Nitrogen, Cover Crop, Tillage and Lime Effects On Soil Acidity In Cotton Production Systems

D.D. Tyler, E.L. Ritchey, M.E. Essington, M.D. Mullen, and A.M. Saxton[1]

AUTHORS: [1] E.L. Ritchey, Graduate Research Assistant, Agronomy Department; M.E. Essington, Professor; M.D. Mullen, Professor, Dept. Plant & Soil Science; A.M. Saxton, Professor, Statistical and Computing Services; D.D. Tyler, West Tennessee Experiment Station, 605 Airways Blvd., Jackson, TN 38301, dtyler@utk.edu

RESEARCH APPLICATION SUMMARY

Research Question

In no-tillage systems fertilizer and lime are surface applied and not incorporated into the soil. Questions remain as to whether this practice effectively neutralizes soil acidity. We examined this in a long term experiment involving tilled and no-tilled cotton grown with four nitrogen rates and a legume and no cover crop. These variables had produced a wide range of initial soil acidity levels based on pH, exchangeable Mn. This provided a unique opportunity to evaluate liming rate and application method.

Literature Summary

Most past data indicates that surface application of lime in no-tillage systems is effective in neutralizing acidity. When the University of Tennessee started using a buffer procedure in conjunction with water pH the amount of lime being recommended at a certain pH level dropped as compared to previous recommendations. This resulted in questions concerning lime rate. It was also observed that pH changes were not occurring as rapidly as expected. Since the reduction in exchangeable Al and Mn are the main goals of liming, the effect of application method, surface or incorporation, and lime rate needed further study. Past research had also shown that acidity can become stratified near the soil surface in notillage. This has led to speculation that less lime might be needed if a thinner zone of soil required lime as compared to recommendations based on liming the top six inches. Therefore, we compared our full rate of lime based on past correlations for liming the top six inches to a one half recommended rate.

Study Description

A study comparing nitrogen rate, cover crops and tillage for cotton was begun in 1981 at the West TN Agricultural Experiment Station in Jackson, TN.

Soil: Lexington silt loam

Experimental design: Randomized complete block with a split-split-split arrangement of treatments. Four replicates

Main plot: Nitrogen rates of 0, 30, 60, or 90 lb. N/acre as ammonium nitrate.
Split plot: Winter annual cover crops of hairy vetch, crimson clover, wheat, and no cover
Split-split plot: Tillage or no-tillage.
Split-split-split plot: full or one half recommended lime rate

Treatments were applied to the same plots each year. Tillage consisted of chisel plowing, disking, and leveling. No-tillage plots were planted after desiccation of cover with either paraquat or glyphosate. Both systems were planted with a smooth narrow coulter planter. Soil samples were analyzed for pH, exchangeable Al, and Mn. Lime was applied in 1995 as normally ground pelletized agricultural limestone that met state lime standards.

Applied Question

Does surface lime application adequately neutralize acidity over a wide range of pH values and are present techniques for lime recommendations reasonable and accurate.

Data from this test indicate that as long as total nitrogen in a system is adjusted for maximum crop yields, the present lime recommendations are adequate. Data does indicate that lime effect will take more than one year in both tillage and no-tillage systems. These data also indicate that levels of exchangeable Al and Mn decrease even before an affect on pH level is observed. A nitrogen adjustment for nitrogen released from a nitrogen fixing legume cover crop should be made or a much greater level of soil acidity will occur, especially in no-tillage systems. In this experiment this reduction could be about 90 lb. N/acre meaning no nitrogen fertilizer was needed for maximum cotton yields. With the advent of variable rate lime application more refinement in rates of lime for effective acidity management to achieve maximum profit will be needed.

ABSTRACT

Continuous long-term management practices are known to impact many soil properties. This study was conducted to document the influence of different continuous long-term (14 years) cotton (*Gossypium hirsutum L.*) management systems on selected soil properties of a loess-derived soil. The experiment was established in 1981 on a well-drained Lexington silt loam (fine-silty, mixed, thermic, Ultic Hapludalf) soil. The effects of four N-rates (0, 30, 60, and 90 lbs. ac^{-1}), two tillage practices (no-tillage (NT), and four cover crops (no cover, wheat, vetch, and clover) were quantified for selected soil properties. Soil samples were taken in the spring of 1995, prior to annual fertilization and analyzed for pH, exchangeable Al, and exchangeable Mn. Nitrogen rate and cover crop significantly influenced exchangeable Mn, and soil pH. As N-rate increased, soil pH values decreased, while exchangeable Mn values increased. Tillage practice significantly influenced exchangeable Al, and pH, with the NT treatments having higher concentrations of exchangeable Al, and lower soil pH values. Excessive amounts of acidity are

avoided when proper N-fertilizer practices are used, including credit for additional N from a legume cover. A study was initiated in the spring of 1995 to document the influence of two lime rates (recommended rate and ½ the recommended rate) on soil chemical properties, and evaluate the effectiveness of surface applied limestone. Pelletized limestone that met minimum State standards was applied in the spring of 1995 at the recommended rate and ½ the recommended rate. All treatments, with the exception of NT vetch plots that received 60 lb. N/acre, had pH values ≥6.1 by the spring of 1997, with either rate of limestone. Both rates of limestone significantly decreased the amount of exchangeable Al and Mn, regardless of tillage practice or choice of cover crop, usually within one year of application. Research is continuing to evaluate the duration of lime effectiveness and cotton yields.

INTRODUCTION

No-till (NT) and other types of conservation practices have gained popularity in recent years in order to comply with soil erosion guidelines, reduce fuel and labor cost associated with seedbed preparation, and to allow for row-crop production on steeply sloping farmland, while still maintaining profitable yields (Dick, 1983). In long-term NT cropping systems, the buildup of plant residues and surface fertilizer placement, especially nitrogen, can influence several soil properties, including soil pH, organic carbon (OC), base saturation, and the amount of exchangeable Al and Mn (Blevins et al., 1978; Blevins et al., 1983; Evangelou and Blevins, 1985; Kamprath, 1970 Ismail et al., 1994; Grove and Blevins, 1988; Dick, 1983).

Nitrogen is the most important fertilizer input in agriculture and is required in one of the largest quantities. Surface application of ammoniacal N fertilizer in NT systems can cause the top few centimeters of the soil surface to become highly acidic due to nitrification (Ismail et al., 1994; Blevins et al., 1978; Blevins et al., 1983). As the pH of the soil decreases, the total acidity and the concentration of exchangeable Al and Mn increase.

Exchangeable Al and Mn in a soil are influenced by several factors. As the soils weather, soluble silicate, basic cations, and acidic cations are released from soil parent material. Basic cations are more readily leached from the soil profile than acidic cations, thus resulting in more acidic cations on the exchange complex, and an acid soil. As the soil becomes more acidic in nature, both Al and Mn become more available for plant uptake with a concomitant decrease in the availability of Ca, Mg, and other essential nutrients (Howard, 1970; Foy, 1984; Adams, 1984). Yield reductions can occur if these elements reach elevated levels. Unless soil pH < 4.0-4.25, H^+ toxicity is usually not found, due to the amount of H^+ involved being very small when compared to exchangeable Al (Howard and Adams, 1965; Foy, 1984). Aluminum and Mn phytotoxicity can occur when sufficient levels of the exchange complex are occupied by Al and Mn, depending on soil organic carbon (SOC) content, soil pH, crop cultivar, soil type, and other crop stresses that might be incurred (Kamprath, 1970; Adams, 1981; Adams, 1984; Adams and Morre, 1983; Blevins et al., 1978). There are difficulties in determining exchange complex saturation by Al and Mn that will be toxic in different situations. Adams and Moore (1983) found phytotoxicity could occur in cotton when 2.2 – 77% of the exchange complex is occupied by Al. They also found in the same experiment phytotoxic symptoms to be absent when up to 60% of the exchange complex is occupied by Al.

Different crops and even different varieties of the same crop exhibit symptoms of phototoxicity at different levels of exchangeable Al and Mn (Foy et al., 1995). However it is generally agreed the problems from Mn and Al can occur with pH<5.55 (Adams, 1984; Foy, 1984; Fox, 1979, Ritchie, 1989). Nutrient solutions containing 5-10 ppm Mn appear to be toxic to cotton (Kennedy and Jones, 1991; Adams and Wear, 1957), and Adams (1984) reported that concentrations of easily reducible Mn around 50-100 ppm appear to be toxic.

Cotton (*Gossypium hirsutum L.*) is a crop that does not produce large amounts of biomass; therefore winter cover crops need to be grown for adequate residue management to reduce the potential of erosion (Reeves et al., 1995; Bauer and Bradow, 1993). Cover crops add organic carbon to the soil, "scavenge" fertilizer that would have otherwise been lost to leaching, provide a good mulch to compete against weeds dramatically reduce soil erosion, and help maintain soil productivity (Reeves et al., 1995; Bauer and Bradow, 1993). Three groups of cover crops are generally used in a conservation-tillage system; winter annual weeds, grass and small grains, and legumes. Wheat (*Triticum* spp.), rye (*Secale cerale* L.), clover (*Trifolium incarnatum* L.), and vetch (*Vicia villosa* L.) are commonly used as winter cover crops following cotton (Reeves et al., 1995; Bauer and Bradow, 1993; Keisling et al., 1995). In addition to the other benefits mentioned about cover crops, legume cover crops also fix N, which is released in the form of ammonium (NH_4^+). This N is then nitrified to nitrate (NO_3^-), which produces acidity reducing the pH of the soil. A legume cover crop can add from very little to about 60 to 90 lb. N/acre each year. The University of Tennessee recommends 60 to 80 lb. N/acre for cotton grown on upland soils and the additional N from legumes should be taken into consideration when applying N following a legume cover. The legume cover crop coupled with high nitrogen rates tends to accelerate the decrease in soil pH. When the soil pH reaches a critical level, limestone applications are recommended. Historically, Tennessee recommended the addition of 3 tons/acre limestone to increase soil pH one unit. In 1985 Tennessee started using the Adams and Evans buffer test in conjunction with the 1:1 water pH to determine the lime requirement (LR) of the soil (Adams and Evans, 1962). This method was still based on a sampling depth of 6 inches. The Adams and Evans buffer test generates lower lime recommendations in many instances as compared to the old method of applying 3 tons/acre to obtain a one unit change in pH.

As noted previously, the most important function of liming is to reduce the amount of exchangeable Al and Mn present in the soil profile (Kamprath, 1970; Blevins et al., 1983; Coleman et al., 1958). Soil pH, which is an indicator of total acidity and exchangeable Al and Mn, must be above a certain critical value for proper nutrient availability and optimal plant growth (which differs with different soils and crops grown). Therefore, the presence of acidic (and phytotoxic) cations on the soil's exchange complex and the absence of basic cations is the cause of most decreased plant growth, not the pH of the soil (Blevins et al., 1983).

The objectives of this study were (i) to document the influence of different continuous long-term (14 years) cotton (*Gossypium hirsutum L.*) management systems on selected soil properties of a loess-derived soil, using two tillage systems, four N rates (0, 30, 60, and 90 lb./acre), and two winter cover crops (no cover and vetch) (ii) document the changes in selected soil properties after limestone application, (iii) evaluate the effectiveness of surface applied lime for increasing soil pH, relative to soil incorporation using the Adams and Evans buffer test, and

(iv) evaluate the effectiveness of the ½ recommended rate of lime as compared to the full recommended rate of lime in raising soil pH.

MATERIALS AND METHODS

The experiment was conducted at the West Tennessee Experiment Station (WTES) located at Jackson, Tennessee, on a Lexington silt loam (fine-silty, mixed, thermic, Ultic Hapludalf) on long-term (14 yr.) NT and DT plots. The Lexington soil is a well-drained upland soil (0-2% slope) formed on an old river terrace with loess being deposited over sand.

The experimental plots were established in 1981 and replicated 4 times in a split-split randomized complete block (RCB) design. The experiment consisted of 4 blocks. Each block was split horizontally 4 times and randomly assigned 4 N rates (0, 30, 60, and 90 lb. N/acre). These blocks were further split into vertical blocks that consisted of randomly assigned cover crops (no cover, wheat, clover, and vetch). These blocks were again split into vertical blocks that were randomly assigned one of two tillage treatments (T and NT). Plots were 26.2 feet wide by 40 feet long. After all the splits were completed the experiment contained 128 plots. In this paper the no cover and vetch cover was chosen to demonstrate the two extremes for various soil properties in the experiment.

Soil samples were taken at random locations in each plot, in the spring of 1995 prior to planting, using a 1 inch diameter soil probe at 0-3, 3-6 and 0-6 inch depths. For the 0-3 and the 3-6 inch depths, a subsample was taken to 6 inches and divided into the two depths. For each plot, approximately 10 subsamples were taken to 6 inches for the 0-3 and 3-6 inch depths and 5 subsamples were taken for the 6 inch depths. The subsamples at each depth were combined for analyses.

Cotton (Stoneville 132) was planted May 15, 1995, following an April 28 burndown application of glyphosate at a rate of 1 quart/acre in all plots. Cotton was planted at a density of approximately 9,000 plants/acre using a John Deere NT planter. Aldicarb at 0.5 lb./acre active ingredients (ai) and quintozene (PCNB) 10G at 1.12 was applied in-furrow at planting. On May 16 fluometuron 4L at 1.5 lb./acre ai, pendimethalin at 1 lb./acre ai, norflurazon at 1 lb./acre ai, and paraquat at 0.6 lb./acre ai, with ½% surfactant were applied. The plots received 90lb/acre of P_2O_5 and K_2O on May 9, based on medium/low soil test results. On May 10 and 11, plots were subjected to an additional split and lime was applied at the full recommended rate and half the recommended rate according to the 1:1 water pH and the Adams and Evans buffer test (Adams and Evans, 1962). The ground agricultural limestone was pelletized and had a calcium carbonate equivalency of 80% and a relative neutralizing value of 80%. Nitrogen, in the form of ammonium nitrate (34% N), was hand broadcast at planting. Tillage on the T plots was accomplished by disking twice and leveling prior to planting. Weed control was accomplished by the above indicated herbicides and hand-hoeing when necessary. Cotton yields were taken from the inside two rows of each plot and ginned using a 1/5 scale gin. After the cotton was harvested the stalks were shredded and winter cover crops were drilled through the residue, except the no cover treatments, which remained fallow.

Soil samples were air dried and ground to pass a 2-mm sieve. All chemical analyses were reported for the 0-3 and 3-6 inch depths, with the exception of soil pH, which was also analyzed for the 0-6 inch depth. Soil pH was determined using 1:1 soil solution ratio using distilled-deionized water. Soils were extracted by using 1M KCl for exchangeable Al (Barnhisel and Bertsch, 1982). Exchangeable bases and Mn were determined using the 1M NH_4OAc (pH 7) method (Thomas, 1982). All extracts were analyzed using inductively coupled argon plasma-optical emission spectrometry (ICP-OES).

Statistics were performed using SAS version 6.12 (SAS Institute, 1989). The Mixed-model procedure was used for analysis of variance and significant differences among means were determined by LSD mean separation. Analysis by certain treatment levels was done in addition to an overall model to simplify mean separation results, and to address unequal variances, particularly across N-rates. The 0.05 probability level was used to define statistical significance. The 0-6 inch sample for pH was also included in the statistical analysis. All other analyses were performed on the 0-3 and 3-6 inch depth data.

Statistical analyses for pH were performed on (H^+), since pH is on a logarithmic scale, and then converted back and reported as pH values. For example, if concentration data are used, pH values of 4.0 and 5.0 average to pH=4.29, instead of pH 4.5 if pH data are used. Some inconsistencies in mean separation have occurred due to this transformation; however this was the most valid way of analyzing the pH variable, due to the pH variable being skewed to the lower pH value.

RESULTS AND DISCUSSION

Initial pH

The initial pH values for the 0 and 90 lb. N/acre rates for no winter cover (NC) and vetch winter cover (V) for the tilled and no-tilled systems at the two sampling depths are shown in Figures 1 and 2. Average pH values were above the 6.1 value for the 0 N rate in both systems at both depths. Values were lower at the 90 lb. N rate and were below the 6.1 pH value in both cover systems resulting in a lime recommendation. Values tended to be lower when vetch was the winter cover as compared to no cover. This difference was significantly lower for the 3 to 6 inch depth for the no-tillage system. This illustrates the additional acidifying effect of the nitrogen contributed from the vetch, a nitrogen fixing legume. If a recommended reduction in nitrogen of 60 lb. / acre is made in the system to account for nitrogen contribution from the legume the pH values are above 5.0 and similar to the 90 lb. rate in the no cover system (Figure 3.) An overall summary of the initial pH values across the four nitrogen rates, two cover systems, and two tillage systems indicated that as N rate increased , pH decreased. No-tillage systems generally had lower pH values than the corresponding tilled systems. Plots that had a nitrogen fixing legume cover crop tended to have lower pH values than those with no cover.

Lime effects on pH

The change in pH from the spring 1995 application of the full recommended lime rate for the 90 lb. N rate for NC tilled and no-tilled systems and the no-tilled system with vetch for 1996 and 1997 is shown in Figures 4, 5, and 6. In the tilled no cover treatment pH values increased in the first year after application to near the 6.1 cutoff value where no additional lime would be recommended. Values continued to increase in the second season after application (Figure 4.) In the no-tillage treatment changes from surface lime application were less one year after application than with the tilled treatment, especially at the 0 to 3 inch depth. Two years were required for the lime to adequately react to raise pH above the 6.1 value (Figure 5). In both situations the lime was effectively changing the pH at the 3 to 6 inch depth even though in no-tillage there was no incorporation of the lime. The effects of very low pH resulting from use of excessive nitrogen in a system and the effect of liming are shown in the V-NT treatment in Figure 6. Two years after lime application the pH values have not increased to the 6.1 value. This system has approximately twice the amount of nitrogen needed for maximum yields if it is assumed that the vetch contributes about 80 lb. of N to the system. This additional nitrogen is detrimental in creating excessive soil acidity. In the vetch treatments with only 0 or 30 lb. N the pH did increase above the 6.1 value by 1997 (data not shown). In both systems at least two years were required to achieve pH values consistently above 6.1. Excessive N when using a legume cover crop with a high N fertilizer application increases soil acidity and makes adequate liming much more difficult.

The comparison of the effect of the full rate of recommended lime to only one-half the rate relative to pH change between 1995 and 1997 is show in Figure 7. The half rate of lime was almost as affective in changing the pH as the full rate and the average of the two depths at the half rate were at the 6.1 cutoff value. Research is continuing to evaluate the yearly changes in pH for both rates of lime.

Exchangeable Aluminum and Manganese

The goal of lime application is to reduce the levels of exchangeable Al and Mn to below toxic levels. The levels of exchangeable Al did not increase in the initial 1995 sampling until the 90lb N rate. This corresponds to the pH value falling below about 5.3. From above 5.3 to 6.3 the values were not significantly affected by lime application in the following two years (Figure 8). This drop in Al occurred even though the pH at both sampling depths was below the 6.1 value in 1996. The initial Mn concentrations were significantly higher at the 60 and 90 lb. N rates with the increase occurring somewhere between a pH of 5.3 to 5.9. As with Al the values fell to the significantly lowest values at all N rates after the first year of liming (Figure 9). Very similar concentrations and changes in Al and Mn were observed for the tilled vetch treatment at the four N rates (Figures 10 and 11). However, with the NT vetch treatment the very acid (Figure 12.) 90 lb. N rate treatment initially had Al values about three times higher than the other two treatments. In this treatment the increase occurred somewhere below a pH of about 5.1. The levels in all treatments fell to their lowest in 1996 after liming even though there were no significant changes in pH (Figure 6.) The concentrations and change in Mn were similar to the other two treatments (Figure 13). Levels of both Al and Mn tended to increase at pH levels less than about 5.5. Lime application significantly lowered levels even with small or no changes in pH.

Changes in pH and Cotton yields

The changes in pH for the two lime rates across all treatments are continuing to be evaluated to determine the longevity of lime effectiveness. Cotton yields are also being evaluated for the two lime treatments. An economic analysis on various aspects of liming is in progress.

Summary

1. The recommended rate of lime, whether incorporated or surface applied, increased pH to greater than the 6.1 liming cutoff value in both tillage systems.
2. Neither rate of lime increased the pH value above 6.1 in NT vetch plots receiving 60 or 90 lb. N/acre.
3. The pH increased more slowly in NT than tilled plots.
4. Exchangeable Al values were the highest at the 90 lb. N/acre rate, with the vetch treatments having greater amounts of Al than no cover plots.
5. Within one year of application, the majority of exchangeable Al was displaced even though the soil pH did not always increase.
6. Exchangeable Mn was found in higher concentration than Al and was highest in treatments that received 60 lb. N/acre or greater.
7. The half rate of recommended lime was almost as effective as the full rate in changing pH.
8. Proper adjustments for fixed N from legume covers should be made to avoid excessive acidity and more frequent lime applications.

Literature Cited

Adams, F. 1981. Modifying the root environment to reduce crop stress. *In* H. M. Taylor (ed.) Alleviating chemical toxicities: Liming acid soils. ASAE 4:267-301. ASAE, St. Joseph, MI.

Adams, F. 1984. Crop response to lime in the southeastern United States. *In* F. Adams (ed.) Soil acidity and liming. Agronomy 12:211-265. ASA, Madison, WI.

Adams, F. and B. L. Moore. 1983. Chemical factors affecting roots growth in subsoil horizons of coastal plains soils. Soil Sci. Soc. Am. J. 47:99-102.

Adams, F. and C. E. Evans. 1962. A rapid method for measuring lime requirement of red-yellow podzolic soils. Soil Sci. Soc. Am. Proc. 26:355-357.

Adams, F. and J. I. Wear. 1957. Manganese toxicity and soil acidity in relation to crinkle leaf of cotton. Soil Sci. Soc. Am Proc. 21:305-308.

Barnhisel, R. and P. M. Bertsch. 1982. Aluminum. p. 275-300. *In* A. L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA, Madison, WI.

Bauer, P. J. and J. M. Bradow. 1993. Cover crops. p. 18-22. *In* N. G. Wyatt (ed.) Conservation-tillage systems for cotton. Spec. Rep. 160. Arkansas Agric. Exp. Stn., Fayetteville.

Blevins, R. L., L. W. Murdock, and G. W. Thomas. 1978. Effect of lime application on no-tillage and conventionally tilled corn. Agron. J. 70:322-326.

Blevins, R. L., M. S. Smith, G. W. Thomas, and W. W. Frye. 1983. Influence of conservation tillage on soil properties. J. Soil Water Cons. 38:301-305.

Coleman, N. T., E. J. Kamprath, and S. B. Weed. 1958. Liming. *In* A. G. Norman (ed.) Adv. Agron. 10:475-522. ASA, Madison, WI.

Dick, W. A. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. Soil Sci. Soc. Am. J. 47:102-107.

Evangelou, V. P. and R. L. Blevins. 1985. Soil-solution phase interaction of basic cations in long-term tillage systems. Soil Sci. Soc. Am. J. 49:357-361.

Fox, R. H. 1979. Soil pH, aluminum saturation, and corn grain yield. Soil Sci.127:330-334.

Foy, C..D. 1984. Physiological effects of hydrogen, aluminum, and manganese toxicities in acid soil. p. 57-97. *In* F. Adams (ed.) Soil acidity and liming. 2nd ed. Agron. Monogr. 12. ASA, CSSA, SSSA, Madison, WI.

Foy, C. D., R.R. Weil, and C. A. Caradetti. 1995. Differential tolerances of cotton genotypes in nutrient solution. J. Plant Nutr. 18:685-706.

Grove, J. H. and R. L. Blevins. 1988. Correcting soil acidification in continuous corn: N-rate, tillage, and time. Comm. Soil Sci. Plant Anal. 19:1331-1342.

Howard, D. D. 1970. Adjust soil pH for profit. Publ. 599. The Univ. of Tennessee Agric. Ext. Serv., Knoxville.

Howard, D. and F. Adams. 1965. Calcium requirement for penetration of subsoils by primary cotton roots. Soil Sci. Soc. Am. Proc. 29:558-562.

Ismail, I., R. L. Blevins, and W. W. Frye. 1994. Long-term no-tillage effects on soil properties and continuous corn yields. Soil Sci. Soc. Am. J. 58:193-198.

Kamprath, E. J. 1970. Exchangeable Al as a criterion for liming leached mineral soils. Soil Sci. Soc. Am. Proc. 34:252-254.

Kennedy, C. W. and J. E. Jones. 1991. Evaluating quantitative screening methods for manganese toxicity in cotton genotypes. J. Plant Nutr. 14:1331-1339.

Keisling, T., C. S. Rothrock, and G. Palmer. 1995. Winter cover crops' influence on cotton yield. *In* W. L. Kingery and N. Buehring (ed.) Southern Cons. Tillage Conf. for Sustainable Agric., Jackson, MS.

Reeves, D. W., D. D. Tyler, and W. L. Hargrove. 1995. Winter cover crops. p. 27-30. *In* G. W. Langdale and W. C. Moldenhauer (ed.) Crop Residue Management to Reduce Erosion and Improve Soil Quality: Southeast. USDA, ARS, Cons. Res. Rep. 39. U. S. Gov. Print. Office, Washington, DC.

Ritchie, G. S. 1989. Aluminum, hydrogen, and manganese. p. 1-60. *In* A. D. Robson (ed.) Soil acidity and plant growth. Academic Press, Sidney.

SAS Institute. 1989. SAS/STAT user guide: Statistics. Version 6. SAS Inst, Cary, NC.

Thomas, G.W. 1982. Exchangeable cations. p. 159-165. *In* A. L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA, Madison, WI.

Figure Legends

Figure 1. Soil pH values in the Spring of 1995 for two soil depths in the 0 nitrogen (N) and 90 lb. N/acre treatments with no winter cover crop (NC) and a vetch (V) winter cover crop in the tilled (T) system. Values with different letters are significantly different at the 5% probability level.

Figure 2. Soil pH values in the Spring of 1995 for two soil depths in the 0 nitrogen (N) and 90 lb. N/acre treatments with no winter cover crop (NC) and a vetch (V) winter cover crop in the no-tilled (NT) system. Values with different letters are significantly different at the 5% probability level.

Figure 3. Soil pH values in the Spring of 1995 for two soil depths in the 90 nitrogen (N) and 30 lb. N/acre treatments with a vetch (V) and no cover (NC) for the no-tilled (NT) system. Values with different letters are significantly different at the 5% probability level.

Figure 4. Soil pH values in the Spring of 1995, 1996, and 1997 for two soil depths in the 90 lb. N/acre, no cover (NC), tilled (T) system after the full recommended lime rate was applied in the Spring of 1995. Values with different letters are significantly different at the 5% probability level.

Figure 5. Soil pH values in the Spring of 1995, 1996, and 1997 for two soil depths in the 90 lb. N/acre, no cover (NC), no-tilled (NT) system after the full recommended lime rate was applied in the Spring of 1995. Values with different letters are significantly different at the 5% probability level.

Figure 6. Soil pH values in the Spring of 1995, 1996, and 1997 for two soil depths in the 90 lb. N/acre, vetch (V), no-tilled (NT) system after the full recommended lime rate was applied in the Spring of 1995. Values with different letters are significantly different at the 5% probability level.

Figure 7. Soil pH values in the Spring of 1997 for two soil depths in the 90 lb. N/acre, no cover (NC), no-tilled (NT) system after the full and one half full recommended rates of lime were applied in the Spring of 1995. Values with different letters are significantly different at the 5% probability level.

Figure 8. Soil exchangeable aluminum (Al) concentrations for the 0 to 3 inch depth for the no cover, no tilled (NT) treatment at all four nitrogen rates in the Spring of 1995, 1996, and 1997 after application of lime at the full recommended rate in the Spring of 1995. Concentrations with different letters are significantly different at the 5% probability level.

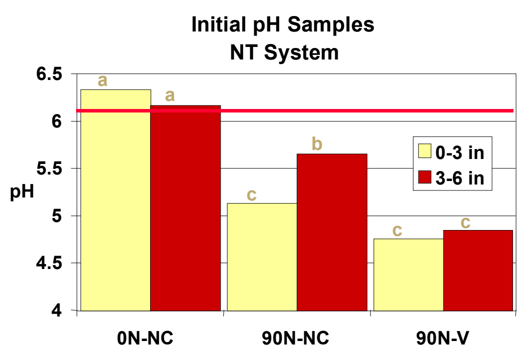
Figure 9. Soil exchangeable manganese (Mn) concentrations for the 0 to 3 inch depth for the no cover no-tilled (NT) treatment at all four nitrogen rates in the Spring of 1995, 1996, and 1997 after application of lime at the full recommended rate in the Spring of 1995. Concentrations with different letters are significantly different at the 5% probability level.

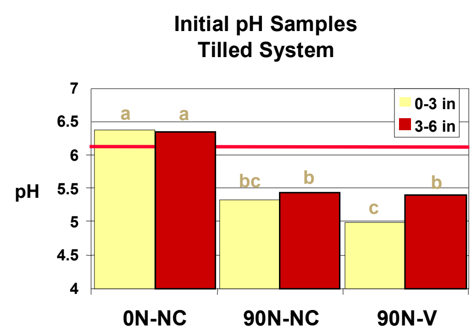
Figure 10. Soil exchangeable aluminum (Al) concentrations for the 0 to 3 inch depth for the vetch, tilled treatment at all four nitrogen rates in the Spring of 1995, 1996, and 1997 after application of lime at the full recommended rate in the Spring of 1995. Concentrations with different letters are significantly different at the 5% probability level.

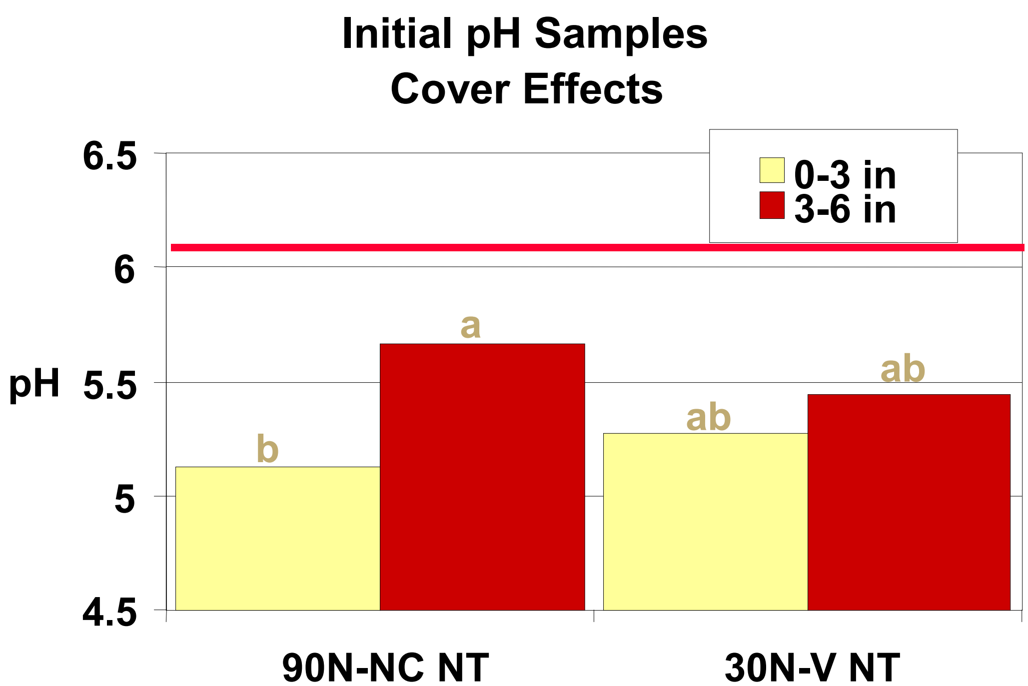
Figure 11. Soil exchangeable manganese (Mn) concentrations for the 0 to 3 inch depth for the vetch, tilled treatment at all four nitrogen rates in the Spring of 1995, 1996, and 1997 after application of lime at the full recommended rate in the Spring of 1995. Concentrations with different letters are significantly different at the 5% probability level.

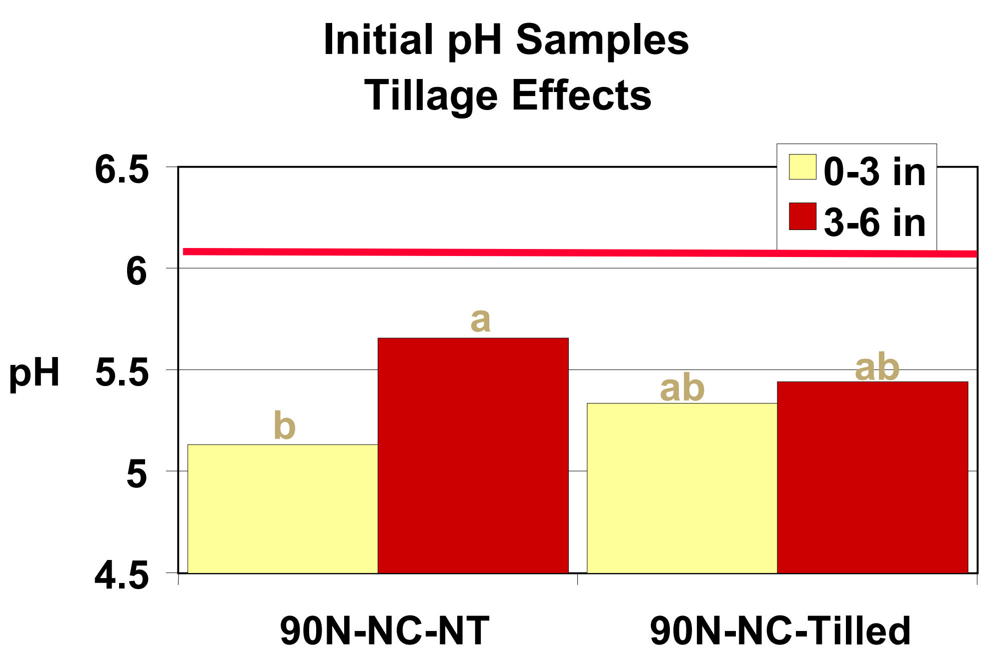
Figure 12. Soil exchangeable aluminum (Al) concentrations for the 0 to 3 inch depth for the vetch, no-tilled (NT) treatment at all four nitrogen rates in the Spring of 1995, 1996, and 1997 after application of lime at the full recommended rate in the Spring of 1995. Concentrations with different letters are significantly different at the 5% probability level.

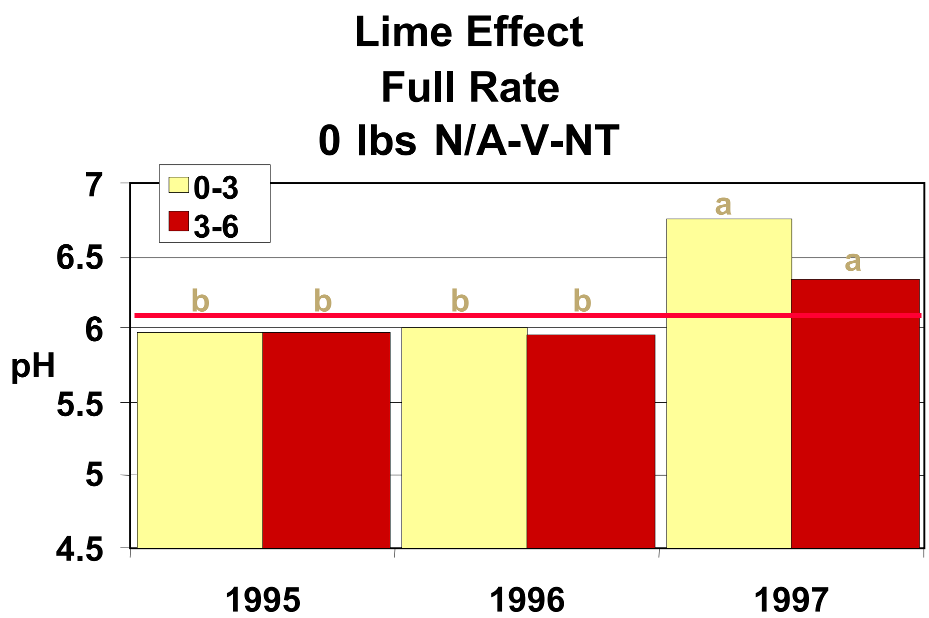
Figure 13. Soil exchangeable manganese (Mn) concentrations for the 0 to 3 inch depth for the vetch, no-tilled (NT) treatment at all four nitrogen rates in the Spring of 1995, 1996, and 1997 after application of lime at the full recommended rate in the Spring of 1995. Concentrations with different letters are significantly different at the 5% probability level.

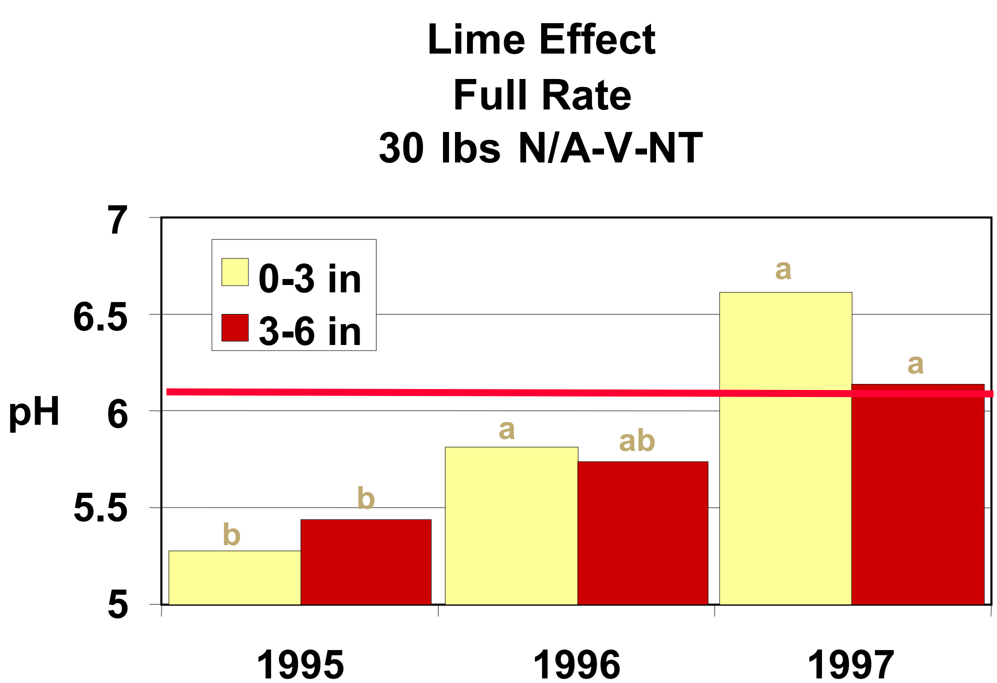


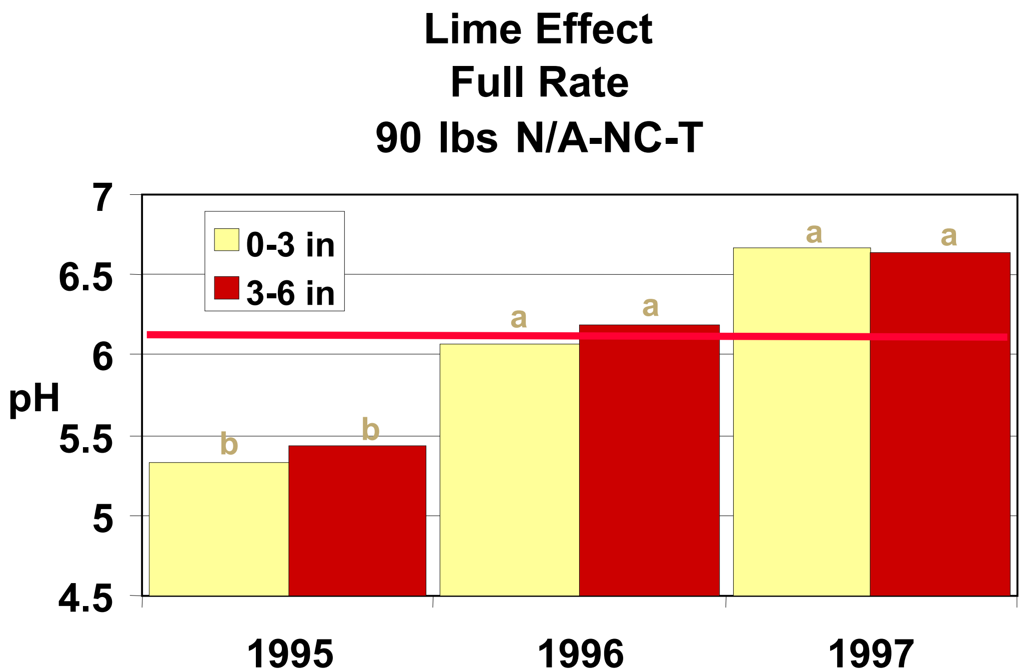


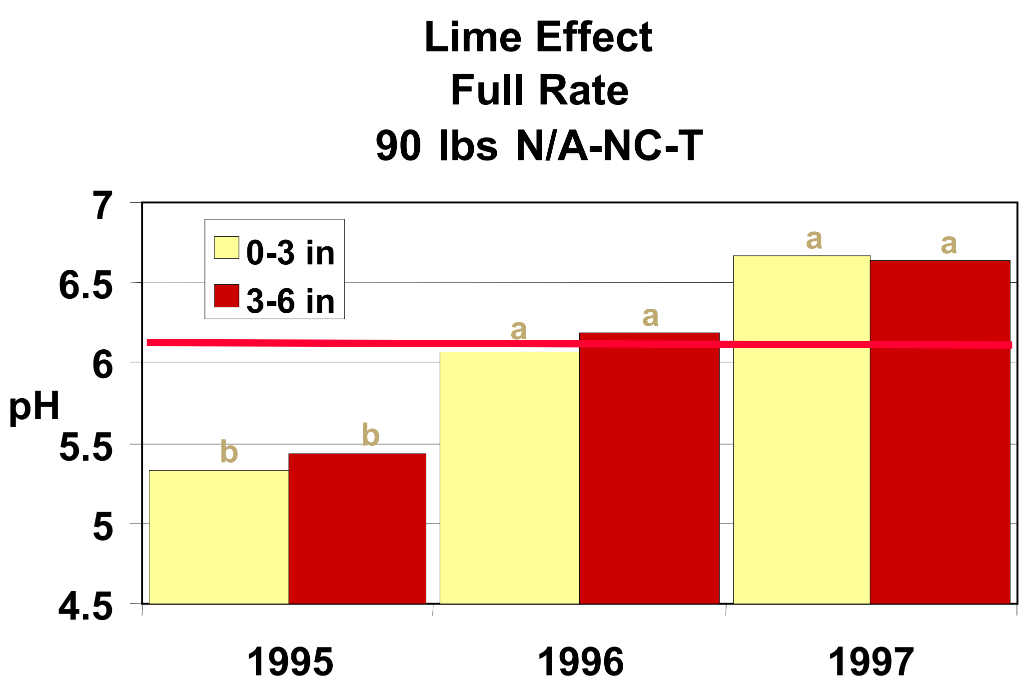

Initial pH Samples
Cover Effects
0-3 in
3-6 in
6.5
6
pH 5.5
5
4.5
a
b
ab
ab
90N-NC NT
30N-V NT

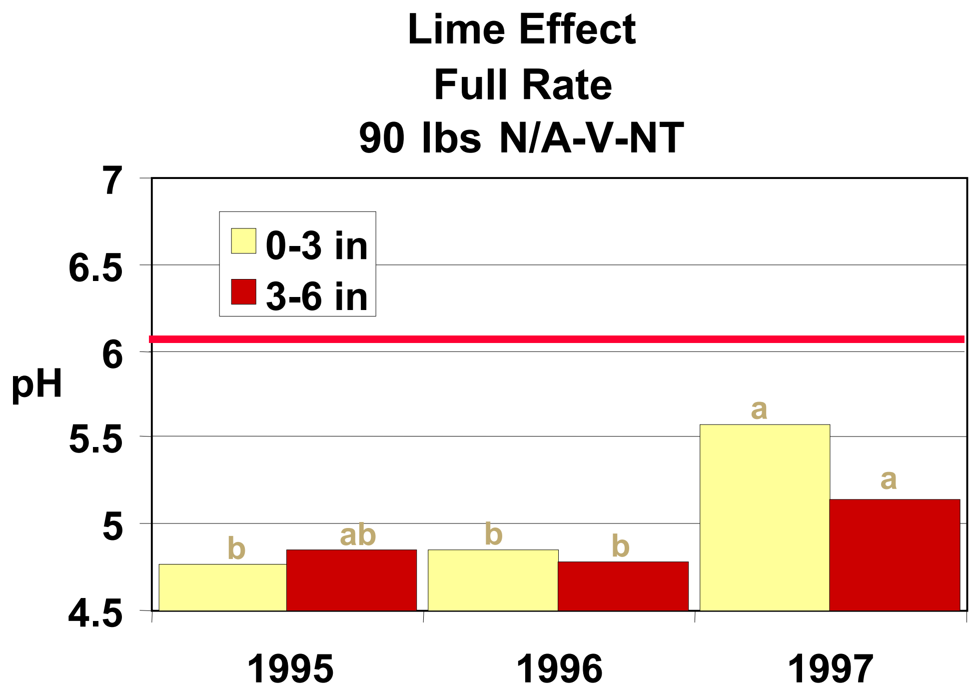

Initial pH Samples
Tillage Effects
0-3 in
3-6 in
6.5
6
pH 5.5
5
4.5
a
b
ab
ab
90N-NC-NT
90N-NC-Tilled

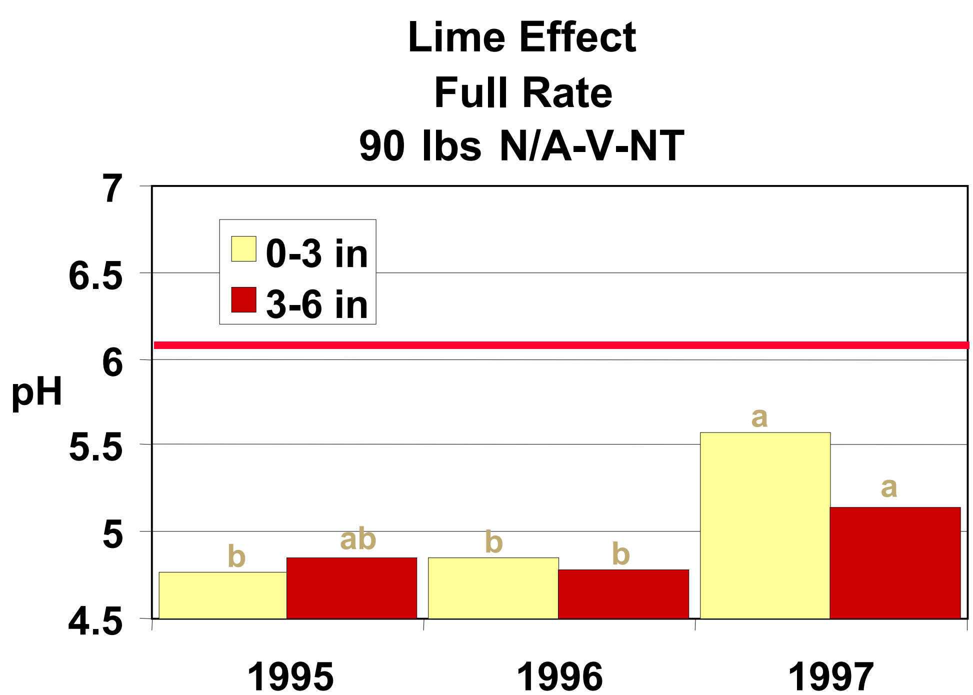

Lime Effect
Full Rate
0 lbs N/A-V-NT
0-3
3-6
7
6.5
6
5.5
5
4.5
pH
a
a
b
b
b
b
1995
1996
1997

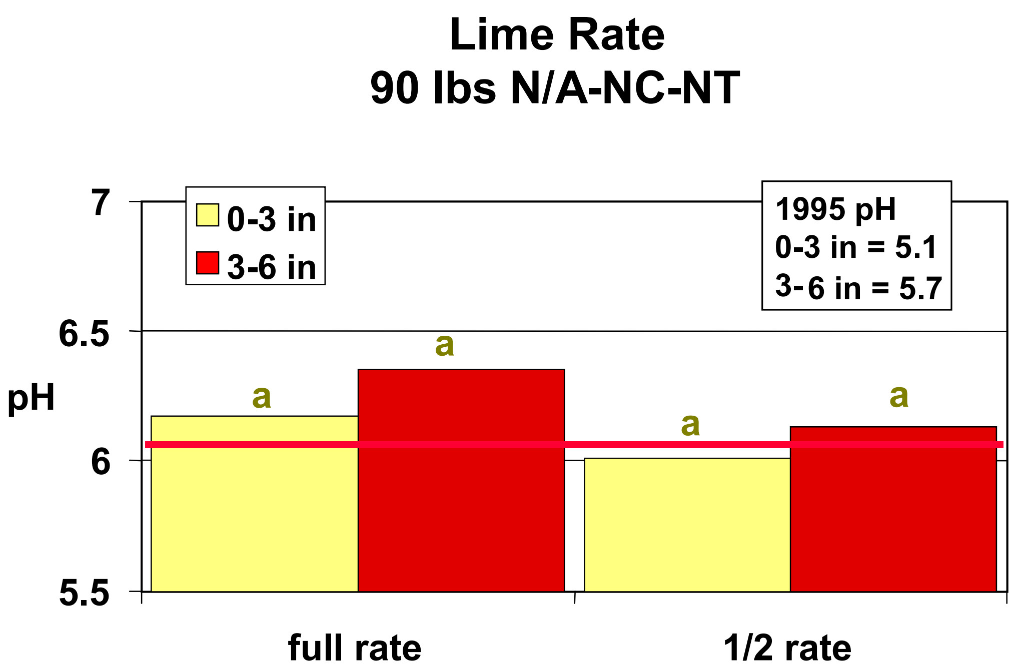

Lime Effect
Full Rate
30 lbs N/A-V-NT
0-3 in
3-6 in
7
6.5
6
5.5
5
pH
a
a
a
ab
b
b
1995
1996
1997

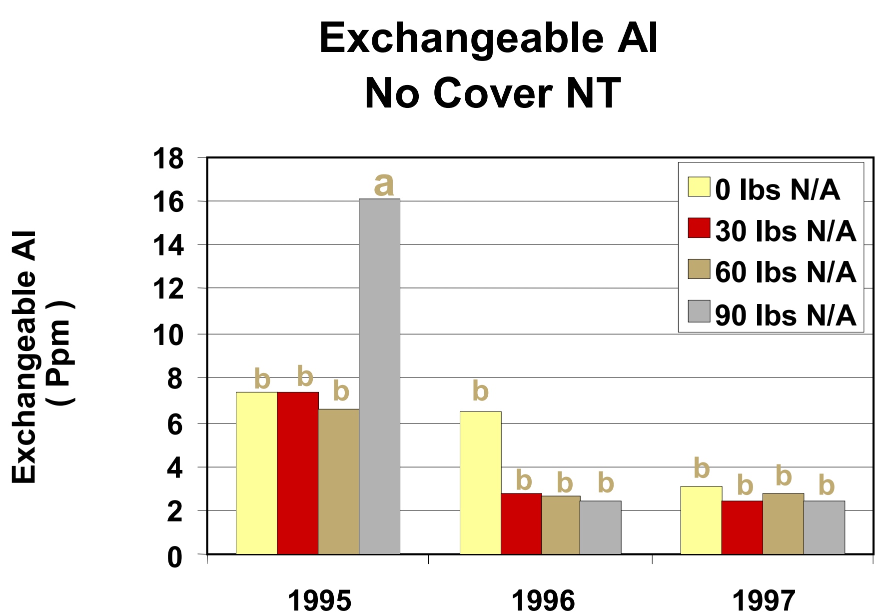

Lime Effect
Full Rate
90 lbs N/A-NC-T
pH
7
6.5
6
5.5
5
4.5
0-3 in
3-6 in
b
b
a
a
a
a
1995
1996
1997

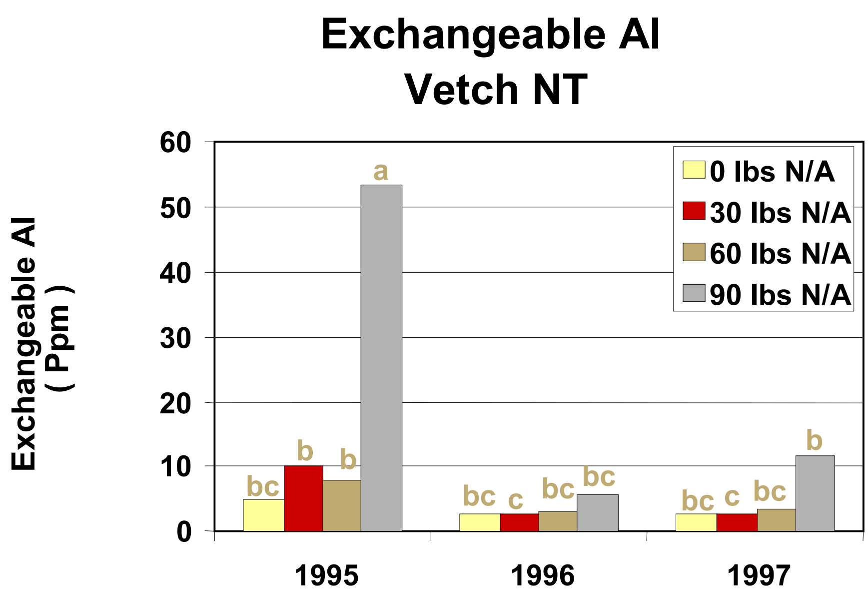

Lime Effect
Full Rate
90 lbs N/A-NC-T
pH
7
6.5
6
5.5
5
4.5
0-3 in
3-6 in
b
b
a
a
a
a
1995
1996
1997

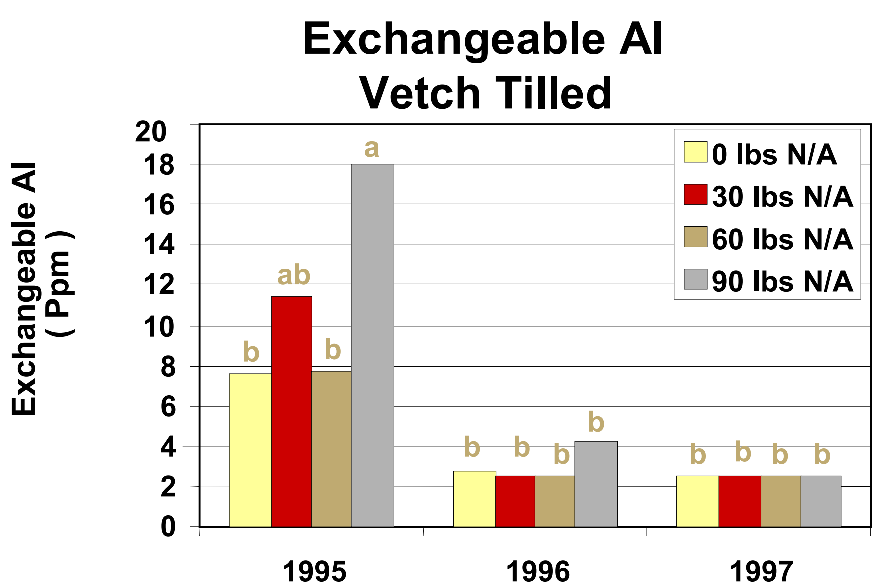

Lime Effect
Full Rate
90 lbs N/A-V-NT
7
6.5
6
5.5
5
4.5
pH
0-3 in
3-6 in
b
ab
b
b
a
a
1995
1996
1997

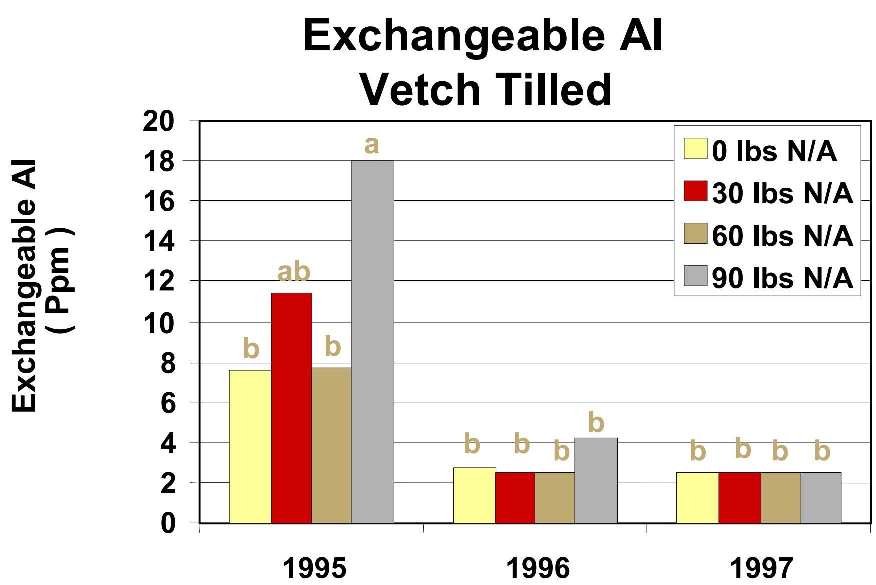

Lime Effect
Full Rate
90 lbs N/A-V-NT
7
6.5
6
5.5
5
4.5
pH
0-3 in
3-6 in
b
ab
b
b
a
a
1995
1996
1997

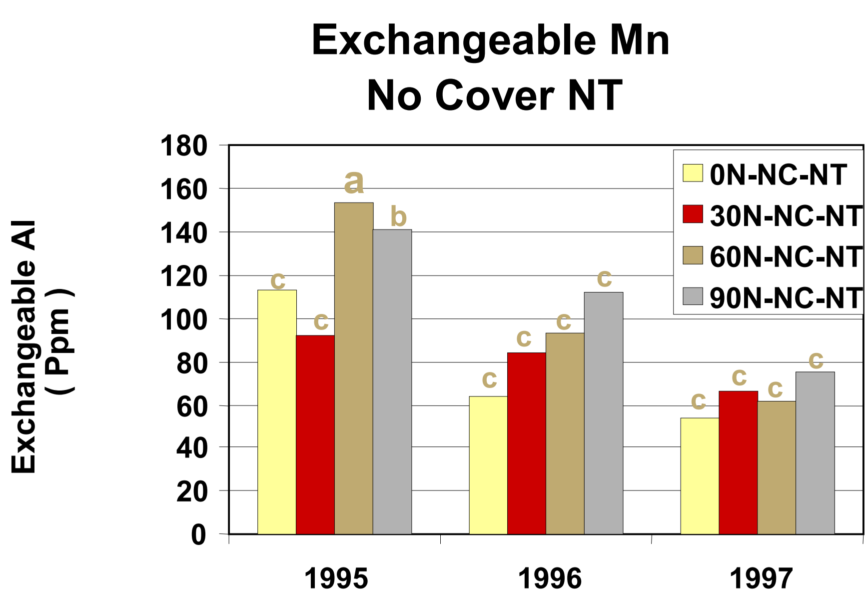

Lime Rate
90 lbs N/A-NC-NT
7
6.5
6
5.5
pH
0-3 in
3-6 in
1995 pH
0-3 in = 5.1
3-6 in = 5.7
a
a
a
a
full rate
1/2 rate

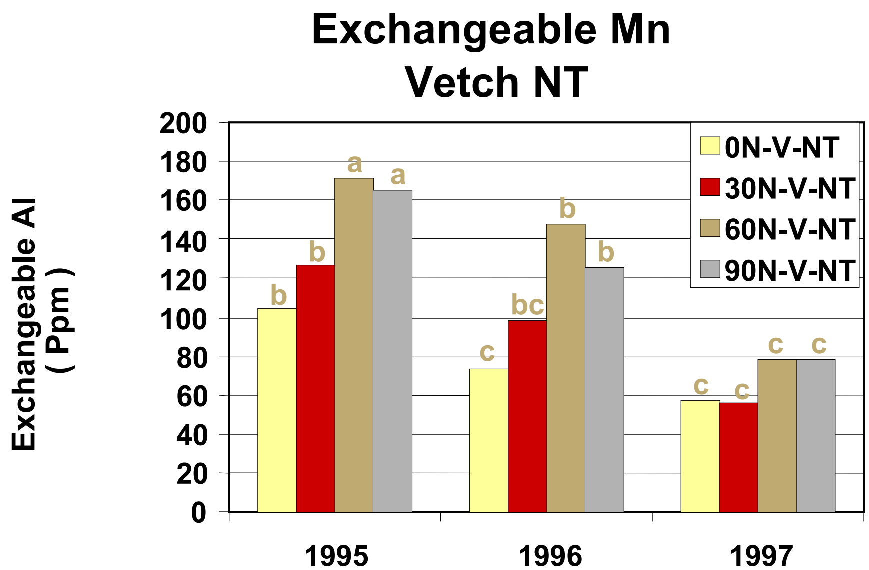

Exchangeable Al
No Cover NT
Exchangeable Al
(Ppm)
18
16
14
12
10
8
6
4
2
0
0 lbs N/A
30 lbs N/A
60 lbs N/A
90 lbs N/A
a
b
b
b
b
b
b
b
b
b
b
b
1995
1996
1997


Exchangeable Al
Vetch NT
Exchangeable Al
(Ppm)
60
50
40
30
20
10
0
a
b
b
bc
bc
c
bc
bc
bc
c
bc
b
0 lbs N/A
30 lbs N/A
60 lbs N/A
90 lbs N/A
1995
1996
1997


Exchangeable Al
Vetch Tilled
Exchangeable Al
(Ppm)
20
18
16
14
12
10
8
6
4
2
0
a
ab
b
b
b
b
b
b
b
b
b
b
0 lbs N/A
30 lbs N/A
60 lbs N/A
90 lbs N/A
1995
1996
1997


Exchangeable Al
Vetch Tilled
Exchangeable Al
(Ppm)
0 lbs N/A
30 lbs N/A
60 lbs N/A
90 lbs N/A
20
18
16
14
12
10
8
6
4
2
0
a
ab
b
b
b
b
b
b
b
b
b
b
1995
1996
1997


Exchangeable Mn
No Cover NT
Exchangeable Al
(Ppm)
0N-NC-NT
30N-NC-NT
60N-NC-NT
90N-NC-NT
180
160
140
120
100
80
60
40
20
0
a
b
c
c
c
c
c
c
c
c
c
c
1995
1996
1997


Exchangeable Mn
Vetch NT
Exchangeable Al
(Ppm)
200
180
160
140
120
100
80
60
40
20
0
1995
1996
1997
0N-V-NT
30N-V-NT
60N-V-NT
90N-V-NT
b
b
a
a
c
bc
b
b
c
c
c
c