cm	1.82	2.52	7.97	1.69	8.72ab	14.01a
7	1782	10-20 cm	1.82	2.07	7.38	1.07	6.03bc	12.34a
8	2688	10-20 cm	4.11	2.71	8.03	1.47	7.87abc	16.33a
9	896	20-30 cm	2.30	2.75	8.13	1.12	7.09abc	14.30a
10	1782	20-30 cm	2.42	1.46	7.63	0.79	6.10bc	12.30a
11	2688	20-30 cm	3.66	4.15	6.89	1.51	8.86ab	16.22a

†All values represent means of three replications

#Actual population per plot mean = 7.76

*Numbers within columns with different letters are significantly different at the 5% level

TABLE IX

EFFECT OF BAND LIME PLACEMENT IN A SHALLABERGER FINE SANDY LOAM ON DRY MATTER YIELD OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (1980-1981)

			Yield (g/8 plants)					
Trt.	ECCE(kg/ha)	Placement	Heads	Stems	Leaves	Crowns	Roots	Tops
1	none	Control	3.03	2.03	6.12	0.77	5.75b	11.96a
2	2688	Broadcast/disc	2.26	2.41	8.15	1.01	4.88a	13.83a
3	896	Band	2.40	2.45	4.35	3.18	6.37b	12.38a
4	1782	Band	2.91	2.07	7.14	1.19	6.00b	13.32a
5	2688	Band	3.02	1.94	6.55	0.92	5.64b	12.43a

†All values represent means of three replications
#Actual population per plot mean = 8.13
*Numbers within columns with different letters are significantly different at the 5% level

Figure 5. Effect of Lime Placement on Root Development of Hybrid Grain Sorghum in a Greenhouse Experiment

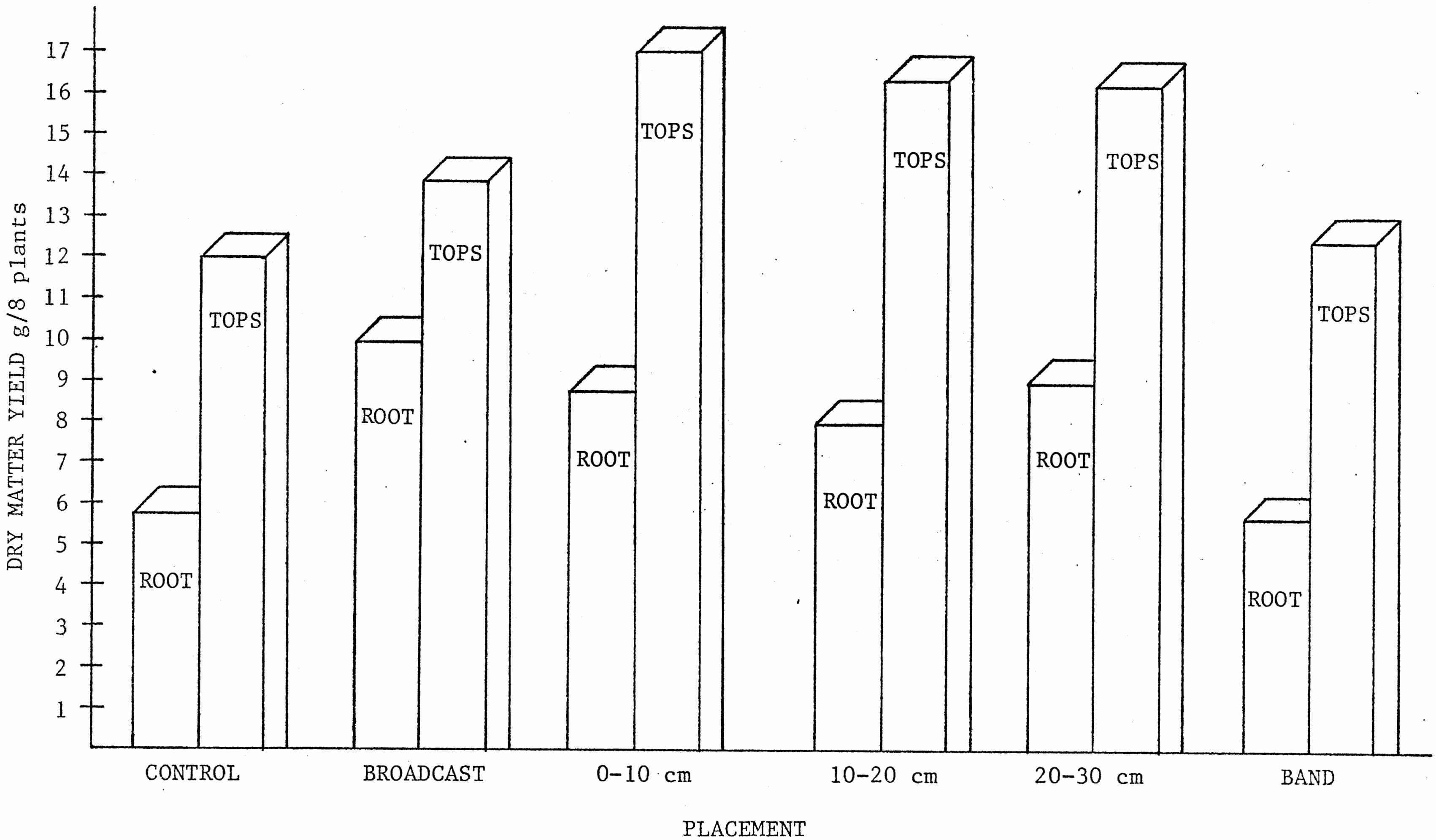

Figure 6. Effect of Lime Placement on Dry Matter Yield of Above Ground Plant Parts and Roots of Hybrid Grain Sorghum in a Greenhouse Experiment

Chemical analysis for Al, Ca, Mg and Mn concentrations in the plant parts showed no significant variation due to treatment (Table X). Complete data is listed in the Appendix (Tables XXIII, XXIV, XXV and XXVI).

In full evaluation of treatment effects on sorghum the overshadowing of surface pH alteration by titanium exposure must be recognized. This contamination retards the effect of treatments in the soil by giving each treatment a possible 10 cm zone of neutrality. This effect on nutrient and toxic element behavior cannot be fully understood due to the unexpected associated error.

The treatment effect on pH is contained in Tables XI and XII. Complete data is listed in the Appendix (Tables XXVII and XXVIII).

The pH effect on magnesium and manganese availability is significant at the 5% level (Table XIII). Figure 7 illustrates the elemental behavior with Mg having an r^2 value of 0.63 and Mn with an r^2 of 0.65. Al and Ca availability were not found to be significant at the 5% level as an effect of soil pH. Complete data is recorded in the Appendix (Table XXIX).

Greenhouse Equilibrium Study

The precise measurement of lime behavior in the greenhouse proved valuable in explaining yield data of cropped experiments.

TABLE X

EFFECT OF LIME PLACEMENT IN A SHALLABERGER FINE SANDY LOAM ON AL, CA, MG AND MN CONCENTRATIONS OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (1980-1981)

ECCE(kg/ha)	Placement	Heads				Leaves				Stems				Crowns				Roots			
		Al	Ca	Mg	Mn	Al	Ca	Mg	Mn	Al	Ca	Mg	Mn	Al	Ca	Mg	Mn	Al	Ca	Mg	Mn
None	Control	108	101	19889	92	508	815	90189	583	192	1001	58398	667	642	387	33645	142	1867	1838	17203	133
2688	0-30 cm	150	244	20441	83	500	1139	98297	542	133	735	68509	342	233	853	48141	58	3663	1016	23118	375
2688	10-20 cm	75	125	20337	0	517	769	89274	742	225	1170	43633	642	333	526	44757	133	3425	357	12985	508
2688	20-30 cm	142	171	22430	100	375	1243	103446	583	150	596	48750	475	517	1386	46777	100	3975	417	25835	167
2688	Band	125	133	23477	88	708	1361	85035	592	133	1480	49599	550	325	484	49432	117	2575	362	24419	200

TABLE XI

EFFECT OF ZONE LIME PLACEMENT ON SOIL PH IN A SHALLABERGER FINE SANDY LOAM IN A GREENHOUSE EXPERIMENT (1980-1981)

Trt.	ECCE(kg/ha)	Placement	Initial	0-10 cm#	10-20 cm***	20-30 cm***
1	Control	None	4.70	7.95ab	4.71d	4.65cd
2	2688	Broadcast/disc	4.70	8.20a	7.12a	6.97a
3	896	0-10 cm	4.70	8.04a	4.75d	4.53d
4	1782	0-10 cm	4.70	8.03a	5.34d	4.76cd
5	2688	0-10 cm	4.70	8.10a	5.45cd	5.90abc
6	896	10-20 cm	4.70	7.32b	5.32d	4.81cd
7	1782	10-20 cm	4.70	7.77ab	6.12bc	4.59d
8	2688	10-20 cm	4.70	7.76ab	6.83ab	4.82cd
9	896	20-30 cm	4.70	7.51ab	4.89d	5.51bcd
10	1782	20-30 cm	4.70	7.87ab	5.33d	6.26ab
11	2688	20-30 cm	4.70	7.84ab	5.02d	6.84a

†All values apart from initial pH represent means of three replications
#Surface soil was exposed to titanium resulting in raised pH

TABLE XII

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A SHALLABERGER FINE SANDY LOAM IN A GREENHOUSE EXPERIMENT (1980-1981)

Trt	ECCE(kg/ha)	Placement	I pH	0-10 cm	10-20 cm	20-30 cm
1	Control	None	4.70	7.95ab	4.71cde	4.65cd
2	2688	Broadcast/disc	4.70	8.20a	7.12a	6.97a
3	896	Band	4.70	5.99c	4.62de	4.33d
4	1782	Band	4.70	6.03c	4.54de	4.33d
5	2688	Band	4.70	6.56c	4.77cde	4.49cd

†All values represent means of three replications
#Surface soil was exposed to titanium resulting in raised pH
I pH = initial pH
*Numbers within columns with different letters are significantly different at the 5% level

TABLE XIII

EFFECT OF SOIL PH IN A SHALLABERGER FINE SANDY LOAM ON AL, CA, MG, AND MN CONTENT IN A GREENHOUSE EXPERIMENT (1980-1981)

pH	Al	Ca	Mg*	Mn*
4.18	54.4	234	14.0	43.2
4.30	48.0	122	11.8	80.0
4.60	48.1	904	24.8	35.2
4.71	45.6	256	22.2	41.6
4.89	48.0	346	32.0	33.6
5.00	67.2	190	15.2	54.4
5.53	35.2	878	29.0	24.0
6.13	25.6	790	57.8	30.4
6.70	27.2	592	34.2	32.0
7.33	49.6	504	41.4	12.8

†All values equal mean of three replications (ppm)
*Significant effect of pH on availability at 5% level

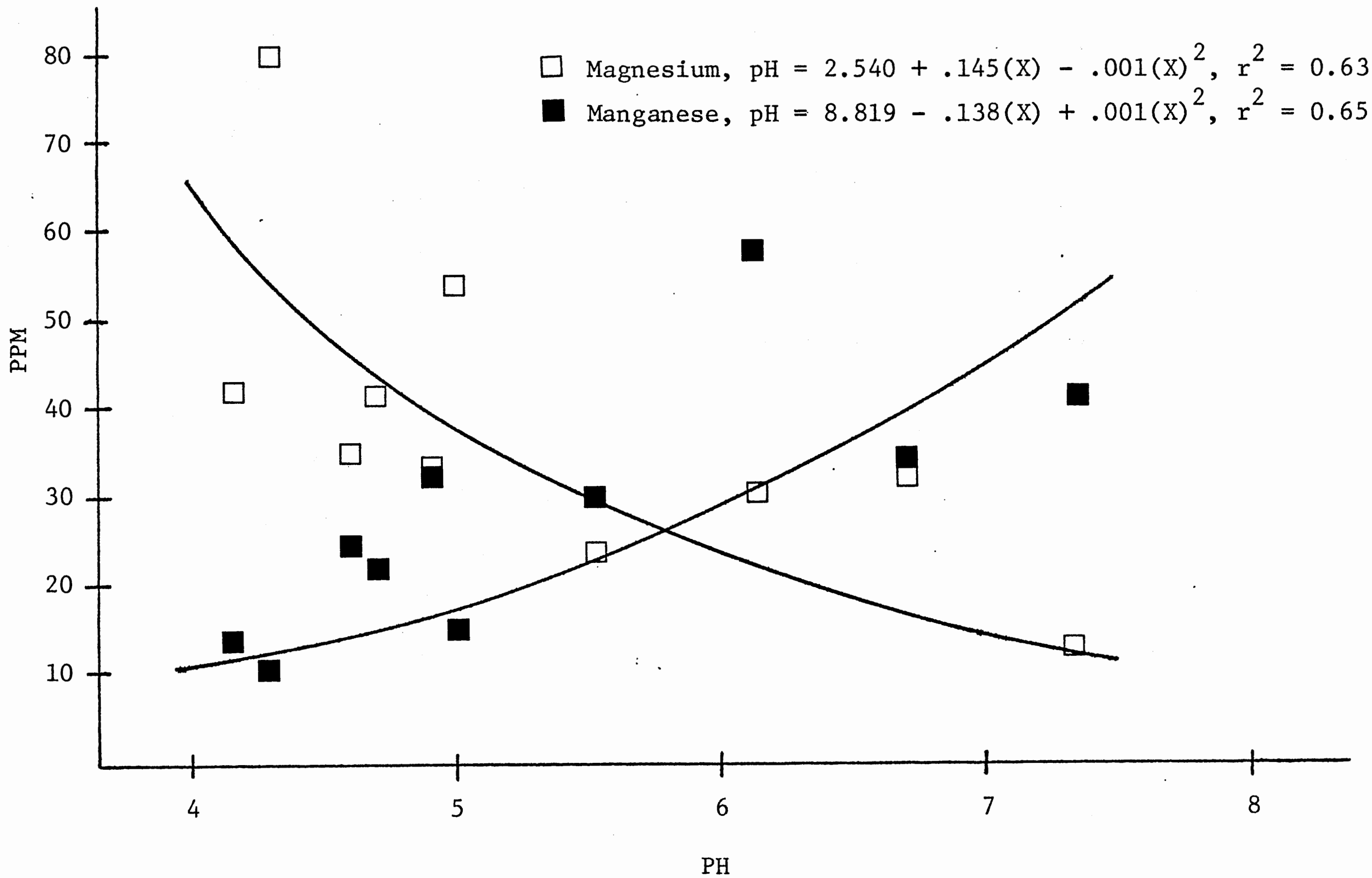

Figure 7. Effect of soil pH on Magnesium and Manganese availability in a Shallaberger Fine Sandy Loam in a Greenhouse Experiment

No significant difference at the 5% level occurred between the lime material treatments, powder, pellet and agriculture limestone (Table XIV). Complete data is listed in the Appendix (Table XXX). All the treatments were significant at the 1% level in regard to the control. It is important to note the moisture level of the soil during the first quarter of this experiment. Figure 8 illustrates the lime materials effect on soil pH over a 102 day period.

The banded treatments resulted in no significant effect on pH 2.5 cm or more from the band (Table XV). This slow movement of lime through the soil complies with earlier work (DeTurk, 1938). Complete data is listed in the Appendix (Tables XXXI through XXXVI). The band treatment effect on soil pH at 102 days is illustrated in Figure 9.

The lime suspension treatments had no significant effect on pH at 2.5 cm or more depth (Table XVI). A very significant treatment effect on surface pH (1% level) was observed in the greenhouse which was not detected in the field. Complete data is listed in the Appendix (Table XXXVII).

TABLE XIV

EFFECT OF SELECTED LIMING MATERIALS MIXED INTO A PRATT LOAMY FINE SAND ON SOIL PH IN A GREENHOUSE EQUILIBRIUM STUDY (1980-1981)

Material	ECCE(kg/ha)	Days 14***	33***	55***	68***	84***	102***
Control	None	4.93b	4.94b	5.09b	5.61b	5.60b	5.75b
Powder	2688	6.55a	6.99a	6.85a	7.12a	7.68a	7.72a
Pellet	2688	6.85a	6.71a	6.71a	6.76a	7.37a	7.62a
Ag-lime	2688	6.57a	6.83a	6.81a	6.95a	7.28a	7.33a

†All values represent means from three replications
#Under very moist conditions
*Numbers within columns with different letters are significantly different at the 5% level
***Significant difference at the 0.01 level

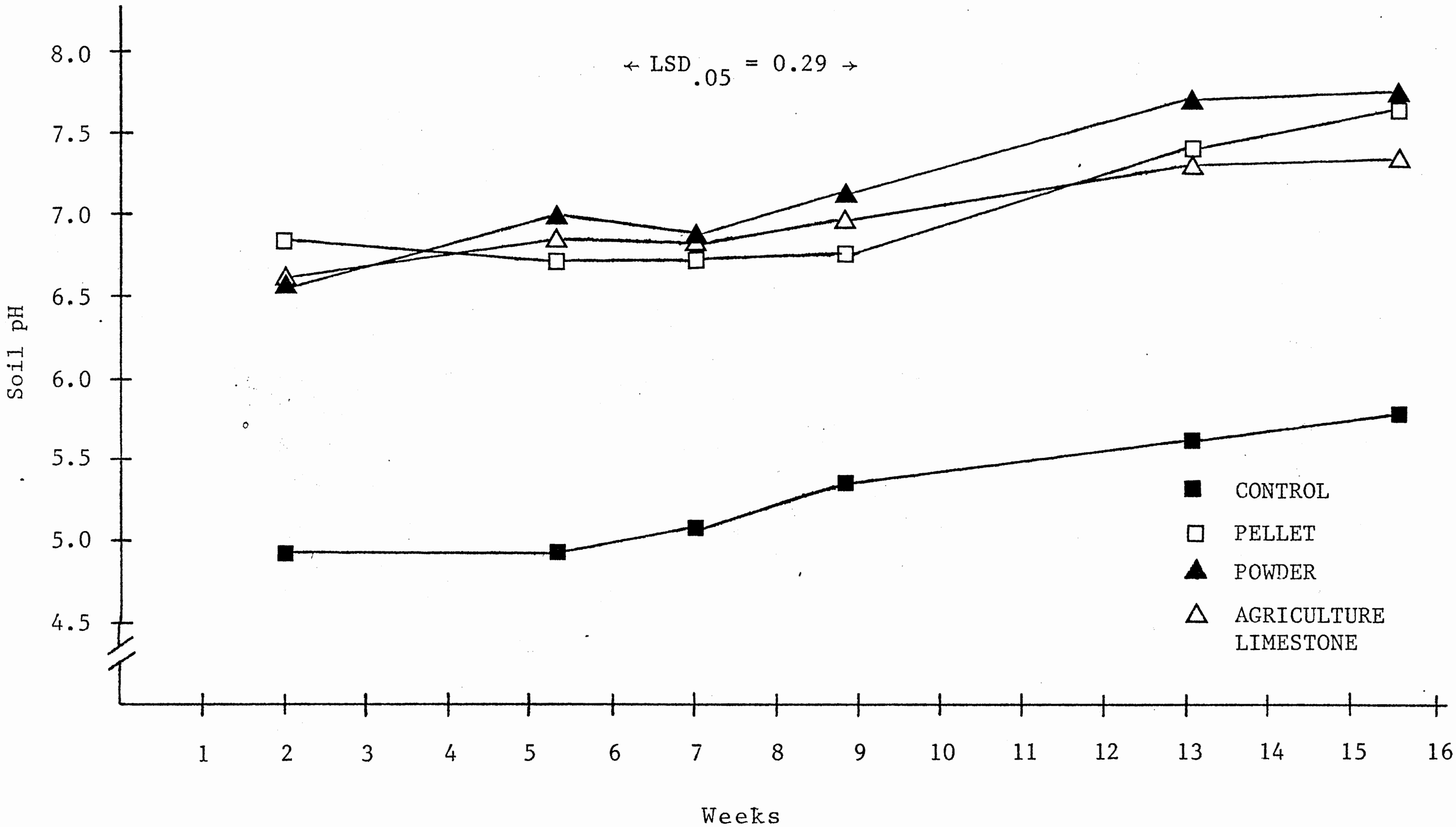

Figure 8. Effect of Selected Liming Materials on Soil pH in a Greenhouse Equilibrium Study

TABLE XV

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A PRATT LOAMY FINE SAND IN A GREENHOUSE EQUILIBRIUM STUDY

Source	Distance from Band (cm)/days											
	0¶						2.5§					
	14	33	54	68	74	102	14	33	54	68	84	102
Ag-lime	7.34**	7.45**	7.62**	7.73**	8.13**	8.18**	5.24	5.58*	5.16	5.21	5.99	6.13
Pellet	6.90**	6.85**	6.89**	6.83**	7.37**	7.11**	4.24	5.05*	5.07	5.37	6.01	5.74
Powder	7.30**	7.34**	7.42**	6.96**	7.97**	7.78**	5.40	5.41*	5.31	5.94	6.06	5.49

Source	Distance from Band (cm)/days											
	5.0††						7.[illegible]##					
	14	33	54	68	84	102	14	33	54	68	84	102
Ag-lime	5.04*	4.92	4.95	4.92	5.42	5.02	5.06	5.02	5.03	4.95	5.27	4.77
Pellet	4.94	4.96	4.75	5.04	5.44	4.89	5.15	4.94	4.86	4.94	5.47	4.84
Powder	5.04*	4.99	4.89	5.14	5.57	4.98	5.06	4.95	4.97	4.96	5.28	4.99

*,**Significant at the 0.05 and 0.01 levels respectively
†Measured in centimenters
#Measured in days
¶,§,††,##Each value represents 3, 12, 9 and 6 pH measurements respectively

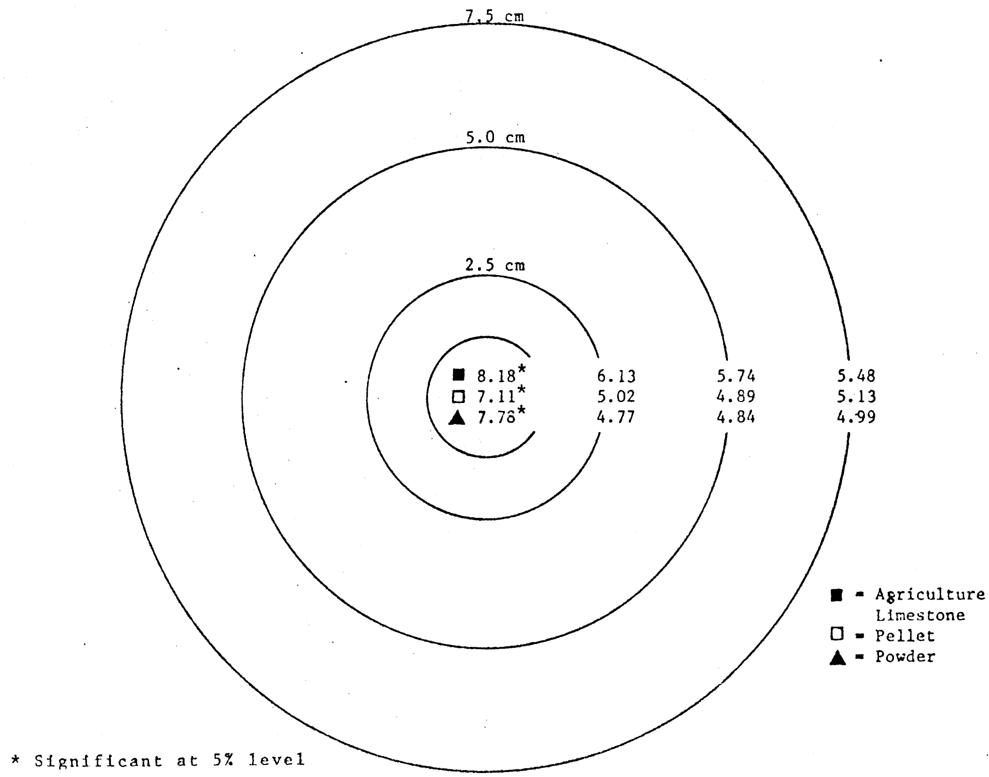

Figure 9. Effect of Lime Bands on Soil pH at 2.5, 5.0 and 7.5 cm 102 Days After Application in a Greenhouse Equilibrium Study

TABLE XVI

EFFECT OF SURFACE APPLIED LIME SUSPENSION ON SOIL PH IN A PRATT LOAMY FINE SAND IN A GREENHOUSE EQUILIBRIUM STUDY

Source	Depth/Days																	
	0 CM						2.5 CM						5.0 CM					
	14	33	54	68	84	102	14	33	54	68	84	102	14	33	54	68	84	102
Control	4.93	4.94	5.09	5.61	5.60	5.75	4.93	4.94	5.09	5.61	5.60	5.74	4.93	4.94	5.09	5.61	5.60	5.74
Suspension	6.92^{**}	7.52^{**}	7.41^{***}	7.22^{*}	7.18^{**}	7.66^{**}	4.95	4.93	5.00	4.90	5.63	5.45	4.91	4.91	4.88	4.81	5.60	5.04

Source	7.5 CM						10.0 CM					
	14	33	54	68	84	102	14	33	54	68	84	102
Control	4.93	4.94	5.09	5.61	5.60	5.74	4.93	4.94	5.09	5.61	5.60	5.75
Suspension	4.88	4.89	4.86	4.82	5.45	4.82	5.06	4.96	4.83	4.78	5.38	4.74

*,**,***Significant at the 5, 1 and .1% levels respectively

CHAPTER V

Summary and Conclusions

The objective of this study was to investigate the performance of liming materials and effect of liming methods on soil pH and crop yield. Greenhouse and field studies were conducted at Oklahoma State University and in western Oklahoma to study this performance and effect.

The field application of lime materials in the form of suspensions or as solids did not affect crop yield or soil pH at the 5% level. Heavy applications of lime applied directly onto wheat in the tillering stage was not toxic to wheat plants. Surface applied lime did not effectively penetrate the soil to neutralize the acid soil condition.

Banding operations of liming materials are inferior to broadcast-disc operations regarding root development on a per plant weight basis in the greenhouse.

The pH of a soil is not significantly affected at 2.5 cm or more from the band itself 102 days after liming.

Shallow incorporation of liming materials at rates equal to or less than recommended may equal yields of soil which have the recommended rate of lime incorporated into the entire plow layer. This finding based on greenhouse studies in our experiment concurs with work done by Lathwell and Peech (1965) on alfalfa.

Sorghum uptake of Al, Ca, Mg and Mn did not correspond with soil pH or element availability in the greenhouse study. It is noted in this study that all the plants had a certain volume of neutralized soil for plant roots to penetrate. The concept is that sorghum will not take up toxic quantities of Al or Mn from low pH areas if there is a suffocient volume of neutralized soil accesible for nutrient uptake. This concept needs to be investigated further.

Under very moist conditions the fineness factor of lime material significantly decreases in importance as to its suitability as a liming agent.

In this work, greenhouse equilibrium studies involving lime and soils offered superior conditions for precise measurement of soil reactivity over field conditions.

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APPENDIX

TABLE XVII

INITIAL SOIL PH OF FIELD PLOTS USED FOR LIME SUSPENSION EXPERIMENTS ON WINTER WHEAT (COMPLETE DATA)

Source	Rep I	Rep II	Rep III	Rep IV
Cleo Springs				
Control	5.1	5.2	5.3	5.2
Suspension	5.0	5.2	5.3	5.0
Suspension	5.1	5.3	5.2	5.0
Suspension	5.0	5.1	5.0	5.2
Solid	5.2	4.9	5.3	5.1
Garver				
Control	4.8	4.9	4.8	
Suspension	5.0	4.7	4.7	4.7
Suspension	4.6	4.8	4.9	4.8
Suspension	4.8	4.6	4.8	4.8
Solid	4.7	5.0	4.6	4.9

TABLE XVIII

EFFECT OF SURFACE APPLIED LIME MATERIALS ON YIELD OF WHEAT GRAIN GROWN UNDER FIELD CONDITIONS IN WESTERN OKLAHOMA (COMPLETE DATA, 1979)

Source	ECCE(kg/ha)	Yield (kg/46.33m^2)			
		Rep I	Rep II	Rep III	Rep IV
Cleo Springs					
Control	0	13.44	12.17	12.85	13.89
Suspension	1120	11.80	10.94	14.26	16.57
Suspension	2240	13.71	9.81	15.16	12.03
Suspension	4480	9.58	11.30	12.71	14.26
Solid	4480	10.99	12.08	14.07	14.48
Garber					
Control	0	13.17	11.62	13.12	14.12
Suspension	1120	16.30	13.39	11.89	15.25
Suspension	2240	13.35	13.85	11.53	17.80
Suspension	4480	14.66	12.89	15.03	13.53
Solid	4480	12.30	13.48	13.85	14.75

TABLE XIX

EFFECT OF SURFACE APPLIED LIME MATERIALS ON SOIL PH AT 2.5 CM INCREMENTS IN THE SURFACE LAYER OF A FIELD EXPERIMENT (COMPLETE DATA-CLEO SPRINGS, 1979)

Source	ECCE (kg/ha)	Rep	pH At Depth In Cm						
			0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0	15.0-17.5
Control	0	1	4.70	4.30	4.45	4.20	4.65	4.55	4.35
		2	4.45	4.60	4.55	4.40	4.40	4.45	4.65
		3	4.65	4.20	3.90	4.00	4.55	5.20	5.40
		4	4.50	4.55	4.10	3.16	4.65	4.75	5.40
Suspension	1120	1	4.35	4.30	4.20	4.10	4.20	4.35	5.10
		2	4.55	4.35	4.25	4.15	4.40	4.55	5.00
		3	4.85	4.20	4.70	4.65	4.90	4.95	5.45
		4	4.45	4.15	4.10	4.10	4.10	4.45	5.05
Suspension	2240	1	5.05	5.00	4.60	4.40	4.20	4.40	5.05
		2	4.60	4.90	4.35	4.30	4.30	4.40	4.30
		3	4.80	4.15	4.35	4.65	4.40	5.05	5.05
		4	5.15	4.50	4.35	4.55	5.00	5.40	5.50
Suspension	4480	1	5.20	4.20	4.20	4.10	4.15	4.45	5.00
		2	4.45	4.85	4.95	4.85	5.10	4.75	5.70
		3	5.00	4.50	4.30	4.55	4.90	5.05	5.45
		4	5.70	4.30	4.45	4.55	4.55	5.10	5.25
Solid	4480	1	4.25	4.30	4.45	4.40	3.95	4.10	4.65
		2	5.80	4.75	4.45	4.60	5.00	4.95	5.50
		3	5.55	4.35	4.20	4.50	4.35	4.50	5.50
		4	4.65	4.25	4.15	4.40	4.70	4.85	5.20

TABLE XX

EFFECT OF SURFACE APPLIED LIME MATERIALS ON SOIL PH AT 2.5 CM INCREMENTS IN THE SURFACE LAYER OF A FIELD EXPERIMENT (COMPLETE DATA-GARBER, 1979)

Source	ECCE (kg/ha)	Rep	pH At Depth In Cm						
			0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0	15.0-17.5
Control	0	1	6.10	4.70	4.60	4.20	4.40	4.40	4.35
		2	6.05	5.05	4.90	4.70	4.45	4.55	4.50
		3	6.10	5.20	4.95	4.60	4.70	4.90	5.10
		4	6.50	5.85	5.20	4.95	4.75	5.05	4.85
Suspension	1120	1	6.40	4.80	4.50	4.75	4.45	4.65	4.60
		2	6.05	5.15	4.90	5.00	4.55	4.45	4.90
		3	5.00	5.00	4.40	4.70	4.85	4.70	4.85
		4	5.20	4.80	4.80	4.80	4.65	4.95	4.75
Suspension	2240	1	5.40	4.70	5.00	4.80	4.65	4.50	4.65
		2	6.00	5.25	5.35	4.60	4.85	4.90	4.65
		3	6.40	5.35	4.95	4.70	4.55	5.00	4.95
		4	5.45	4.90	4.65	4.90	4.30	4.45	4.75
Suspension	4480	1	7.10	5.40	4.95	4.55	4.80	4.80	4.65
		2	5.30	5.10	5.00	4.95	4.65	4.75	4.90
		3	6.10	4.90	4.40	4.40	4.60	4.80	4.65
		4	6.75	6.15	5.45	5.30	5.30	5.30	4.90
Solid	4480	1	6.10	5.15	4.85	4.60	4.50	4.65	4.50
		2	7.10	5.60	5.20	5.20	4.75	4.75	5.00
		3	7.25	6.10	4.90	4.65	4.15	4.70	5.00
		4	6.45	5.45	4.40	4.65	4.70	4.75	4.45

TABLE XXI

EFFECT OF ZONE LIME PLACEMENT IN A SHALLABERGER FINE SANDY LOAM ON DRY MATTER YIELD OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

				Yield (g/8 plants)				
Trt	ECCE (kg/ha)	Placement	Rep	Heads	Stems	Leaves	Crowns	Roots
1	None	Control	1	3.60	1.88	5.83	0.31	5.30
			2	2.19	2.30	6.54	0.97	6.47
			3	3.30	1.92	6.00	0.99	5.48
2	2688	Broadcast/disc	1	2.20	2,60	7.40	1.15	12.00
			2	2.52	2.35	9.71	1.10	9.54
			3	2.06	2.29	7.35	0.77	8.10
3	896	0-10 Cm	1	1.65	0.62	2.17	0.22	5.19
			2	1.61	3.02	10.50	2.34	11.76
			3	2.17	3.19	7.21	1.17	7.23
4	1782	0-10 Cm	1	2.96	2.47	7.77	1.78	8.21
			2	1.62	1.44	5.98	1.38	8.28
			3	2.61	2.47	6.33	1.16	8.78
5	2688	0-10 Cm	1	5.30	2.72	9.13	1.19	8.83
			2	1.54	4.07	10.31	1.67	9.87
			3	3.30	3.64	7.18	1.16	7.44
6	896	10-20 Cm	1	2.31	3.30	7.02	1.29	8.67
			2	1.93	2.53	6.19	1.21	7.03
			3	1.23	1.74	10.70	2.57	10.47
7	1782	10-20 Cm	1	0.43	0.73	4.18	0.46	5.77
			2	1.78	2.32	9.63	1.47	6.19
			3	3.24	3.16	8.32	1.29	6.11
8	2688	10-20 Cm	1	4.63	3.35	8.37	1.29	7.79
			2	4.45	3.13	8.62	2.15	9.57
			3	3.25	1.66	7.09	0.98	6.24
9	896	20-30 Cm	1	1.54	2.79	6.97	0.78	6.52
			2	3.05	1.63	8.02	0.86	6.57
			3	2.31	3.83	9.39	1.73	8.18
10	1782	20-30 Cm	1	2.20	0.76	6.60	0.65	5.93
			2	1.93	1.85	9.59	1.14	6.09
			3	3.14	1.78	6.69	0.58	6.29
11	2688	20-30 Cm	1	3.02	4.04	6.37	1.63	8.93
			2	4.54	4.35	7.56	1.62	8.95
			3	3.42	3.98	6.75	1.29	8.70

TABLE XXII

EFFECT OF BAND LIME PLACEMENT IN A SHALLABERGER FINE SANDY LOAM ON DRY MATTER YIELD OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

				Yield (g/8 plants)				
Trt	ECCE (kg/ha)	Placement	Rep	Heads	Stems	Leaves	Crowns	Roots
1	None	Control	1	3.60	1.88	5.83	.37	5.30
			2	2.19	2.30	6.54	.97	6.47
			3	3.30	1.92	6.00	.99	5.48
2	2688	Broadcast/disc	1	2.20	2.60	7.40	1.15	12.00
			2	2.52	2.35	9.71	1.10	9.54
			3	2.06	2.29	7.35	.77	8.10
3	896	Band	1	2.94	2.64	1.22	7.74	6.72
			2	2.15	2.47	6.10	.85	6.03
			3	2.11	2.23	5.74	.91	6.35
4	1782	Band	1	2.43	1.41	5.70	1.05	6.12
			2	2.85	2.47	7.72	.94	5.30
			3	3.46	2.35	8.00	1.58	6.58
5	2688	Band	1	1.94	2.06	5.77	1.16	5.43
			2	5.16	2.96	8.56	1.01	6.42
			3	1.96	.82	5.31	.59	5.09

†Actual population per plot mean = 8.13

TABLE XXIII

EFFECT OF LIME PLACEMENT IN A SHALLABERGER FINE SNADY LOAM ON ALUMINUM CONCENTRATION OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

ECCE(kg/ha)	Method of Placement	Rep	Heads	Stems	Leaves	Crowns	Roots
None	Control	1	75	250	575	975	925
		2	125	200	425	325	2425
		3	125	125	525	625	2250
2688	0-30 cm	1	150	150	575	325	2925
		2	175	175	400	175	
		3	125	75	525	200	4400
2688	0-10 cm	1		175	575	300	2500
		2		375	525	425	3850
		3	75	125	450	275	3925
2688	10-20 cm	1	200	175	375	450	2900
		2	125	175		350	
		3	150	200	625	425	2700
2688	20-30 cm	1	125	175	400	550	4550
		2	175	150	400	575	
		3	125	125	325	425	3400
2688	Band	1	150	100	525	375	3725
		2	100	125	500	275	3175
		3		175	1100		825

†Concentration is in parts per million

TABLE XXIV

EFFECT OF LIME PLACEMENT IN A SHALLABERGER FINE SANDY LOAM ON CALCIUM CONCENTRATION OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

ECCE(kg/ha)	Method of Placement	Rep	Heads	Stems	Leaves	Crowns	Roots
None	Control	1	134	1040	784	394	528
		2	84	981	831	384	2493
		3	84	981	831	384	2493
2688	0-30 cm	1	472	559	1437	1446	1590
		2	119	922	840	628	803
		3	140	725		484	656
2688	0-10 cm	1		409	515	603	365
		2		859	900	512	340
		3	125	2243	890	462	365
2688	10-20 cm	1	159	1053	1203	637	503
		2	106	756	1059	1631	425
		3	325	968	768	722	371
2688	20-30 cm	1	181	472	1084	2412	406
		2	197	409	1324	1287	428
		3	134	906	1321	459	
2688	Band	1	150	2836	990	522	275
		2	115	1440	622	503	322
		3		1653	981	428	490

†Concentration is in parts per million

TABLE XXV

EFFECT OF LIME PLACEMENT IN A SHALLABERGER FINE SANDY LOAM ON MAGNESIUM CONCENTRATION OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

ECCE(kg/ha)	Method of Placement	Rep	Heads	Stems	Leaves	Crowns	Roots
None	Control	1	18713	71415	108840	31209	16370
		2	22087	38206	78194	31896	13215
		3	18869	65573	85910	37832	22024
2688	0-30 cm	1	20525	68134	111839	38644	20931
		2	19494	68884	84754	42049	21587
		3	21306			63727	26835
2688	0-10 cm	1		37394	100624	41799	15433
		2		48609	74101	45610	21555
		3	20337	44986	93095	46860	
2688	10-20 cm	1	27710	47484	70321	43892	23461
		2	21712	55732	85754	47079	27304
		3	23461		89909		
2688	20-30 cm	1	22118	47672	94720	52077	30459
		2	22743		106966	34676	20556
		3		49828	108653	53577	26491
2688	Band	1	23867	70196	85285	46298	18713
		2	23086	34645	87441	51546	26991
		3		43955	82380	50453	27554

†Concentration is in parts per million

TABLE XXVI

EFFECT OF LIME PLACEMENT IN A SHALLABERGER FINE SANDY LOAM ON MANGANESE CONCENTRATION OF SORGHUM PLANT PARTS IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

ECCE(kg/ha)	Method of Placement	Rep	Heads	Stems	Leaves	Crowns	Roots
None	Control	1	25	700	425	125	50
		2	150	625	550	175	100
		3	100	675	775	125	250
2688	0-30 cm	1	50	200	550	75	400
		2	100	425	500	50	575
		3	100	400	575	50	150
2688	0-10 cm	1		600	750	175	600
		2		675	825	100	375
		3	0	650	650	125	550
2688	10-20 cm	1	150	600	650	125	200
		2	125	325	750	125	150
		3	125	600	500	50	650
2688	20-30 cm	1	150	475	450	150	175
		2	50	550	575	50	150
		3	100	400	725	100	175
2688	Band	1	75	500	350	50	125
		2	100	425	625	125	150
		3		725	800	175	325

†Concentration is in parts per million

TABLE XXVII

EFFECT OF ZONE LIME PLACEMENT ON SOIL PH IN A SHALLABERGER FINE SANDY LOAM IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

Trt	ECCE(kg/ha)	Placement	Rep	0-10 cm	10-20 cm	20-30 cm
1	None	Control	1	7.91	4.67	4.45
			2	8.20	4.61	4.74
			3	7.75	4.86	4.77
2	2688	Broadcast/disc	1	8.16	6.96	6.13
			2	8.27	7.41	7.77
			3	8.18	6.98	7.00
3	896	0-10 cm	1	7.92	4.82	4.52
			2	8.16	4.79	4.58
			3	8.04	4.63	4.48
4	1782	0-10 cm	1	8.29	5.20	5.00
			2	8.03	4.55	4.65
			3	7.75	6.27	4.63
5	2688	0-10 cm	1	8.05	6.39	8.02
			2	8.12	5.11	4.89
			3	8.12	4.86	4.79
6	896	10-20 cm	1	6.22	5.05	4.67
			2	7.84	5.63	4.76
			3	7.91	5.28	4.99
7	1782	10-20 cm	1	7.43	6.05	4.40
			2	7.75	5.89	4.76
			3	8.12	6.46	4.60
8	2688	10-20 cm	1	7.81	6.70	4.77
			2	7.84	6.94	4.71
			3	7.63	6.85	4.98
9	896	20-30 cm	1	6.80	4.96	5.33
			2	7.66	4.67	5.29
			3	7.33	5.13	5.53
10	1782	20-30 cm	1	7.57	5.07	6.15
			2	7.97	5.86	6.70
			3	8.06	5.05	5.92
11	2688	20-30 cm	1	7.77	5.17	6.67
			2	7.92	5.02	7.20
			3	7.82	4.87	6.64

TABLE XXVIII

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A SHALLABERGER FINE SANDY LOAM IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

Trt	ECCE (kg/ha)	Placement	Rep	0-10 cm	10-20 cm	20-30 cm
1	None	Control	1	7.91	4.67	4.45
			2	8.20	4.61	4.74
			3	7.75	4.86	4.77
2	2688	Broadcast/disc	1	8.16	6.96	6.13
			2	8.27	7.41	7.77
			3	8.18	6.98	7.00
3	896	Band	1	6.53	4.55	4.32
			2	6.09	4.78	4.45
			3	5.35	4.53	4.42
4	1782	Band	1	5.80	4.45	4.18
			2	5.76	4.46	4.43
			3	6.52	4.72	4.38
5	2688	Band	1	7.11	4.97	4.67
			2	6.58	4.57	4.17
			3	5.99	4.47	4.62

TABLE XXIX

EFFECT OF SOIL PH IN A SHALLABERGER FINE SANDY LOAM ON AL, CA, MG AND MN AVAILABILITY IN A GREENHOUSE EXPERIMENT (COMPLETE DATA, 1980-1981)

pH	Rep	[Al]	[Ca]	[Mg]	[Mn]
4.18	1	33.6	168	14.4	72.0
	2	52.8	180	12.6	38.4
	3	76.8	354	15.0	19.2
4.30	1	48.0	120	9.6	105.6
	2	57.6	96	15.0	96.0
	3	38.4	150	10.8	38.4
4.60	1	43.2	294	22.8	33.6
	2	33.6	2082	29.4	33.6
	3	57.6	336	22.2	38.4
4.71	1		336	39.6	48.0
	2	19.2	186	14.4	24.0
	3	72.0	216	12.6	52.8
4.89	1	28.8	282	23.4	33.6
	2	76.8	492	49.2	24.0
	3	38.4	264	23.4	43.2
5.00	1	67.2	228	13.2	28.8
	2	72.0	270	19.8	48.0
	3	62.4	72	12.6	86.4
5.53	1	38.4	240	29.4	28.8
	2	28.8	288	27.0	38.4
	3	38.4	2106	30.6	4.8
6.13	1	28.8	594	46.8	33.6
	2	19.2	612	56.4	19.2
	3	28.8	1164	70.2	38.4
6.70	1	19.2	426	30.6	33.6
	2	48.0	504	31.8	24.0
	3	14.4	846	40.2	38.4
7.33	1	52.8	516	47.4	9.6
	2	48.0	438	44.4	28.8
	3	48.0	558	32.4	00.0

†ALL VALUES ARE PARTS PER MILLION

TABLE XXX

EFFECT OF SELECTED LIMING MATERIALS MIXED INTO A PRATT LOAMY FINE SAND ON SOIL PH IN A GREENHOUSE EQUILIBRIUM STUDY (COMPLETE DATA, 1980-1981)

Material	ECCE(kg/ha)	Rep	Days					
			14	33	55	68	84	102
Control	None	1	4.92	4.96	5.02	5.27	5.35	5.51
		2	4.98	5.00	5.21	6.04	6.00	6.34
		3	4.89	4.86	5.04	5.52	5.45	5.39
Powder	2688	1	6.61	7.16	6.92	7.10	7.75	7.68
		2	6.46	6.98	6.65	7.28	7.70	7.86
		3	6.57	6.84	6.98	6.99	7.60	7.63
Pellet	2688	1	6.50	6.85	6.58	6.66	7.40	7.71
		2	6.78	6.51	6.83	6.88	7.35	7.42
		3	6.67	6.77	6.73	6.74	7.35	7.22
Ag-lime	2688	1	6.64	6.61	6.59	6.64	7.10	7.18
		2	6.43	6.91	7.18	6.93	7.30	7.37
		3	6.65	6.97	6.66	7.27	7.45	7.58

TABLE XXXI

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A PRATT LOAMY FINE SAND AT 14 DAYS IN A GREENHOUSE EQUILIBRIUM STUDY (COMPLETE DATA, 1980-1981)

Source	Rep	pH02	pH03	pH04	pH05	pH06	pH07	pH08	pH09	pH10	pH11
	1	5.46	5.04	4.99	4.93	7.40	5.34	5.11	5.02	5.08	4.98
AG-LIME	2	5.52	5.42	5.12	5.36	7.22	5.04	4.99	4.99	5.21	5.11
	3	5.47	5.07	5.06	5.40	7.54	4.94	4.96	4.85	5.12	5.07
	1	5.10	5.72	5.04	4.91	6.92	5.16	4.93	5.00	5.19	4.84
PELLET	2	5.28	4.99	4.90	4.97	6.76	5.11	5.02	4.93	4.95	4.89
	3	5.05	5.15	4.95	6.87	7.01	5.04	5.06	5.15	5.20	.
	1	5.77	5.12	4.97	5.39	6.83	6.38	4.94	5.11	5.37	5.01
PODER	2	5.57	5.21	5.11	5.41	7.20	5.13	5.09	5.13	5.27	5.10
	3	5.14	4.84	5.12	5.17	7.05	5.07	4.95	4.96	5.08	5.06

†See Figure 3 for location

TABLE XXXII

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A PRATT LOAMY FINE SAND AT 33 DAYS IN A GREENHOUSE EQUILIBRIUM STUDY (COMPLETE DATA, 1980-1981)

Source	Rep	pH02	pH03	pH04	pH05	pH06	pH07	pH08	pH09	pH10	pH11
AG-LIME	1	5.36	5.04	4.95	5.10	7.66	6.40	4.79	4.85	6.95	4.90
	2	5.42	4.99	5.04	5.15	7.24	5.05	4.99	5.18	5.34	4.83
	3	5.60	4.93	4.92	4.93	7.45	4.79	4.96	5.11	6.88	4.93
PELLET	1	5.55	4.87	4.83	4.79	6.82	6.54	4.96	4.92	5.00	4.93
	2	6.77	4.81	4.88	4.74	6.85	5.01	5.00	5.13	5.41	5.09
	3	5.97	4.97	4.88	4.97	6.90	4.94	5.01	4.94	5.69	5.08
POWDER	1	5.69	4.78	5.00	6.68	7.12	4.98	4.88	5.10	5.86	5.45
	2	5.29	4.86	.	5.26	7.05	4.89	4.95	5.12	4.76	4.88
	3	5.31	4.91	4.94	5.01	7.85	5.20	4.73	4.93	5.95	4.97

[†]See Figure 3 for location

TABLE XXXIII[†]

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A PRATT LOAMY FINE SAND AT 55 DAYS IN A GREENHOUSE EQUILIBRIUM STUDY (COMPLETE DATA, 1980-1981)

Source	Rep	pH02	pH03	pH04	pH05	pH06	pH07	pH08	pH09	pH10	pH11
	1	5.83	5.03	4.93	4.84	7.74	5.05	4.85	4.91	5.54	4.91
AG-LIME	2	5.29	5.32	4.94	4.81	7.58	4.81	4.80	4.69	5.14	5.04
	3	5.15	5.03	5.01	4.98	7.53	5.43	5.05	5.18	5.06	5.02
	1	5.81	4.93	4.72	4.63	7.00	4.92	4.68	4.83	4.67	4.85
PELLET	2	5.67	5.03	.	4.83	6.85	4.93	.	.	.	4.87
	3	5.21	4.84	5.05	5.55	6.83	4.89	4.95	4.85	4.88	.
	1	6.11	5.15	5.00	4.81	7.20	4.85	4.89	4.83	4.80	4.83
POWDER	2	5.30	4.99	4.89	4.83	7.53	4.97	4.87	4.83	6.21	4.84
	3	6.38	4.97	4.87	4.95	7.53	5.63	5.01	5.08	4.83	4.83

†See Figure 3 for location

TABLE XXXIV[†]

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A PRATT LOAMY FINE SAND AT 68 DAYS IN A GREENHOUSE EQUILIBRIUM STUDY (COMPLETE DATA, 1980-1981)

Source	Rep	pH02	pH03	pH04	pH05	pH06	pH07	pH08	pH09	pH10	pH11
AG-LIME	1	6.31	4.88	4.81	4.71	8.02	5.02	4.77	4.86	5.29	5.01
	2	5.99	5.18	5.13	4.96	7.56	4.73	4.88	4.87	5.68	4.80
	3	5.09	4.90	4.97	5.06	7.61	4.93	4.96	5.02	4.80	4.93
PELLET	1	6.49	5.11	4.89	4.82	6.83	4.81	4.83	4.86	4.80	4.83
	2	6.49	4.98	4.69	5.55	6.52	4.78	4.87	5.01	5.07	6.19
	3	5.22	4.97	4.82	6.76	7.14	4.85	5.09	4.71	4.82	5.11
POWDER	1	5.97	4.98	4.82	4.96	6.65	6.94	5.72	5.14	7.37	5.58
	2	5.91	5.02	4.83	4.88	.	7.23	4.82	4.76	7.72	.
	3	5.74	4.97	4.94	4.80	7.27	4.79	4.82	4.87	4.93	4.94

[†]See Figure 3 for location

TABLE XXXV

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A PRATT LOAMY FINE SAND AT 84 DAYS IN A GREENHOUSE EQUILIBRIUM STUDY (COMPLETE DATA, 1980-1981)

Source	Rep	pH02	pH03	pH04	pH05	pH06	pH07	pH08	pH09	pH10	pH11
	1	7.00	5.10	5.50	5.70	8.25	5.70	5.60	5.25	.	5.55
AG-LIME	2	6.55	5.00	5.30	5.25	7.95	5.75	5.15	.	6.40	5.30
	3	5.80	5.15	5.40	.	8.20	5.45	5.30	5.60	.	5.65
	1	6.85	5.35	5.55	5.25	7.55	5.55	5.35	5.30	5.25	5.20
PELLET	2	7.40	5.80	5.45	.	7.15	7.20	5.55	5.80	6.60	5.60
	3	6.90	5.35	5.65	7.20	7.40	5.60	5.35	5.25	5.50	5.30
	1	6.05	5.45	5.70	5.65	8.35	5.70	5.30	5.15	6.95	5.60
POWDER	2	6.30	5.20	5.30	6.20	7.60	5.65	5.65	5.10	5.90	5.90
	3	7.00	5.40	5.55	5.50	7.95	5.60	5.45	5.40	6.20	5.65

†See Figure 3 for location

TABLE XXXVI

EFFECT OF BAND LIME PLACEMENT ON SOIL PH IN A PRATT LOAMY FINE SAND AFTER 102 DAYS IN A GREENHOUSE EQUILIBRIUM STUDY (COMPLETE DATA, 1980-1981)

Source	Rep	pH02	pH03	pH04	pH05	pH06	pH07	pH08	pH09	pH10	pH11
	1	7.32	4.72	4.99	5.22	7.80	7.22	4.80	4.75	6.58	5.31
AG-LIME	2	6.39	4.59	4.65	5.19	8.39	5.00	4.67	4.70	6.32	5.12
	3	6.49	4.87	5.12	5.06	8.35	5.15	5.04	4.97	7.66	5.45
	1	7.12	4.72	4.86	6.95	.	4.91	5.06	5.02	5.39	4.76
PELLET	2	5.68	.	4.65	6.66	7.07	4.67	4.68	4.66	4.76	4.75
	3	5.98	4.62	4.82	7.07	7.15	4.87	5.13	5.00	4.84	5.32
	1	5.30	4.77	7.05	4.80	7.57	4.85	4.59	4.86	5.16	4.90
POWDER	2	5.82	5.11	5.11	5.13	7.81	5.24	4.98	4.94	5.69	4.94
	3	6.85	5.07	5.20	5.27	7.97	6.32	5.20	5.18	5.40	4.20

†See Figure 3 for location

TABLE XXXVII

EFFECT OF SURFACE APPLIED LIME SUSPENSION ON SOIL PH IN A PRATT LOAMY FINE SAND IN A GREENHOUSE EQUILIBRIUM STUDY (COMPLETE DATA, 1980-1981)

Source	Rep	Depth/Days																	
		0 CM						2.5 CM						5.0 CM					
		14	33	54	68	84	102	14	33	54	68	84	102	14	33	54	68	84	102
Control	1	4.92	4.96	5.02	5.27	5.35	5.51	4.92	4.96	5.02	5.27	5.35	5.51	4.92	4.96	5.02	5.27	5.35	5.51
	2	4.92	5.00	5.21	6.04	6.00	6.34	4.98	5.00	5.21	6.04	6.00	6.34	4.98	5.00	5.21	6.04	6.00	6.34
	3	4.89	4.86	5.04	5.52	5.45	5.39	4.89	4.86	5.04	5.52	5.45	5.37	4.89	4.86	5.04	5.52	5.45	5.39
Suspension	1	6.96	7.33	7.35	7.46	6.85	7.74	5.15	4.99	4.89	5.00	6.45	5.11	5.01	4.87	4.92	4.92	6.05	4.87
	2	7.27	8.04	7.54	7.05	7.00	7.96	4.91	4.85	5.08	4.82	5.25	4.75	4.83	4.94	4.96	4.73	5.35	5.10
	3	6.54	7.19	7.33	7.14	7.70	7.28	4.80	4.96	5.03	4.88	5.20	6.50	4.88	4.92	4.76	4.77	5.40	5.15

Source	Rep	7.5 CM						10 CM					
		14	33	54	68	84	102	14	33	54	68	84	102
Control	1	4.92	4.96	5.02	5.27	5.35	5.51	4.92	4.96	5.02	5.27	5.35	5.51
	2	4.98	5.00	5.21	6.04	6.00	6.34	4.98	5.00	5.21	6.04	6.00	6.34
	3	4.89	4.86	5.04	5.52	5.45	5.39	4.89	4.86	5.04	5.52	5.45	5.39
Suspension	1	4.83	4.86	4.71	4 94	6.35	5.00	5.08	4.94	5.53	4.85	5.90	4.80
	2	4.88	4.91	4.93	4.73	4.90	4.80	5.05	5.12	4.15	4.73	5.05	4.57
	3	4.94	4.91	4.93	4.78	5.10	4.66	•	4.81	4.82	4.77	5.20	4.84

VITA[2]

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