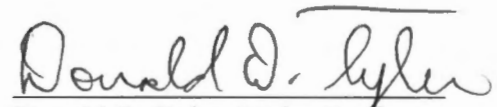
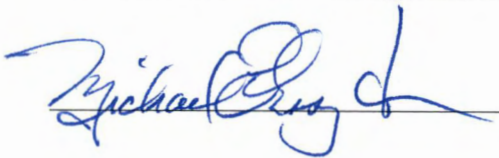


To the Graduate Council:

I am submitting herewith a thesis written by Edwin Louis Ritchey entitled "Influence of Nitrogen Rate, Cover Crop, and Tillage Practices on Liming in Cotton". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment for the degree of Master of Science, with a major in Plant and Soil Science.


Donald D. Tyler, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Associate Vice Chancellor and
Dean of the Graduate School

Influence of Nitrogen Rate, Cover Crop, and Tillage Practice of Liming in Cotton

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

**Edwin Louis Ritchey
August 1999**

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Dedication

This thesis is dedicated to my grandparents (Fred and Dollie Ritchey) and (James and Kizzie Vance). They have been an instrumental part of my life, and have helped me to become what I am today. Their persistence, knowledge, and advice have been a valuable resource for me to call on in times of need. Growing up in poverty, they constantly battled Mother Nature and made a living on land that would barely keep a goat alive. They survived and flourished without the modern comforts that we now have which has made them some of the strongest people I know.

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There are a number of people whose assistance should be recognized. I would like to thank Sloane for her friendship, advice, and the use of her computer during completion of my thesis. I would also like to thank Ron, Andy, Eric, Cheryl, Jeff, and Cindy for their friendship, technical support, and moral support while working in the lab and in the writing of my thesis. My friends have helped me to make it through this program when times were tough and gave me the needed companionship that one must have. I would also like to thank the faculty of The Plant and Soil Science department for their support and patience with my never ending questions. And finally, I would like to thank the department for financial support and giving me the opportunity to pursue this degree.

Abstract

Soil acidity is a major concern in crop production in the southeastern United States and is influenced by several factors, including N-rate, cover crops, and tillage. A field experiment was established in 1981 to examine the influence of these practices on soil properties on a Lexington silt loam (Ultic Hapludalf) soil. In 1995 the effect of limestone application, as determined by a 1:1 water pH and the Adams and Evans buffer test, was added to the experiment on the existing soil treatments at the full recommended rate and half the recommended rate. Soil samples were taken in the spring prior to fertilization at the following depths: 0-7.5 cm, 7.5-15 cm, and 0-15 cm. Laboratory analyses of soils included 1:1 soil pH, Adams and Evans buffer test, organic carbon, cation exchange capacity, exchangeable bases (Ca, Mg, Na, K), exchangeable Al, and exchangeable Mn. As N-rate increased soil pH decreased throughout the experiment and the amount of exchangeable Al and exchangeable Mn tended to increase with increasing N-rate. The use of a cover crop significantly influenced soil pH, Ca, Mg, Mn, and SOC. The vetch cover crop added to the acidic characteristics of the treatments, and typically added approximately 40-60 kg N ha⁻¹ to the treatments. Tillage practice significantly influenced CEC, exchangeable Al and pH. No-till treatments tended to have lower pH values and had higher amounts of SOC, exchangeable Al, and exchangeable Mn than corresponding tilled treatments. The difference in pH in the full rate of limestone and the half rate of limestone were not significant, however the full rate of limestone did tend to increase the soil pH more and at a faster rate than the half rate of limestone. Both rates of limestone displaced

most of the exchangeable Al and Mn for the exchange complex, usually within one year of application. Both rates of limestone appear to be adequate in raising soil pH>6.0 in either system, however neither rate was adequate in raising the soil pH>6.0 in the NT vetch plots that received ≥ 67 kg N/ha. Excessive amounts of acidity are avoided when proper N-fertilizer practices are used, and additional N from legume cover is accounted for. The Adams and Evans buffer test does appear to be adequate in determining lime requirement for NT cotton production in Tennessee, however if pH $\leq$ 4.8, incorporation of limestone or a increased lime rate is advised.

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Part 1

Literature Review

Soil acidity is a common problem in the southeastern United States. As the soil losses essential basic cations (Ca, Mg, K, and Na) through leaching, the amount of acidic cations that occupy the exchange complex increases. The acidic cations that are most commonly associated with soil acidity are aluminum (Al), manganese (Mn), and to a limited extent iron (Fe) (Thomas and Hargrove, 1984; Foy, 1984; Ritchie, 1989; Adams, 1984). These cations typically are the cause of reduced yields under acidic soil conditions, rather than the lowered soil pH, or the amount of exchangeable hydrogen (H) found in the system. It has been determined that yield reductions associated with acidic conditions are not attributed to the H^+ unless the soil pH is <4.0 (Howard and Adams, 1965; Foy, 1984). Instead yield reductions are primarily associated with elevated levels of exchangeable Al and Mn, which are phytotoxic (Ritchie, 1989). To complicate matters, the soil pH does influence the availability of essential and potentially toxic elements, possibly resulting in yield reduction. There are also other factors that influence the amount of acidity in soils under agronomic crops. These include N-rate and form, parent material, soil organic matter (SOM) content, cover crop, tillage practice, and lime addition (Blevins et al., 1978, 1983; Bloom et al., 1979a,b; Conyers, 1990; Chung et al., 1994; Evans and Kamprath, 1970).

Parent Material

The inherent concentration of acidic cations in a soil, or any nutrient for that matter, will be determined primarily by the parent material from which the soil has

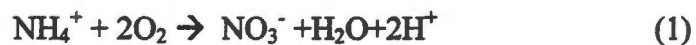
formed and the soil's relative age (Mc Lean and Brown, 1984). Soils that form from calcareous parent material would have less acidic cations relative to a soil that weathered from sedimentary sand and gravel parent material, such as coastal plain deposits. The loessal soils that are predominate in west Tennessee are inherently acid (Soil Survey Staff, 1978). As soils become more acidic from weathering and leaching of base cations, Al solubilizes, and is released from primary minerals and aluminosilicate clays into readily available forms (Zelazny and Jardine, 1989).

Soil pH

Soil pH is one of the most measured of all soil characteristics (Adams, 1984). It is useful in obtaining a general understanding of nutrient availability, potential herbicide activity, and the need for lime, but not the amount of lime needed to neutralize acidity (Thomas and Hargrove, 1984). Soil acidity may influence the availability of nutrients to the extent of causing toxicity or deficiency problems (Howard, 1970). Generally as the pH decreases the amount of acidic cations in the soil solution and on the exchange complex increases (Richardson and Riecken, 1977). It is this elevated amount of acidic cations and the decreased amount of basic cations present that usually limits crop yields (Blevins et al., 1983; Thomas, 1988; Howard and Adams, 1965). In general, yield reductions will start to become apparent as pH values fall below 5.0-5.5, but this is not always the case, depending on SOM content, amounts of exchangeable Al and Mn, and production practices employed (Adams, 1984).

Nitrogen

The most influential factor that can produce rapid changes in soil acidity under production agriculture is N-fertilization. Nitrogen is the plant nutrient that is required in the largest amounts. As the N-rate increases, the soil pH decreases (Ismail et al., 1994; Blevins et al., 1978; Blevins et al., 1983). Rates of acidification are also much higher in the surface (0-7.5 cm) of NT systems, due to the concentrating effect of the surface application of N (Ismail et al., 1994; Blevins et al., 1978; Blevins et al., 1983). This decrease in soil pH is attributed to the nitrification of NH_4^+ to NO_3^- , which produces 2 moles of acidity for every mole of NH_4^+ that is nitrified:



As soils become more acidic in nature the release of acidic and basic cations from soil materials is enhanced, due to the action of H^+ , which is a primary component in mineral weathering reactions. The surface application of N, which is practiced in conservation tillage systems, can lead to the rapid decrease in soil pH in the top few centimeters of the soil surface (Blevins et al., 1978; Blevins et al., 1983; Reeves et al., 1983). This increase in soil acidity, as mentioned before, in turn effects the availability or predominance of indigenous acidic cations, due to the leaching of basic cations. The leaching of basic cations and the dissolution of soil minerals decreases the acid neutralization capacity (ANC) and increases the total acidity of the soil solid

and solution phases. The ANC of a soil can be defined as the quantities of basic soil components minus the quantities of acidic soil components (van Breemen, 1991). However in most cropping systems the decreased soil pH can usually be overcome with the surface application of a base cation source, such as limestone, except in very acidic conditions where incorporation is advised (Blevins et al., 1978; Grove and Blevins, 1988).

Tillage

The effect of tillage in a cropping system can effect several properties, including and most importantly the amount of soil that is lost due to erosion. Soil pH, the vertical distribution of nutrients and SOM, and the amount of SOM present are also effected by tillage practice employed (Blevins et al., 1978; Blevins et al., 1983; Dick, 1983; Evangelou and Blevins, 1985; Ismail et al., 1994; Grove and Blevins, 1988). (Blevins et al., 1983; Dick, 1983; Evangelou and Blevins, 1985; Ismail et al., 1994). The amount of SOM in NT-managed soils is generally higher relative tilled soils. The relatively higher amounts of SOM in the surface of NT-managed soils treatments are due to several factors. Probably the most influential factor is the lack of mixing of the soil surface in NT (Dick, 1983). Plant residues that are deposited on the soil surface, remain on the soil surface. As a result, there is much less intimate contact of the plant residues with soil particles and the microbial populations compared with tilled (mixed) soils. This leads to lower rates of mineralization and higher levels of SOM (Dick, 1983).

The amount of soil nutrients, such as, P, K, exchangeable Ca, and exchangeable Mg can be influenced by the tillage practice employed, and closely related to the amount of SOM present (Blevins et al., 1983; Ismail et al., 1994). The total concentration of a fertilizer in a soil profile might be similar, but the distribution can be largely different (Blevins et al., 1983). The physical dispersion of nutrients is evident in tilled soils as compared to NT soil, and would explain why there are usually higher concentrations of nutrients in the surface of NT as compared to the surface of tilled soils. When fertilizer amendments are surface applied, movement is facilitated by water and diffused through the soil profile, a slower process than physically mixing the soil. Further, the amount of SOM is also higher in the surface of NT systems, which leads to the greater storage capacity and cycling of nutrients in NT soils. Nutrients are also deposited on the soil surface by plant residues, which largely remain on the soil surface. All of these processes lead to the stratification of nutrients in NT soils.

Cover Crops

In conservation-tillage systems, crop residues are left on the soil surface to help lower the erosion potential of the soil; this is especially helpful for highly erodible soils. One crop that does not produce large amounts of residue is cotton. In order to minimize erosion from cotton-producing fields, a winter cover crop should be used in conjunction with the conservation-tillage practice (Reeves et al., 1995). Before the 1940s, legume cover crops were commonly used to provide N to

subsequent crops. However, after World War II, the use of commercial sources of N increased due to the wider availability and cheaper cost relative to cover crops.

Cover crops not only increase the amount of residue on the soil surface, but they also can reduce the amount of N lost through leaching, increase the SOM content, increase the extent of water infiltration, and in the case of legume cover crops, add N to the soil (Reeves et al., 1995).

For a cover crop to be acceptable, it must meet several criteria. It should be easy to establish, have a rapid growth rate to quickly provide ground cover, produce sufficient biomass for best-management, not act as a host for disease or insects to the subsequent cash crop, be easy to kill at the proper time, and be economically priced (Reeves et al., 1995; Bauer and Bradow, 1993).

In a cotton system there are three types of cover crops used, natural vegetation (winter weeds), small grains or grasses, and legumes (Reeves et al., 1995). Legumes can fix N, in turn supplying as much as 60-90 kg N/ha to the subsequent crop. This added N is in the form of ammonia, which is nitrified to nitrate (see equation 1), thus creating acidity. Irrespective of cropping system, when using a legume cover crop, one should decrease the amount of N fertilizer applied to account for the additional N being added to the system from the legume cover crop.

Soil Organic Matter

Another very important soil quality aspect is the amount of SOM present. Soil organic matter, or humus, is formed by the action of microorganisms during the

decomposition of animal and plant tissues. The accumulation of SOM is enhanced when conservation tillage practices are implemented. Generally as the amount of tillage in a system decreases the amount of SOM in the system is increased (Blevins et al., 1983; Dick, 1983; Evangelou and Blevins, 1985; Ismail et al., 1994). Several investigators have found that SOM can complex Al species [Al^{3+} , AlOH^{2+} , $\text{Al}(\text{OH})^+$] reducing the negative effect on plant growth (Thomas, 1975; Blevins et al., 1978; Conyers, 1990; Evans and Kamprath, 1970; Fox, 1979). Soil organic matter also complexes Mn species, but to a lesser extent relative to Al species (Sanchez and Kamprath, 1959; Adams, 1984; Ritchie, 1989; Foy, 1984).

Soil pH, carbon-to-nitrogen (C:N) ratio, and temperature also influence SOM accumulation. When the C:N ratio drops below 20:1, N is released from the residues and mineralization reactions dominate. When the C:N ratio is above 30:1, then immobilization reactions dominate as the soil microbes responsible for the decomposition of SOM tie up N in the residues (Reeves et al., 1995). The various microbes that break down plant residues thrive at different pH levels, with the maximum amount of SOM production occurring near a neutral pH. At a pH>6.0, bacteria and actinomycetes are usually the dominant microbes in residue degradation. As pH decreases below 5.5, fungi are more active in residue decomposition (Foy, 1984). Residue decomposition is optimal when warm conditions and adequate water are present.

Like solid organic compounds, soluble organic carbon, which is also called dissolved organic carbon (DOC), is increased under NT management (Essington et al., 1994). The transfer of organics from solid phase to solution phase is the first step

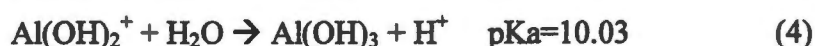
in the redistribution of elements associated with DOC (Homann and Grigal, 1992). Like solid organic compounds, DOC can complex essential and toxic elements, and transport the complexes through and eventually out of the soil profile (Lundstrom, 1993; Hayes, 1991; Hern et al., 1988). Organic compounds complex acidic cations in the following order: $\text{Fe} = \text{Al} > \text{Mn}$ (Alloway, 1990).

Soil organic matter has been shown to impact Al solubility, influence pH, and the amount of soluble Al present in the system (Ross and Bartlett, 1996; Bloom et al., 1979b; Thomas, 1975). Soil organic matter creates a large pH dependent CEC. Due to the numerous and varied functional groups SOM buffers soil pH (Richardson and Riecken, 1977; Hargrove and Thomas, 1982). Soil organic matter is a weak acid, due to the ability of the functional groups to ionize and donate protons (Thomas and Hargrove, 1984; Coleman et al., 1958). However this weak acid effect is overwhelmed by the ability of SOM to complex large amounts of acidic cations such as Al, Fe, and to a lesser extent Mn, rendering them harmless (Alloway, 1990; Ritchie, 1989). Another aspect of SOM and Mn complexes is the fact that SOM can enhance the amount of Mn that is present in toxic forms, by supplying electrons for the reduction of Mn IV to Mn II (Ritchie, 1989).

Aluminum Chemistry

Probably the most important growth limiting factor in acid soils is excess Al. This condition is typically found in soils with $\text{pH} < 5.5$ (Foy, 1984; Fox, 1978; Adams, 1984). As pH falls below 5.0, Al occupies an increasing amount of the

exchange complex (Gillman and Sumpter, 1985). The trivalent form of Al and the hydrolysis species are thought to be the primary Al products that are detrimental to plant growth (Thomas, 1977; Ritchie, 1989). Complexation of Al species by DOC mitigates the phytotoxic effects of Al (Stevenson and Vance, 1989).



At pH > 4.0 the hydrolysis of Al becomes significant and around pH 4.9 more than 80% of the Al^{3+} is hydrolyzed (Ritchie, 1989). The hydrolyzed Al ions, Al(OH)^{2+} and Al(OH)_2^+ , bind to SOM more tightly than Al^{3+} (Bloom et al., 1979a). At pH > 5.0 more than 90% of the total Al in solution is complexed by DOC (Gerke, 1994). Aluminum can exist in several different forms: soluble complexes, inorganic Al-bearing minerals, and exchangeable (Ritchie, 1989). These different forms are constantly trying to reach and maintain an equilibrium condition in the dynamic soil environment.

The relationship between SOM, soluble Al, and soil pH has been found to be a function of the degree of H^+ saturation of the SOM (Hargrove and Thomas 1982; Bloom et al., 1979b). Soil organic matter could increase the amount of Al in solution through the dissociation of functional groups as pH increases, resulting in Al complexation and the dissolution or release of Al from soil materials (Bloom et al., 1979b;). However, the effect of SOM usually reduces the amount of Al in solution

due to the increased amount of binding associated with the organic functional groups (Thomas, 1975; Bloom et al., 1979a). The effect of SOM on Al retention is usually much greater than the effect of pH and is what controls the Al activity in most surface soils (Chung et al., 1994; Bloom et al., 1979a,b).

As the soils become more acidic through weathering and leaching of base cations, the concentrations of available Al can increase. This released Al can then be adsorbed onto soil exchange sites, readsorbed by inorganic Al minerals, or remain in the soil solution (Ritchie, 1989). Exchangeable Al is an important buffer reserve of labile pools of Al that can be readily solubilized by other exchangeable cations (Zelazny and Jardine, 1989) and is the cause of poor plant growth on acid soils high in Al. The fate of Al in soil depends on several criteria, including total Al concentration, ionic composition, solubility constants, and the equilibrium that exists with the soil solution (Zelazny and Jardine, 1989). The amount of exchangeable Al is ultimately controlled by the solubility of the nonexchangeable Al and the adsorption characteristics of the soil (Zelazny and Jardine, 1989).

Typical symptoms associated with Al phytotoxicity are expressed in the plant roots and cause roots to be short, thick, and often lacking in lateral branching (Foy, 1984; Howard and Adams, 1965; Adams and Lund, 1966). These alterations in the roots then lead to other biochemical malfunctions such as the reduction of nutrient and water uptake, which would lead to a reduction in yield and in extreme cases the death of the plant (Sumner et al., 1991). The amount of exchangeable Al that is deemed toxic to plants varies, depending on the crop, soil type, amount of SOM present, and the cultivar of crop that is planted (Adams, 1984; Adams and Lund,

1966). However, it is hard to obtain a universal value of Al saturation of the exchange complex for soil, due to the fact that phytotoxicity occurs at different exchangeable Al levels on different soils and even different levels on the same sites between different horizons (Adams, 1984). The soil is too complicated and dynamic to assign a single value that will produce phytotoxic symptoms.

Manganese Chemistry

Manganese phytotoxicity occurs under conditions similar to those for Al toxicity. Manganese toxicity is usually not found in soils with a pH > 5.5 or where low concentrations of Mn are present in the soil. Manganese availability is influenced by several soil properties, including: pH, SOM content, redox status, microbial activity, and total Mn content (Foy, 1984; Adams, 1984). Manganese can exist in the soil environment in three oxidation states, Mn (II), Mn (III), and Mn (IV), with Mn (II) being the oxidation state that is taken up by plants and in turn can be detrimental to plant growth (Foy, 1984; Bartlett and James, 1993). Symptoms of Mn toxicity can occur in cotton at concentrations of 5-10 mg/L in nutrient solutions and in the field at concentrations around 50-100 mg/kg of easily reducible Mn, which as measured is Mn that can be reduced by NH₄OAc (pH 7) containing 0.2% hydroquinone (Adams and Wear, 1957; Adams, 1984; Kennedy and Jones, 1991).

Manganese can be both chemically and microbially reduced or oxidized. Unlike Al phytotoxicity, Mn phytotoxicity can be influenced by microbial mediated redox reactions. These redox reactions are influenced by SOM, soil pH, soil moisture

content, and soil temperature (Ritchie, 1989). The microbially-mediated reduction of Mn (IV) to Mn (II) is favored by low soil pH, increasing levels of SOM, levels of moisture greater than field capacity, increasing soil temperature, and the presence of anaerobic microbial populations (Ritchie, 1989). The low soil pH leads to increased Mn availability, due to the decreased adsorption onto soil particles and increased Mn-bearing mineral solubility. Organic matter stimulates microbial growth and results in higher microbially-mediated reduction rates. Elevated moisture content (near saturation) can increase the amount of Mn (II) present, however in well drained sites the released Mn (II), from previous flooding, could be transported out of the system due to leaching (Ritchie, 1989). Soil temperature can influence microbially-mediated reduction of Mn(IV) up to a temperature of approximately 30⁰ C, at higher temperatures the microbial populations will not thrive (Ritchie, 1989).

Generally, Mn reduction is microbially controlled, where as Mn oxidization is usually chemically controlled. Chemical oxidization of Mn (II) is favored by low soil moisture, low SOM content, and high pH values, and under optimal conditions is much quicker than microbially-mediated oxidation. Like microbially-mediated Mn reduction, Mn oxidation is favored by an adequate population of oxidizing microbes, adequate temperatures (<30⁰ C), and adequate amounts of substrates for microbial growth (Ritchie, 1989). In acidic soils Mn reduction is more prevalent than oxidization, mainly due to the low pH, which will result in a lower redox potential of the soil at a fixed electron activity.

Manganese phytotoxicity is expressed in the plant tops more than the plant roots. Symptoms include of top dieback, chlorosis of mature blades, stunting, and

leave puckering. Manganese phytotoxicity is the cause of crinkle leaf in cotton (Foy et al., 1995; Foy 1984; Kennedy and Jones, 1991; Ohki et al., 1979; Ohki, 1984). As mentioned before, the amount of Mn that is deemed toxic to plants varies, and depends on the cultivar of the crop, SOM content, soil pH, and redox status of the soil (Sanchez and Kamprath, 1959; Foy et al., 1995; Schmehl et al., 1950; Kennedy and Jones, 1991; Adams, 1984; Foy 1984).

Limestone

To neutralize the effects of soil acidity, farmers have practiced the application of limestone. Liming of soil has been practiced since about 200 BC (Barber, 1984). Edmund Ruffin was the first person to add limestone for the correct reason: to neutralize soil acidity (Thomas, 1977). Thomas (1977) discussed a method for determining CaCO_3 in soils which initiated research on soil acidity dating back to 1813. Ruffin analyzed his own land and found no CaCO_3 according to the CaCO_3 method discussed by Thomas (1977). To remedy his problem he added partly decomposed oyster shells to his fields and kept careful records of the amount of shells and the yields after application. Ruffin believed, incorrectly, that all acidity was due to organic acids, but nonetheless became the first to lime to correct soil acidity.

Limestone can be applied to the soil at anytime, as long as weather and crop conditions permit, with the maximum pH occurring 2-3 years after limestone addition (Adams, 1984; Howard, 1970). Limestone should be applied when a soil reaches a critical pH, and where a yield response from limestone will occur. An acid soil can

be defined as any soil that <100% of the cation exchange capacity (CEC) is occupied by base cations (Thomas and Hargrove, 1984). Soil acidity (Al and Mn) can be effectively neutralized by the addition of limestone (Schmehl et al., 1950; Sanchez and Kamprath, 1959; Adams, 1984; Ismail et al., 1994; Blevins et al 1977; Barber, 1984), in any cropping system (NT or tillage systems). However, in NT systems the remediation of soil acidity might not occur as quickly or might not be as drastic as observed in tilled systems (Ismail et al., 1994; Grove and Blevins, 1988).

Researchers have found that Ca^{2+} and Mg^{2+} do not effectively compete with Al-species, when present in equal concentrations, for exchange sites due to the higher affinity Al has for bonding sites as compared to Ca^{2+} and Mg^{2+} (Bohm et al., 1985; Hern et al., 1988). In order for basic cations in limestone to displace Al and/or Mn it must overwhelm the exchange complex through mass action. The amount of base cations from limestone present in a treated soil is many times greater than the amount of Al and Mn present on the exchange complex. This results in the displacement of Al and Mn by base cations. Subsequently, the released Al and Mn forms sparingly soluble precipitates.

The addition of limestone not only reduces the amount of Al and Mn on the exchange complex, but it also raises the pH of the soil, (Coleman et al., 1958). The classic view of the 1950's and before was that lime neutralized soil acidity through the replacement of exchangeable H^+ by Ca^{2+} and/or Mg^{2+} , and the neutralization of H^+ by carbonate to form CO_2 and H_2O (Coleman et al., 1958). However it is now known that the reaction of lime involves the displacement of Al-species by Ca^{2+} , to result in exchangeable Ca^{2+} and Mg^{2+} and ultimately $\text{Al}(\text{OH})_3$ (e.g. gibbsite), (Thomas

and Hargrove, 1984). The generalized and over-simplified overall reaction of an acid soil reacting with limestone, according to Thomas and Hargrove (1984), is as follows:



The objectives of this study are to; 1) document the impact of different continuous long-term cropping systems on selected soil properties, 2) document the influence of two lime rates on soil chemical properties, 3) evaluate the effectiveness of surface applied limestone, and 4) to validate the effectiveness of the Adams and Evans buffer test on limestone application in cotton production on loess-derived soil.

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Part 2

Nitrogen, Cover Crop, and Tillage Effects on Soil Acidity

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Tyler, M. E. Essington, M. D. Mullen, and A. M. Saxton**

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, 34, 67, and 101 kg N ha⁻¹), two tillage practices (NT and disk-tillage (DT)), 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, total carbon (TC), cation exchange capacity (CEC), exchangeable bases, exchangeable Al, and exchangeable Mn. Nitrogen rate significantly influenced exchangeable Ca, exchangeable Mn, and soil pH. As N-rate increased, exchangeable Ca concentrations and soil pH values decreased, and was accompanied by an increase in exchangeable Mn values. The cover crop significantly influenced soil pH, exchangeable Ca, exchangeable Mg, OC, and exchangeable Mn, which resulted in the vetch cover having lower pH values, lower concentrations of exchangeable Ca and Mg, higher levels of TC, and higher concentrations of exchangeable Mn than corresponding tilled treatments. Tillage practice significantly influenced CEC, exchangeable Al, and pH, with the NT treatments having higher CEC values, higher concentrations of exchangeable Al, and lower soil pH values. The NT treatments that received 101 kg N/ha and a vetch cover crop had the lowest pH values, highest amount of OC, highest CEC, lowest saturation of bases, highest amount of exchangeable Al, and one of the highest amounts of exchangeable

Mn for the experiment. Excessive amounts of acidity are avoided when proper N-fertilizer practices are used, and additional N from legume cover is accounted for.

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). Based on information from the universal soil loss equation (USLE), NT farming practices could reduce erosion on loess soils with a 0.5-2% slope >60 % as compared to a tilled system. In NT crop production fertilizer additions are surface applied without mechanical incorporation, also nutrients taken up from the subsoil by plant roots are redeposited on the soil surface (Beare et al., 1994), which can lead to the stratification of nutrients. In long-term NT cropping systems, the buildup of plant residues and surface fertilizer placement 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 quantity. 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, and

the acid neutralizing capacity (ANC) of the soil decreases. The ANC of a soil can be defined as the quantities of basic soil components minus the quantities of acidic soil components (van Breemen, 1991). As solid components of the ANC are solublized and leached from the system, the ANC of the soil decreases and the total acidity increases.

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 than the 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). Parent material will also help govern levels of exchangeable Al and Mn in the soil at any particular time, the more total Al and Mn present in the system, the more potential there is for Al and Mn to reach phytotoxic levels (Mc Lean and Brown, 1984). Also, as the soil becomes more acidic, the weathering process is enhanced and releases more acidic and basic cations from soil minerals, which are leached accordingly. 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.

Complexes formed with dissolved organic carbon (DOC) also make it difficult to ascertain a specific level of acidic cations that will cause yield reductions (Ritchie, 1989). Different crops and even different varieties of the same crop exhibit symptoms of phytotoxicity at different levels of exchangeable Al and Mn (Foy et al., 1995). However it is generally agreed that problems from Mn and Al can occur with $\text{pH} < 5.5$ (Adams, 1984; Foy, 1984; Fox, 1979, Ritchie, 1989). Nutrient solutions containing 5-10 mg kg^{-1} 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 mg kg^{-1} 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, and help maintain soil productivity (Reeves et al., 1995; Bauer and Bradow, 1993). Winter cover crops have shown to reduce soil erosion on loess soils from over 11 tonnes/hectare/year to about 0.000112 tonne (Reeves et al., 1995). 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 cereale* 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 most instances the choice of a cover crop can influence the organic carbon content of the soil, the amount of N available for next years crop, and soil pH. 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 ANC of the soil. A legume cover crop can add from very little to about 60 kg N ha⁻¹ each year. The University of Tennessee recommends 67-90 kg N ha⁻¹ 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. The lower soil pH tends to lower activity of soil microorganisms and in turn raise soil organic carbon (SOC) content.

Several researchers have determined that SOC can complex large amounts of exchangeable Al at low pH values and high SOC contents, thus offsetting the increased concentration of exchangeable Al at lower soil pH values (Thomas, 1975; Hern et al., 1988; Hargrove and Thomas, 1981; Fox, 79; Conyers, 1990; Evans and Kamprath, 1970). In most instances the increased amount of SOC can complex the increased soluble Al in the system, rendering it harmless to plants and mobile. At elevated levels of Al and Mn the functional groups of DOC present might become saturated and not be able to

counter all of the acidic cations present in solution. Organic matter also influences the role Mn plays in soil acidity in a similar manner. Manganese levels can also be influenced by microbially-mediated redox reactions, is weakly complexed by SOC, and can exist in more than one oxidation state (Foy, 1984; Adams, 1984; Sanchez and Kamprath, 1959; Ritchie, 1989).

The objective of this study is 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 (DT and NT), four N rates (0, 34, 67, and 101 kg N ha⁻¹), and two winter cover crops (no cover and vetch).

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 tilled 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. There is no evidence of a fragipan within the top meter of soil. The mean annual temperature for 1995 was 15.6⁰ C and the mean annual rainfall were 129.6 cm.

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, 34, 67, and 101 kg N ha⁻¹). 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 (DT and NT). Plots were 8 meters wide by 12 meters long. After all the splits were completed the experiment contained 128 plots. In this paper the no cover and vetch cover were chosen to demonstrate the two extremes for soil various properties in the experiment.

Soil samples were taken at random locations in each plot, in the spring of 1995 prior to planting, using a 2.54 cm soil probe at 0-7.5, 7.5-15, and 0-15 cm depths. For the 0-7.5 and the 7.5-15cm depths, a sample was taken to 15 cm and divided into the two depths. For each plot, approximately 10 subsamples were taken to 15 cm for the 0-7.5 and 7.5-15cm depths and 5 subsamples were taken for the 15 cm 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 2.34 L ha^{-1} in all plots. Cotton was planted at a density of approximately $22,275 \text{ plants ha}^{-1}$ using a John Deere NT planter. Aldicarb at 0.56 kg ha^{-1} active ingredients (ai) and quintozone (PCNB) 10G at 1.12 kg ha^{-1} ai was applied in-furrow at planting. On May 16 fluometuron 4L at 1.68 kg ha^{-1} ai, pendimethalin at 1.12 kg ha^{-1} ai, norflurazon at 1.12 kg/ha ai , and paraquat at 0.69 kg ha^{-1} ai, with $\frac{1}{2}\%$ surfactant were applied. The plots received 101 kg ha^{-1} 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). Nitrogen, in the form of ammonium nitrate (34g N kg^{-1}), was hand broadcast at planting at the above indicated rates. Tillage on the tilled 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 0-7.5 and 7.5-15 cm depths, with the exception of soil pH, which was also analyzed for the 0-15 cm depth. Soil pH was determined using 1:1 soil:solution ratio using distilled-deionized water. Total carbon (TC) was determined using a LECO high temperature induction furnace (Nelson and Sommers, 1996). Previous research has shown TC to be identical to OC for the Lexington soil in unlimed (unpublished data). Cation exchange capacity was determined using the NH_4OAc (pH 7) method (United States Salinity Laboratory Staff, 1954). 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, 1997). 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 0-15 cm sample for pH was also included in the statistical analysis. All other analyses were performed on the 0-7.5 and 7.5-15 cm 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

Soil pH

Soil pH was influenced N-rate, cover crop, tillage practice. There were also Cover*tillage and N-rate*cover interactions (Table 1). The most influential variables in this experiment effecting soil pH were N-rate and cover. As nitrogen rates increased across all treatments, soil pH values decreased (Figure 1). Although not always significantly different throughout the experiment, the influence of N-rate is consistent with the findings of other studies (Blevins et al., 1983; Blevins et al., 1978; Grove and Blevins, 1988; Ismail et al., 1994). The decrease in pH was greater at the 0-7.5 cm depth than the 7.5-15 cm depth; however the higher N-rates generally had the lowest pH values at either depth (Figure 1). This decrease in pH is probably due to the nitrification of ammonium to nitrate. In most instances the pH of the 0-15 cm sample is near the average of the 0-7.5 and 7.5-15 cm depth (Table 2).

No-till treatments in the 0-7.5 cm depth generally had lower pH values than tilled treatments (Blevins et al., 1978; Blevins et al., 1983; Dick, 1983), however the differences are generally not significant at $P=0.05$, due to the extent of the depth increment (Figure 1). Mixing the soil in the tilled system helped to dilute the acidity present in the profile, but differences were not large between the two systems. The pH values in the 7.5-15 cm depth were not influenced as much by tillage practice, with the exception of the 101 kg N ha⁻¹ vetch treatment, which had the lowest pH value throughout the experiment at both depths (Figure 1).

The differences in the stratification of pH were not as evident as one would expect between the two tillage systems (Figure 2), with the exception of the 67 kg N ha⁻¹ vetch treatment and the 101 kg N ha⁻¹ no cover treatment. Even in these treatments the stratification was not consistent, with the no cover treatment showing more stratification in the NT and the tilled treatments showing more stratification with the vetch cover. One possible reason for the lack of stratification is due to the treatments being in place for 14 years and the stratification being overcome by the excessive amounts of acidity present and by the movement of acidity from the surface horizon to the lower depth.

The use of a winter cover crop also influenced soil pH. All of the N contributed from the vetch is in an organic form, which is mineralized to NH₄⁺, followed by the nitrification to nitrate (NO₃⁻), producing additional acidity in the system. The differences in pH values would be similar to an additional 35-50 kg N ha⁻¹ as NH₄NO₃, when compared to the difference in pH between the no cover treatments and the vetch treatments (Figure 1). This explains why the treatments that received the vetch cover crop had lower pH values

than the treatments that received no cover. According to yield response data, the vetch cover crop contributes approximately 60 kg N ha⁻¹ to the system (data not shown).

Soil Organic Carbon

Soil organic carbon ranges from 5.8 g kg⁻¹ in the 0 kg N ha⁻¹ NT treatment receiving no cover to 13.2 g kg⁻¹ in the 101 kg N ha⁻¹ NT treatment receiving the vetch cover. Other research has indicated that there is more SOC in NT systems than in tilled systems, usually due to the slower rate of decomposition of SOC and the more acidic soil surface associated with NT crop production (Dick, 1983; Blevins et al., 1983; Ismail et al., 1994). However, in this experiment large differences did not occur, due to the depth increment used (0-7.5 cm as compared to 0-3 cm) (Figure 3). The differences found in SOC between the tillage systems within the same depth are not very large and usually not significant at P=0.05, with the exception of the 101 kg N ha⁻¹ treatments that received the vetch cover. No-till systems did appear to exhibit greater stratification than corresponding tilled treatments, again not being significantly different at P=0.05. Regardless of cover or tillage, the 0-7.5 cm depths contained more SOC than the 7.5-15 cm depths (Figure 3). The effect of the vetch cover significantly influenced the amount of SOC present (Table 1), although the differences are not very large (Figure 3).

Exchangeable Al and Mn

As the soil pH decreases below a value of ~ 5.5-6.0, there is typically an increase in exchangeable Al and Mn present. The Al-species present and the pH of the soil solution

influence the availability of Al. As more acidic cations are released from soil minerals, more of the basic cations (Ca, Mg, and K) are displaced from the exchange complex by Al and Mn and leached from the system. Exchangeable Al did not increase until there was $> 67 \text{ kg N ha}^{-1}$ in the NT system, and even then the increase was only significant at the 0-7.5 cm depth (Figure 4). Treatments that received the highest inputs of N (inorganic and legume cover), in both tillage systems, had the highest amounts of exchangeable Al in the 0-7.5 cm depth. The exchangeable Al in the tilled system was not significantly different within a particular N-rate, with the vetch treatment at the 0-7.5 cm depth being the only treatment in the tilled system that significantly increased from the 67 kg N ha^{-1} rate to the 101 kg N ha^{-1} rate (Figure 4). The exchangeable Al values for 101 kg N ha^{-1} with the vetch in the NT system were statistically higher than all other treatments ($P < 0.05$). The concentration of exchangeable Al in the NT vetch treatments appears to be the only treatments that were greatly influenced by high N-rate and was observed at both depths.

The pH value of the treatments where the increase of exchangeable Al occurred was between approximately 5.0 and 5.5 irrespective of tillage system for the 0-7.5 cm depth (Figures 5 and 6). In the NT vetch treatment the increase occurred at about pH 4.8; whereas in the other systems the increase occurred at pH values of about: pH 5.2 for the NT no cover; pH 5.0 for the DT, vetch cover; and pH 5.4 for the DT no cover. The lower soil pH in the NT, vetch cover soils may be explained by the rhizosphere chemistry. The vetch system probably had an increased amount of biochemical chelating agents present in the rhizosphere due to the increased activities of microorganisms and organic excretions from plant roots when compared to the no cover system (Stevenson and Vance, 1989). The

same influence would occur to a lesser extent in systems that did not contain a cover crop, but the primary source of the chelating agents would be from the cotton crop. Since these organic chelating agents are transient, one would not expect an impact of Al chemistry unless the rhizosphere occupies a substantial volume of soil, such as in the vetch treatments. Clearly one can see the influence of a cover crop on complexing greater amounts of Al. This could help explain why the increase in exchangeable Al occurred at about pH 4.8 as compared to the no cover system, which increased at about pH 5.2. The increase of exchangeable Al in the NT no cover system was evident, but was not as large of an increase as the vetch system. The tilled systems were similar, but showed a slightly greater increase up to 67 kg N ha^{-1} , then the large increase occurred in a manner consistent with the other treatments when $\text{pH} \geq 5.5$ and $\text{N-rate} > 67 \text{ kg N ha}^{-1}$ (Figure 6). From this one might conclude that the NT system is buffered more than the tilled system until $\text{pH} \geq 5.0$ or when $\text{N-rate} > 67 \text{ kg N ha}^{-1}$ and $< 101 \text{ kg N ha}^{-1}$.

N-rate also influenced the amount of exchangeable Mn present, with the highest amounts of exchangeable Mn occurring in the treatments that received $\geq 67 \text{ kg N ha}^{-1}$ in either tillage system (Figure 7), (although not significantly different within treatments). The tilled, 101 kg N ha^{-1} vetch treatment had the highest amount of exchangeable Mn present ($0.658 \text{ cmol kg}^{-1}$). In the both systems at both depths, the amount of exchangeable Mn was the highest for the vetch cover crop. This might be due to the added nitrogen by the vetch cover and the increased acidity created from the nitrification of $\text{NH}_4\text{-N}$ to $\text{NO}_3\text{-N}$. Also the amount of exchangeable Mn present was higher and sometimes significantly different in the 0-7.5 cm depth as compared to the 7.5-15 cm depth, regardless of system.

CEC and Base Saturation

Cation exchange capacities were between 8.94 and 12.16 cmol_c kg⁻¹ soil. The CEC of the NT treatments were significantly higher than that of the DT treatments and the 0-7.5 cm depths were significantly higher than that in the 7.5-15 cm depths. The higher CEC in the NT and in the 0-7.5 cm depth may be due to the higher levels of SOC present. The treatment that received 101 kg N ha⁻¹, at both depths, numerically had the highest CEC, although not significantly different from many of the treatments.

The 0 and 34 kg N ha⁻¹ rate, regardless of tillage, that received no cover crop, had the highest base saturation values for the experiment. Generally, as N-rate increased, the base saturation decreased, regardless of tillage or cover (Figure 8). The decrease in base saturation with increasing N-rate is due to the elevated amount of acidic cations. The same would be true with the vetch cover crop, which added appreciable amounts of N to the system. The treatments that received the vetch cover crop had a lower percent base saturation compared to the treatments that received no cover crop. The tilled treatments appeared to have slightly higher base saturation values than the NT treatments in the 0-7.5 cm depth, however, the same trend was not seen in the 7.5-15 cm depth. Treatments that received 101 kg N ha⁻¹ in the 0-7.5 cm depth, regardless of tillage, had the lowest percent base saturation within a particular cover. The 101 kg N ha⁻¹ NT treatment that received the vetch cover had the lowest base saturation for the experiment. Exchangeable Al and Mn values appear to be inversely related to the base saturation, as one would expect. The 0 and 34 kg N ha⁻¹ rate, regardless of tillage and cover crop, had the lowest amount of

exchangeable Al and Mn, where the 101 kg N ha⁻¹ rate had the highest amount of exchangeable Al and Mn.

Conclusions

Surface application of N fertilizers in NT cotton caused the surface 7.5 cm of the soil to become more acidic than the corresponding CT treatments. The stratification of pH is more pronounced at higher N-rates, however it was observed at all rates. Soil acidification was somewhat similar in both tillage systems, but NT plots were generally more acidic throughout the whole profile (0-15 cm) relative the tilled soils. The exchangeable Al and Mn values were greatest in the treatments that received high rates of N, with the exchangeable Mn levels being greater than the exchangeable Al levels. The use of a legume cover crop resulted in lower pH values in all treatments as compared to the plots that received no cover; this due to the increased amount of N present in the system. In treatments that received 67 kg N ha⁻¹ or more, the vetch covers had more SOC than the plots that received 34 kg N ha⁻¹ or less. A legume cover crop can be used in both systems, however the additional N that is fixed by the legume cover crop should be taken into consideration for best fertilizer management.

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Table 1. Analysis of variances (Observed Prob>F) for all soil data for all main effects and interactions in 1995†.

Variable	pH	TC	KCl-Al	NH ₄ -Mn	CEC	Exchangeable Bases			
						Ca	Mg	K	Na
Depth (D)	0.0024	0.0001	NS	0.011	0.0005	0.0005	0.0001	0.0001	NS
Cover (C)	0.0001	0.0032	NS	0.0001	NS	0.0001	0.046	NS	NS
Tillage (T)	0.0063	NS	NS	0.004	0.004	NS	NS	NS	NS
N-rate (N)	0.0001	NS	NS	NS	NS	0.003	NS	NS	NS
T*D	NS††	0.016	NS	NS	NS	NS	NS	NS	NS
C*D	0.0087	NS	NS	NS	NS	NS	0.041	NS	NS
N*D	NS	NS	NS	NS	NS	NS	NS	NS	NS
N*C	0.0007	NS	0.026	NS	NS	0.044	NS	0.046	NS
N*T	NS	NS	0.047	NS	NS	NS	NS	NS	NS

† pH of 1:1, soil : deionized-distilled water; TC, total carbon by combustion; KCl-Al, 1M KCl extractable Al; NH₄-Mn, NH₄-acetate (pH 7) extractable Mn; CEC, cation exchange capacity by NH₄-acetate (pH 7) method; exchangeable bases, NH₄-acetate (pH 7) extractable

†† Not significant at P ≤ 0.05.

Table 2. Treatment averages for the H⁺ ion, presented as pH, in the NT and tilled systems, for both covers, at the 0-15 cm depth.

N-rate	NT				Tilled			
	No Cover		Vetch		No Cover		Vetch	
	IA †	0- 15	IA	0-15	IA	0-15	IA	0-15
kg N ha ⁻¹	-----pH units-----							
0 kg N/ha	6.26	6.24	5.98	5.77	6.36	6.32	6.03	6.04
34 kg N/ha	6.12	6.02	5.36	5.42	6.04	6.03	5.62	5.53
67 kg N/ha	5.52	5.48	5.22	5.24	5.65	5.60	5.39	5.42
101 kg N/ha	5.40	5.38	4.81	4.71	5.39	5.36	5.19	5.13

† Increment average: average proton concentration of the 0-7.5 cm and the 7.5-15 cm depth increments.

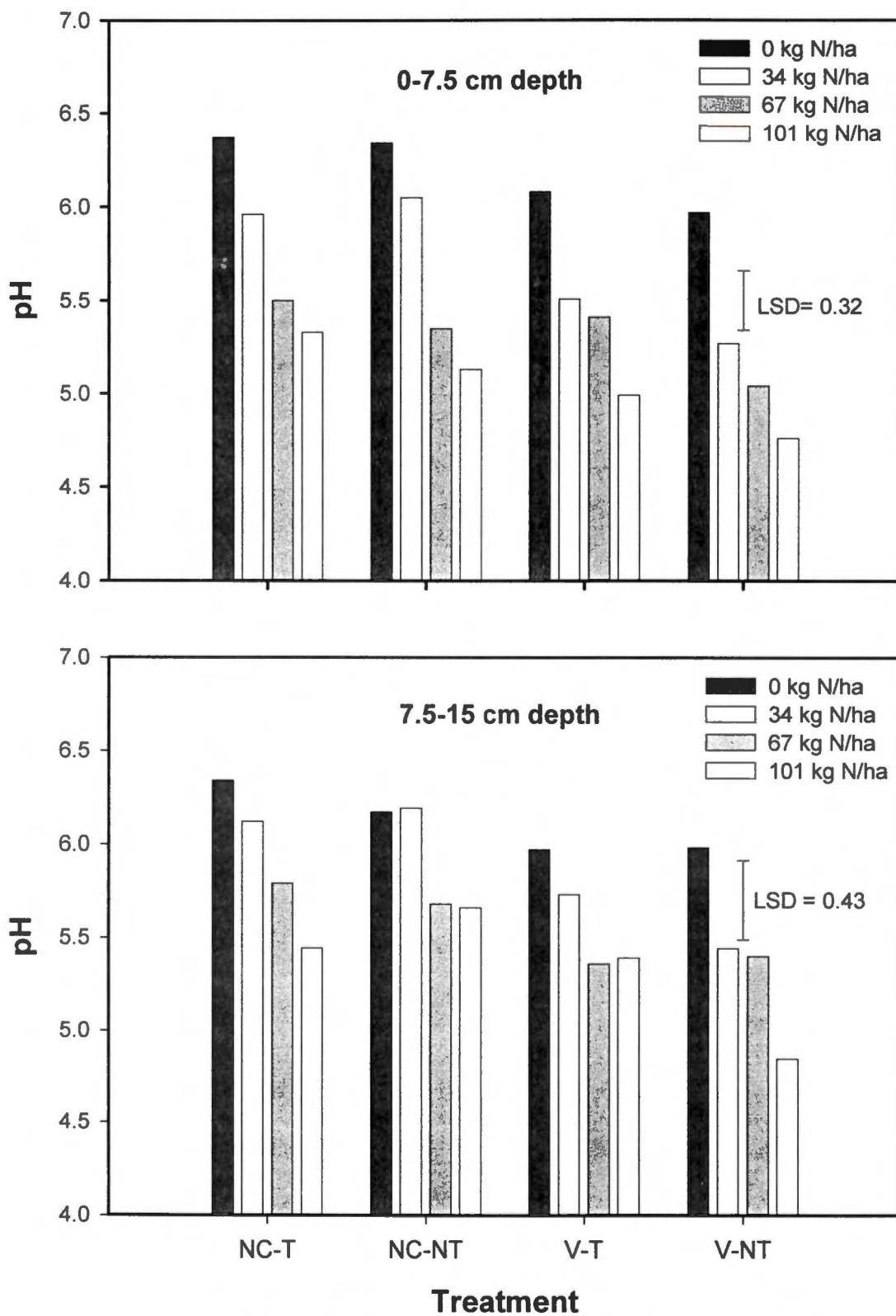


Figure 1. The effect of N-rate on pH values for no cover (NC) and vetch (V) cover in no-till (NT) and tilled (T) systems for the 0-7.5 and 7.5-15 cm depths. LSD values represent differences within each depth at the $\alpha=0.05$ level.

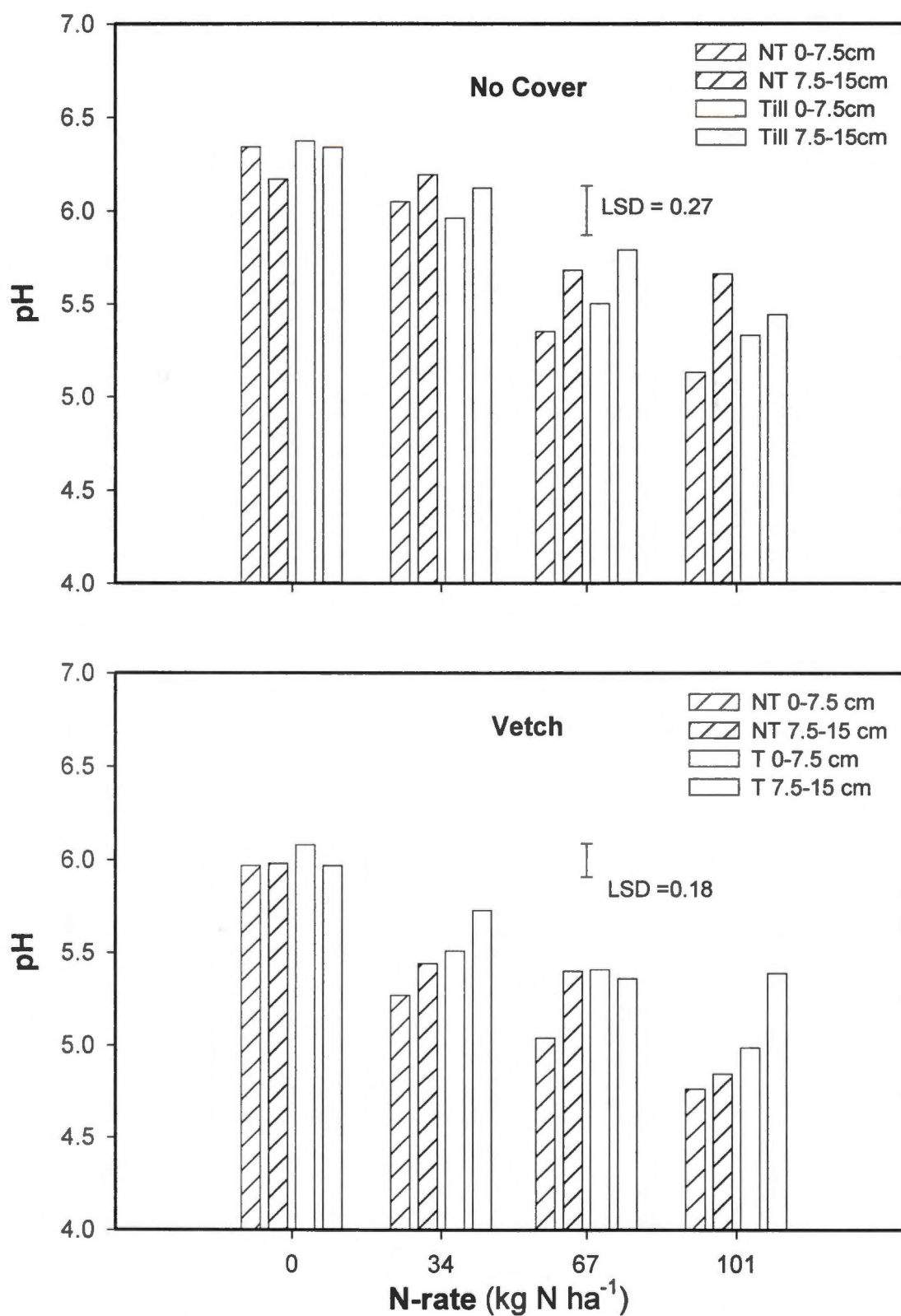


Figure 2. The stratification of pH in the no-tilled (NT) and tilled (T) systems at the 0-7.5 and 7.5-15 cm depths for all N-rates with no cover and with vetch cover. LSD values represent differences at the $\alpha=0.05$ level within each cover.

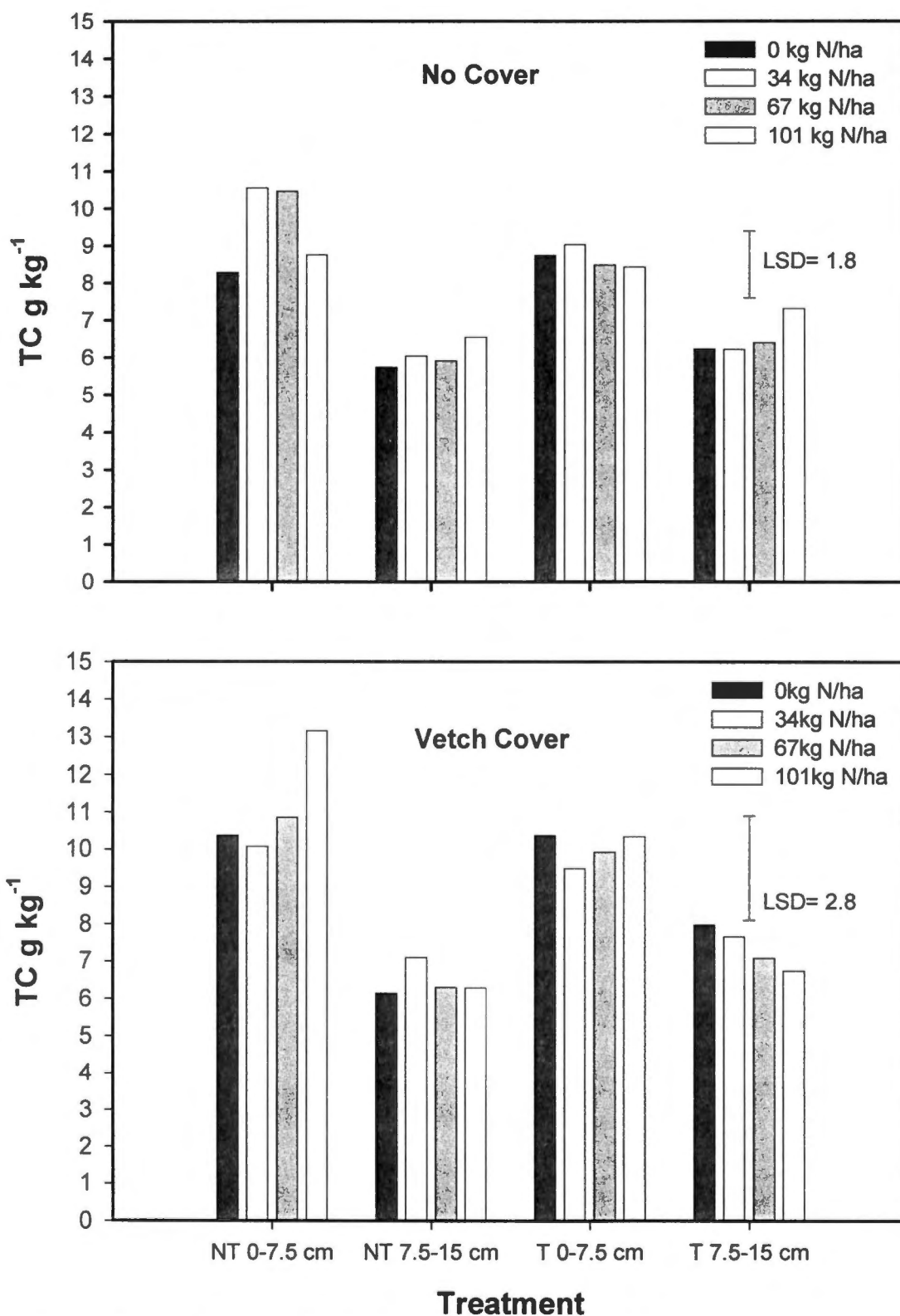


Figure 3. Difference in distribution of total carbon (TC) in no-tilled (NT) and tilled (T) treatments with vetch cover and no cover. LSD values represent differences at the $\alpha=0.05$ level within each cover.

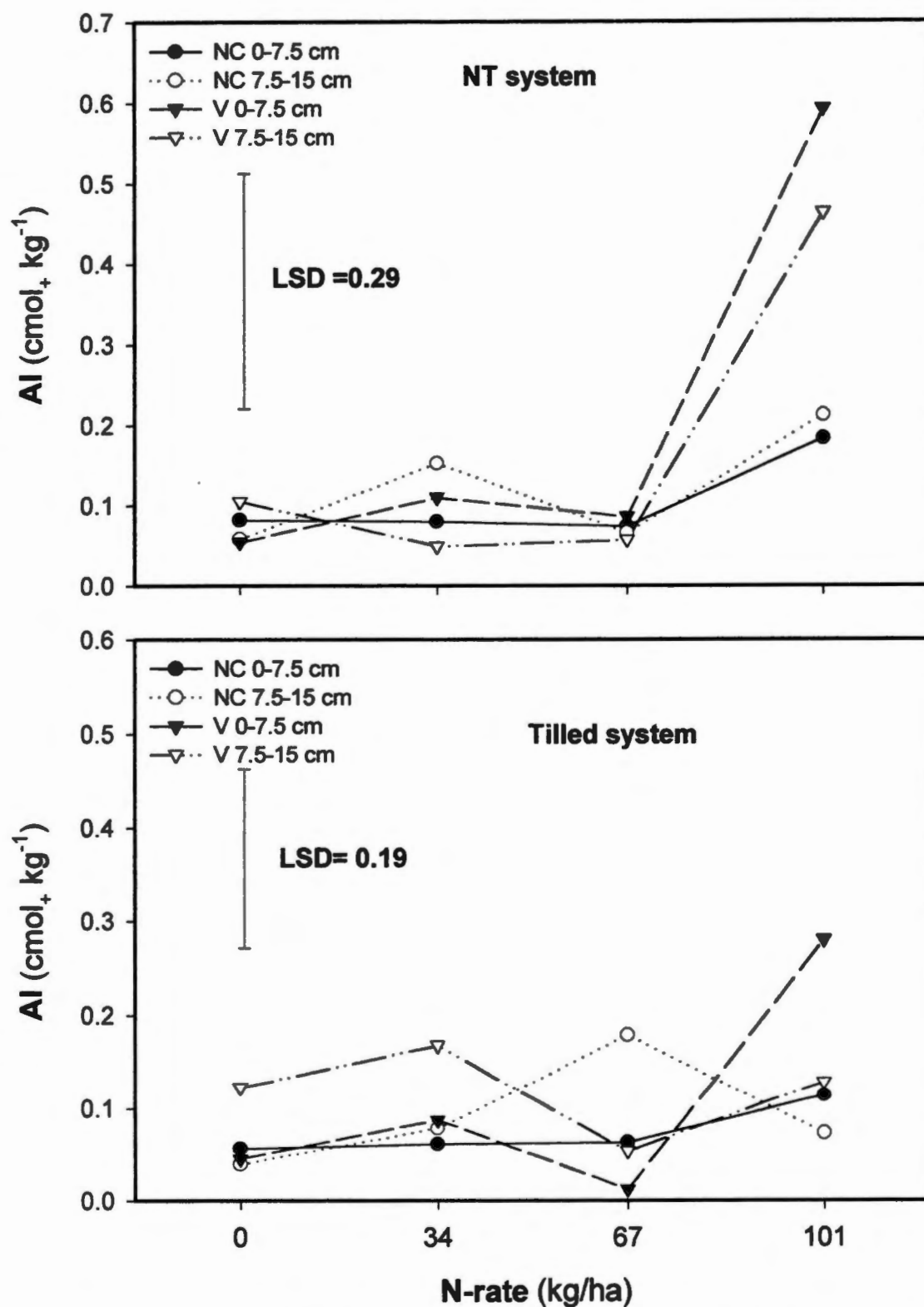


Figure 4. The effect of N-rate and cover (no cover, NC; vetch cover, V) on exchangeable Al values in the no-till (NT) and tilled (T) systems. LSD values represent differences within each tillage system.

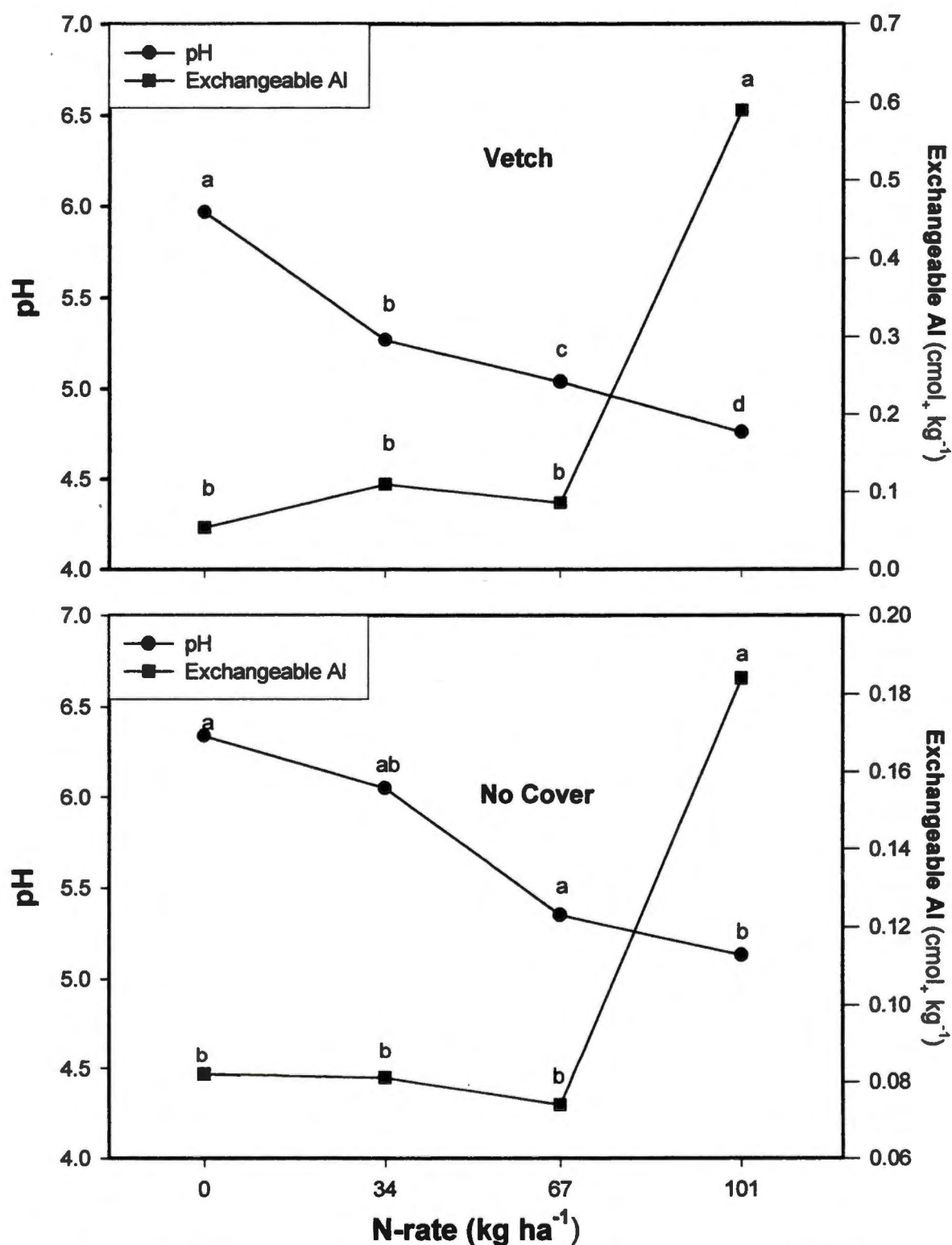


Figure 5. Exchangeable Al and pH against N-rate for the no-till (NT) treatments that received the vetch cover and no cover at the 0-7.5 cm depth. Data points identified by the same letter for the same data set are not significantly different at $\alpha=0.05$.

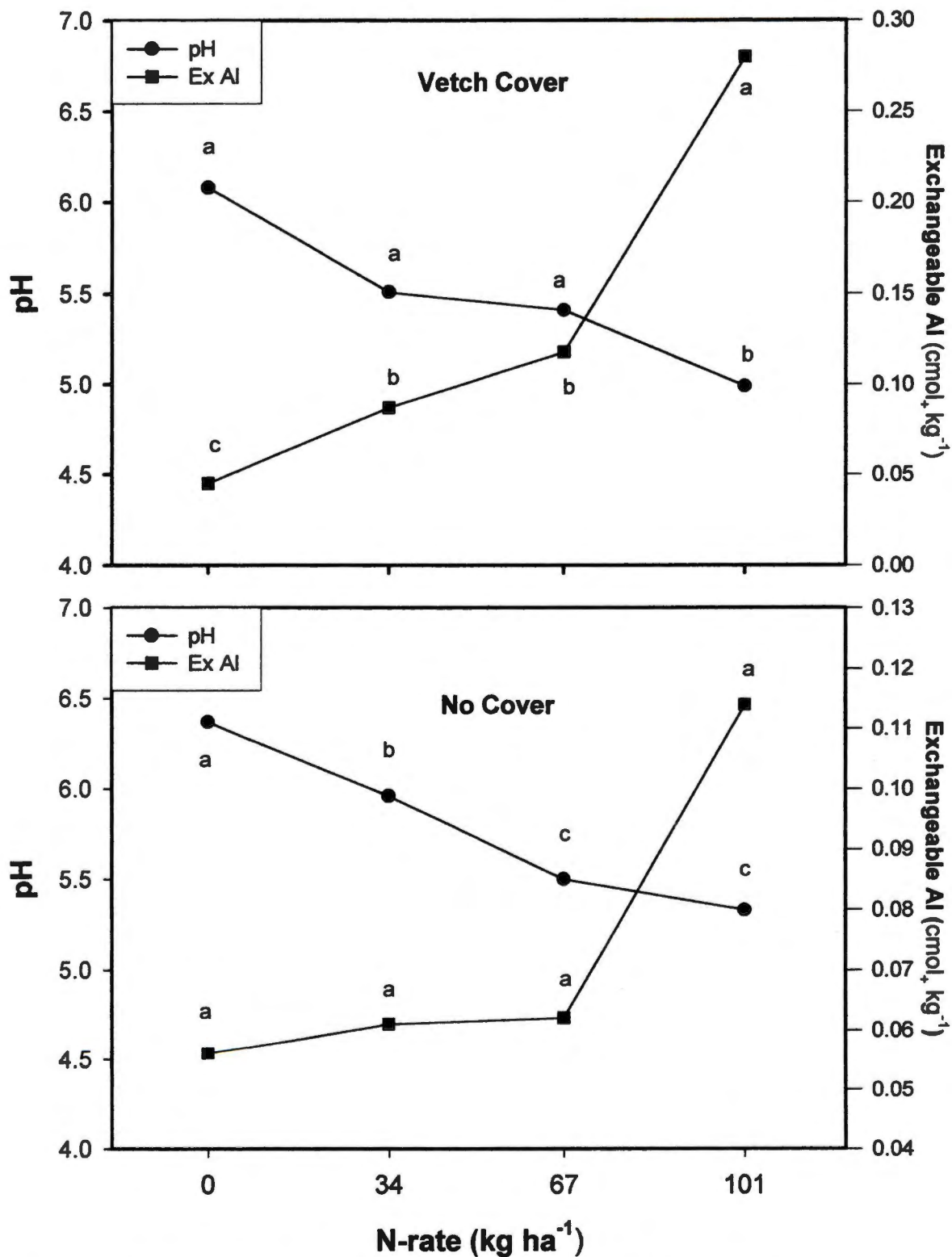


Figure 6. Exchangeable Al and pH against N-rate for the tilled treatments that received the vetch cover and no cover at the 0-7.5 cm depth. Data points identified by the same letter for the same data set are not significantly different at $\alpha=0.05$.

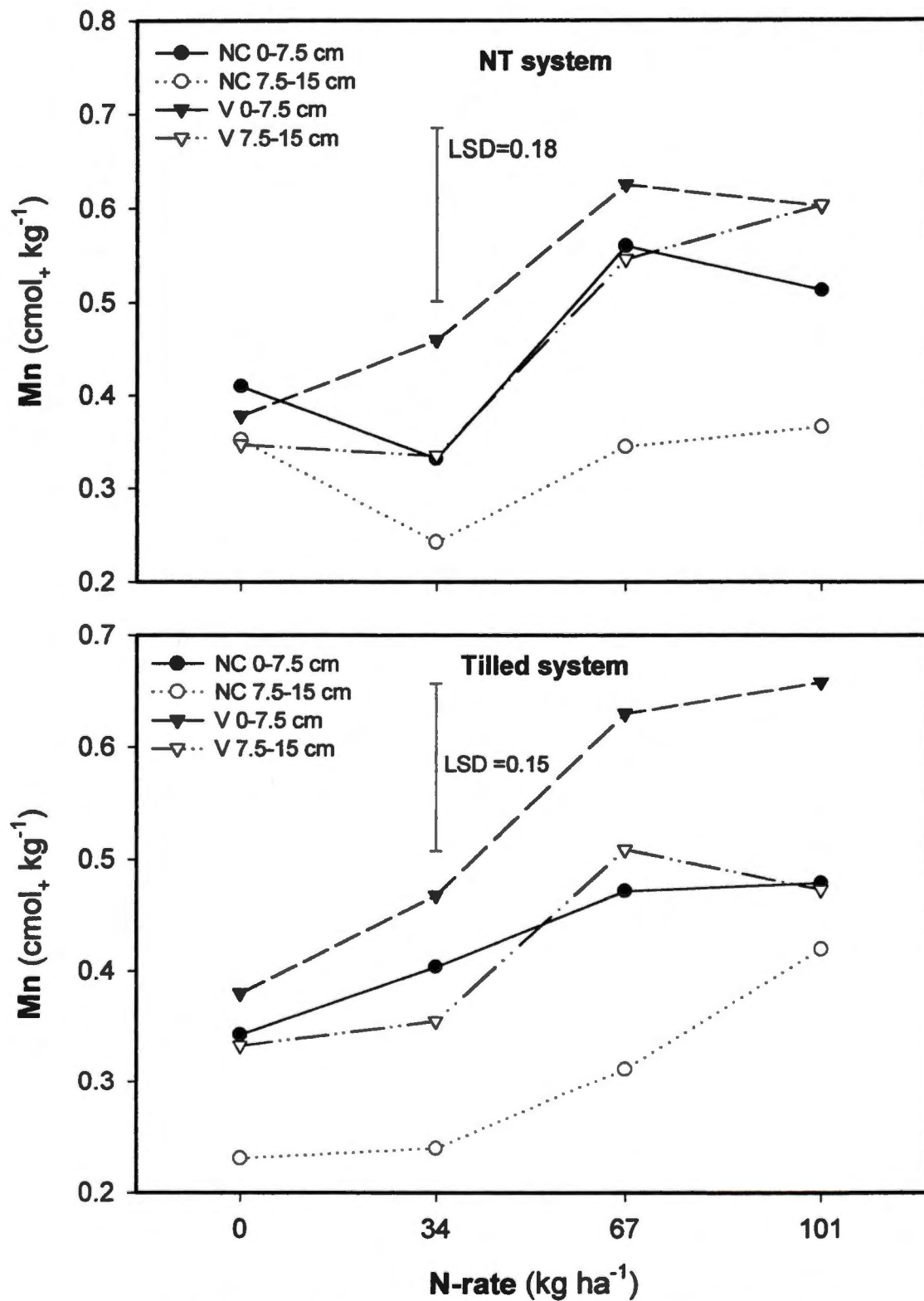


Figure 7. The effect of N-rate and cover (no cover, NC; vetch cover, V) on NH_4OAc exchangeable (pH 7) Mn at both depths in both systems. The LSD values represent differences at the $\alpha=0.05$ level within each tillage system.

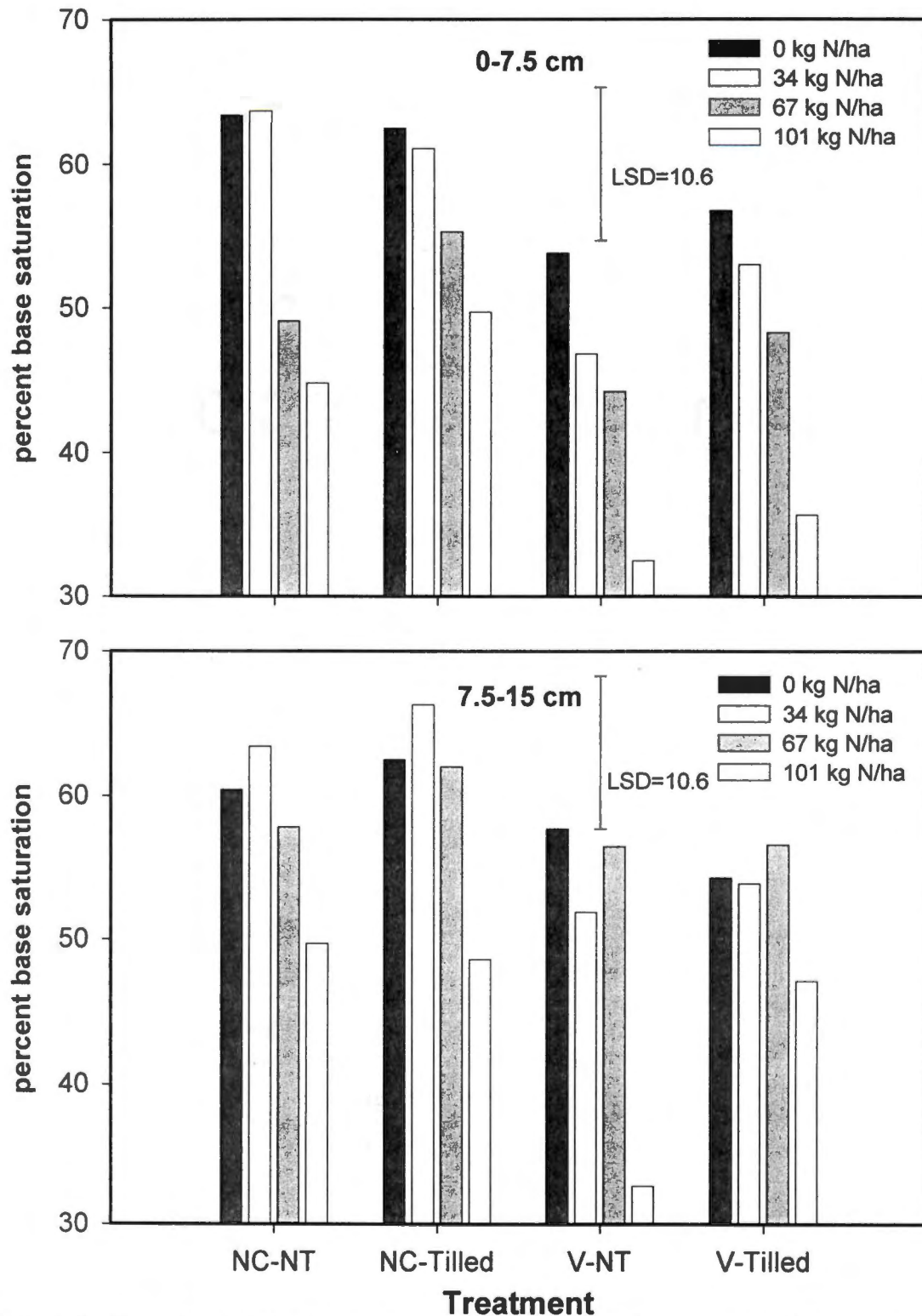


Figure 8. The effect of N-rate on base saturation values for no cover (NC) and vetch (V) cover in no-till (NT) and tilled (T) systems for the 0-7.5 and 7.5-15 cm depths. LSD values represent differences within each depth at the $\alpha=0.05$ level.

Part 3

Response of pH to Limestone in a Loess Derived Soil

Note: Paper to be submitted to the Soil Science Society of America Journal under the authorship of E. L. Ritchey, D. D. Tyler, M. D. Mullen, M. E. Essington, and A. M. Saxton

Abstract

Soil acidity is a common problem in the southeastern United States, and is a major concern in long-term conservation systems, especially no-till (NT) crop production. A study was initiated in the spring of 1995 to document the influence of two lime rates (recommended rate and $\frac{1}{2}$ the recommended rate) on soil chemical properties, evaluate the effectiveness of surface applied limestone, and to validate the effectiveness of the Adams and Evans buffer test on limestone application in cotton production on a loess-derived soil. A long-term study investigating the influence of N-rate (0,34, 67, and 101 kg N ha⁻¹), cover crop (no cover and vetch), and tillage practice (no-till and tilled) on soil chemical properties in continuous long-term cotton production was conducted on a Lexington silt loam (Ultic Hapludalf) soil. Soil samples were taken in the spring, prior to annual fertilization and analyzed for pH, TC, CEC, exchangeable bases, exchangeable Al, and exchangeable Mn. Pelletized limestone that met minimum State standards was applied in the spring of 1995 at the recommended rate and $\frac{1}{2}$ the recommended rate to individual plots according to the 1:1 water pH and the Adams and Evans buffer test. All treatments, with the exception of NT vetch plots that received ≥ 67 kg N ha⁻¹, had pH values ≥ 6.1 by the spring of 1997, with either rate of limestone. The $\frac{1}{2}$ rate of limestone was as effective as the full rate of limestone in raising pH at both depths, however the full rate tended to increase pH slightly more and at a faster rate than the $\frac{1}{2}$ 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. The Adams and Evans buffer test appears to overestimate the lime requirement for NT cotton production in Tennessee; however if $\text{pH} \leq 4.8$, incorporation of limestone or the full lime rate is advised.

Introduction

No-till (NT) farming practices have become widely used in recent years. In NT crop production, all fertilizer additions are surface applied. The addition of surface applied N can lead to a rapid decrease in soil pH in the top few centimeters of the soil surface (Blevins et al., 1978; Blevins et al., 1983; Grove and Blevins, 1988; Dick, 1983). When the soil pH reaches a critical level, limestone applications are recommended. A critical level is defined as the pH value that divides response from limestone from no response from limestone (Adams, 1969). Tennessee currently bases its lime recommendations on soil samples taken to a depth of 15 cm. Based on this recommendation, there is a concern that surface applied limestone to NT systems may not adequately neutralize soil pH. In NT systems the acidity is created at the surface, so it would be logical to assume that surface applied lime would neutralize this acidity. Several researchers have determined that surface applied lime adequately raises soil pH and increases corn yields in NT plots, however, incorporation might be needed if soil pH is at a critically low value (pH 4.5-5.0) (Blevins et al., 1983; Grove and Blevins, 1988).

Historically, Tennessee recommended the addition of 6.72 Mt ha^{-1} 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 a sampling depth of 15 cm. The Adams and Evans buffer test generates lower lime recommendations in many instances as compared to the old method of applying 6.72 Mt ha⁻¹ to obtain a one unit change in pH.

The most important function of liming is to reduce the amount of exchangeable Al and Mn (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). Thomas (1975) found that pH values could be as low as pH 3.8 without adverse effects on corn growth when ample amounts of organic carbon (OC) are present. Howard and Adams (1965) determined that the elongation of primary cotton roots is inhibited by H⁺ only when pH < 4.25.

Aluminum phytotoxicity can occur when about 20% of the exchange complex is occupied by Al. Aluminum phytotoxicity is typically expressed as retarded root growth (Blevins et al., 1978; Kamprath, 1970; Foy, 1984; Adams 1981). The exchange of Al-species from carboxyl sites on organic matter appears to be one of the most important factors in the control of Al³⁺ activity in acid soils low in permanent charge CEC (Bloom et al., 1979). Two or 3 cmol_c kg⁻¹ of Al could cause

enough saturation of the exchange complex and cause reductions in yield (Blevins et al., 1978). They also found that this is complicated by the fact that the same yield reductions can occur with pH greater than 4.3 and 1 to 2 cmol_c Al kg⁻¹ soil as with pH values of 4.8 and <.3 cmol_c kg⁻¹. Toxic values for particular crops are not well defined for several reasons associated with other varying soil chemical properties.

Manganese toxicity is not as easy to predict as Al toxicity, but is expected in soils with 50-100 mg kg⁻¹ easily reducible Mn and pH < 5.0, or when concentrations greater than 10 mg L⁻¹ in solution are evident (Adams, 1984; Adams and Wear, 1957; Foy, 1984). Manganese is adsorbed by plants in the divalent form, Mn (II), however the amount of Mn (II) can vary in a field, depending on the amount of SOC present, pH of the soil, and the soil's moisture content (Ritchie, 1989; Adams, 1984). Manganese toxicity is expressed in the leaves causing the leaves to become puckered and distorted (Adams, 1984; Foy, 1984).

The objectives of this study were to: (i) document the changes in selected soil properties after limestone application, (ii) evaluate the effectiveness of surface applied lime for increasing soil pH, relative to soil incorporation using the Adams and Evans buffer test, and (iii) 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

Haphudalf) on long-term (14 yr.) NT and tilled 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. There is no evidence of a fragipan within the top meter of soil.

The experimental plots were established in 1981 and replicated 4 times in a split-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, 34, 67, and 101 kg N ha⁻¹). 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 (DT and NT). These blocks were further split into vertical blocks that were randomly assigned two lime rates (full recommended rate and ½ the recommended rate). After all the splits were completed the experiment contained 256 plots. Plots were 4 meters wide by 12 meters long. In this paper the no cover and vetch cover were chosen to evaluate their different effects relative to liming response.

Soil samples were taken at random locations in each plot, in the spring, prior to planting, using a 2.54 cm soil probe at 0-7.5, 7.5-15, and 0-15 cm depths. For the 0-7.5 and the 7.5-15cm depths, a sample was taken to 15 cm and divided into the two depths. For each plot, approximately 10 subsamples were taken to 15 cm for the 0-7.5 and 7.5-15cm depths and 5 samples were taken for the 15 cm depths. The subsamples at each depth were combined for analyses.

Cotton (Stoneville 132) was planted during the first two weeks of May, following an burndown application of glyphosate at a rate of 2.34 L ha⁻¹ in all plots. Cotton was planted

at a density of approximately 22,275 plants ha⁻¹ using a John Deere NT planter. Aldicarb at 0.56 kg ha⁻¹ active ingredients (ai) and quintozone (PCNB) 10G at 1.12 kg ha⁻¹ ai was applied in furrow at planting. The following chemicals were applied in furrow at planting: fluometuron 4L at 1.68 kg ha⁻¹ ai, pendimethalin at 1.12 kg ha⁻¹ ai, norflurazon at 1.12 kg ha⁻¹ ai, and paraquat at 0.69 kg ha⁻¹ ai, with ½% surfactant were applied. The plots received 101 kg ha⁻¹ of P₂O₅ and K₂O on May 9, based on medium/low soil test results. On May 10 and 11, 1995, plots were subjected to an additional split and lime was applied at the full recommended rate and half the recommended rate according to the Adams and Evans buffer test (Adams and Evans, 1962). Individual plots within each treatment were limed according to the LR to reach the pH value of 6.5. Using the average LR for the treatment would have resulted in the over-application of limestone in some plots and the under-application of limestone in others. Nitrogen, in the form of ammonium nitrate (34g N kg⁻¹), was hand broadcast at planting at the above indicated rates. Tillage on the tilled 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 0-7.5 and 7.5-15 cm depths, with the exception of soil pH, which was also analyzed for the 0-15 cm depth. Soil pH was determined using 1:1 soil:solution ratio using distilled-deionized water. Total carbon (TC) was determined using a LECO high

temperature induction furnace (Nelson and Sommers, 1996). Previous research has shown TC to be identical to OC for the unlimed Lexington soil (unpublished data). Cation exchange capacity was determined using the NH_4OAc (pH 7) method (United States Salinity Laboratory Staff, 1954). 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, 1997). 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 0-15 cm sample for pH was also included in the statistical analysis. All other analyses were performed on the 0-7.5 and 7.5-15 cm 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 $\text{pH}=4.29$, instead of pH 4.5 if pH data are used. Some inconsistencies in mean separation have occurred due to the transformation; however this was the most valid way of analyzing the pH variable, due to the pH variable being skewed towards the lower pH value.

Results and Discussion

Soil pH

The addition of limestone, at both rates, showed an increase in pH in all plots. For a summary of ANOVA tables refer to Table 1. The plots that received 0 kg N ha⁻¹ with no cover, regardless of tillage, initially had the highest pH values of the experiment, and usually no limestone was applied (Figures 1 and 2). The treatment average for the 0 kg N ha⁻¹ treatments was above the pH 6.1 cutoff value, however some of the individual plots were below pH 6.1 and limestone was added to those particular plots. The plots that received the vetch cover crop without additional N had lower initial pH values than the no cover plots and were below the 6.1 cutoff value (Figures 3 and 4). At either rate of limestone the pH of these treatments was raised above pH 6.1 by 1997 in both tillage systems.

The 34 kg N ha⁻¹ treatment that received no cover crop appeared to have had higher initial pH values than the 0 kg N ha⁻¹ vetch treatments, but by 1997 the pH values were increased to about 6.5 at either rate of limestone (Figures 5 and 6). At 34 kg N ha⁻¹ with a vetch cover crop in the NT system, the pH values in 1995 were below 5.5 at all depths (Figure 7). By 1996 neither rate of limestone had increased the pH to values greater than 6.1. However, by 1997 both rates of limestone had increased the pH of the soil to 6.1 with the full rate increasing pH more than the ½ rate. Since the LR is determined by the 0-15 cm depth, more limestone would not be recommended in these plots. The ½ rate of limestone did not increase the 7.5-15 cm depth to pH 6.1 in the NT treatment with a vetch cover crop, however all other

treatments that received 34 kg N ha⁻¹ were increased to pH values greater than 6.1.

In the 34 kg N ha⁻¹ tilled treatments that received the vetch cover crop, the initial pH was approximately 5.5, with the 7.5-15 cm depth being slightly higher (Figure 8).

The change was similar for both rates of limestone, with the full rate increasing the pH slightly more than the ½ rate. The tilled treatments appeared to have initially higher pH values than the NT treatments and resulted in a higher final pH values than the NT treatments (Figures 7 and 8). For both tillage systems, the final change in pH values were acceptable.

The 67 kg N/ha treatments that received no cover crop were similar to the 34 kg N ha⁻¹ treatments that received a vetch cover crop and reaffirms that the vetch cover is adding the equivalent of approximately 30-50 kg N ha⁻¹ to the system (Figures 9 and 10). In both tillage systems the 0-15 cm depth had initial pH values around 5.5. By 1997, both rates of limestone had effectively raised soil pH to values greater than 6.1 in the no cover crop system. The full rate of limestone raised the pH to the target value of pH 6.5 in both tillage systems, however the ½ rate was slightly below the 6.5 target value.

For the treatments that received 67 kg N ha⁻¹ and the vetch cover crop, the initial pH values were between 5.0 and 5.5, with the pH of the tilled treatments being numerically higher than the NT treatments (Figures 11 and 12). In the NT system, pH values increased little by 1996 and were below the 6.1 cutoff value in 1997 (Figure 11). Since the limestone was expected to take 2-3 years to attain maximum pH change (Adams, 1984; Howard, 1970), the results of this limestone application

may not have been fully demonstrated. The tilled system that received 67 kg N ha^{-1} and a vetch cover crop increased the soil pH more and at a faster rate than the NT system (Figure 11 and 12). By 1997 both rates of limestone increased soil pH well above the 6.1 cutoff value in the tilled system (Figure 12). The full rate of limestone increased soil pH above the 6.5 target value at all depths for this treatment.

The NT treatments that received 101 kg N ha^{-1} and no cover crop were similar to the 67 kg N ha^{-1} NT treatments that received the vetch cover crop; however, this treatment showed slightly more initial stratification (Figure 13). The initial pH values were approximately, 5.4 and by 1996 the pH had increased to about 5.7 with the full rate of limestone. However, stratification was still evident. In 1997 both rates of limestone had increased the 0-15 cm depth above the 6.1 cutoff value and most of the stratification was overcome. The initial pH values of the tilled treatments that received 101 kg N ha^{-1} appeared to be similar to the NT treatments that received the same N-rate, but were not as stratified (Figures 13 and 14). By 1996, the full rate of limestone in the tilled system had increased the pH to greater than 6.1, and by 1997 the pH greater than 6.5 (Figure 14). The $\frac{1}{2}$ rate of limestone showed an increase in 1996, and by 1997 the pH had increased above the 6.1 cutoff value, although the change was not as sudden or of the same magnitude as the full rate of limestone.

The NT treatment that received the vetch cover crop and 101 kg N ha^{-1} had the lowest initial pH values of the experiment ($\text{pH} < 4.8$), and by 1997 the soil pH values were still below the 6.1 cutoff value with either rate of limestone (Figure 15).

By 1997, soil pH was still below 5.4 for both rates of limestone. These treatments had the largest amounts of N inputs and would typically not be representative of most cotton production systems, since it would be recommended to reduce N fertilizer by 60 kg N ha⁻¹ to account for N release from the legume cover. Further, in a production system, pH values would usually not be allowed to drop to such low values before limestone additions would be applied. The same would be true with the NT vetch treatments that received 67 kg N ha⁻¹, which is the only other treatment that did not reach the pH 6.1 cutoff value by 1997 (Figure 11). These treatments were creating more acidity than the limestone could overcome due to the high rates of inorganic N and the additional N from the legume cover. The NT system lacked the mixing that the tilled system received and there was not as much contact of soil and limestone, so it would be expected that the NT systems would have a lower soil pH than the corresponding tilled treatments, at least during the initial year or two after limestone application (Blevins et al., 1978; Blevins et al., 1983).

The absence of the intimate contact of the soil and limestone, and possibly stronger buffering capacity could also explain why the NT treatments typically were slower to change soil pH as compared to the tilled treatments (Ismail et al., 1994). Also, N is continually produced by the vetch cover crop in the years after limestone application and Ca must mobilize into the soil profile (occurs only after limestone dissolution). The tilled treatments that received the vetch cover crop and 101 kg N ha⁻¹ had the second lowest initial pH values in the experiment (pH<5.2) in the 0-15 cm depth. However, pH changed more quickly than NT treatments that received the

same N inputs (Figure 16). Both rates of limestone in the tilled treatments increased pH to greater than 6.1 in the 0-15 cm depth by 1997.

Summarized across all treatments and all depths, the NT treatments had lower initial pH values (5.33) than corresponding tilled treatments (5.55), and by 1997 the NT treatments still had lower pH values (5.96) as compared to tilled treatments (6.49). The pH of the vetch cover treatments were significantly lower ($P < 0.001$) than that of the no cover treatments; the vetch treatments having an average pH value approximately 0.40 pH units lower than no cover treatments. This is probably due to the additional N and subsequent nitrification of this N in the vetch system. Soil pH under NT treatments were significantly lower ($P < 0.001$) than tilled treatments with the pH average for the NT treatments being approximately 0.30 pH units lower than the tilled treatments. The 0-7.5 cm depth had a significantly lower ($P < 0.0001$) pH average (5.58) than the 7.5-15 cm depth (5.72). Lime rate did not significantly impact soil pH at $P = 0.05$, however the full rate of limestone did increase pH numerically more and faster than the $\frac{1}{2}$ rate of limestone (Table 1).

Exchangeable Al and Mn

It is generally agreed that problems from Mn and Al can occur in $\text{pH} < 5.5$, due to decreased concentrations of base cations and increased concentrations of Al and Mn (Foy, 1984; Blevins et al., 1978; Fox, 1979; Adams, 1984). In 1995, before limestone was applied, the highest amount of exchangeable Al ($0.58 \text{ cmol}_+ \text{ kg}^{-1}$) was found in the treatment that received 101 kg N ha^{-1} and a vetch cover in the NT

system, with the vetch tilled treatment generating the next highest value ($0.278 \text{ cmol}_+ \text{ kg}^{-1}$) (Figure 17). By 1996, the full rate of limestone lowered exchangeable Al values to $0.028 \text{ cmol}_+ \text{ kg}^{-1}$ in all treatments in the vetch system, with the exception of the 101 kg N ha^{-1} treatment, which was slightly higher (Figure 17). By 1997, all exchangeable values were lowered to between 0.028 to $0.130 \text{ cmol}_+ \text{ kg}^{-1}$. The same general trend was observed in the no cover treatment, with the 101 kg N ha^{-1} NT treatment having the highest amount of exchangeable Al present ($0.184 \text{ cmol}_+ \text{ kg}^{-1}$), and the tilled treatment having the next highest value ($0.114 \text{ cmol}_+ \text{ kg}^{-1}$) (Figure 18). The full rate of limestone decreased all exchangeable Al values in the no cover system to around 0.028 to $0.033 \text{ cmol}_+ \text{ kg}^{-1}$ by 1996.

Levels for exchangeable Mn were much higher than for exchangeable Al throughout the experiment, but they tended to follow the same trend, with the highest levels usually occurring in the treatments that received the highest inputs of N. For the treatments that received the vetch cover crop and the full rate of limestone, the highest level of exchangeable Mn was observed in the 101 kg N ha^{-1} tilled treatment ($0.658 \text{ cmol}_+ \text{ kg}^{-1}$). These exchangeable Mn values were not significantly different from treatments that received $\geq 67 \text{ kg N ha}^{-1}$ (Figure 19). Exchangeable Mn levels decreased in 1996, with the NT treatments that received $\geq 67 \text{ kg N ha}^{-1}$ being more resistant to change than the other treatments. By 1997, exchangeable Mn for all treatments were below $0.236 \text{ cmol}_+ \text{ kg}^{-1}$, with the exception of the NT treatments that received $\geq 67 \text{ kg N ha}^{-1}$ (Figure 19). The high levels of exchangeable Mn are not unexpected in the NT vetch treatments that received ≥ 67

kg N ha⁻¹, since these are the same treatments that had the lowest pH values in 1997 two years after limestone application (Figures 11 and 15). The absence of mixing and the stronger buffering capacity of the NT soil probably minimized the effect the limestone had on exchangeable Al and Mn. The treatments in the no cover system that received the full rate of limestone had similar values for exchangeable Mn as the vetch system, but were generally lower initially (Figure 20). By 1997, all treatments had lower levels of exchangeable Mn than in 1995 ($<0.556 \text{ cmol}_+ \text{ kg}^{-1}$), although not always significantly lower. Exchangeable Mn values for the no cover treatments were slightly higher than in the treatment that received the vetch cover crop. One reason for this difference could be associated with the vetch system having higher levels of SOC, which could reduce the Mn present as the free cation, Mn^{2+} , and in turn provide an avenue for the removal of Mn out of the profile through leaching (Ritchie, 1989).

Individual Basic Cations

The lower availability of essential basic cations, coupled with the high amounts of potentially phytotoxic cations on the exchange complex can result in decreased yields when pH values decrease (Blevins et al., 1983). The influence of limestone on individual base cations was evident, specifically the amount of Ca on the exchange complex, which increased with the addition of limestone. Nitrogen rate significantly influenced ($P<0.01$) the amount of Ca on the soil exchange complex, but did not significantly effect the amount of Mg present (Table 1). The NT system did

have significantly less Mg ($P < 0.001$) than the tilled system, although the differences for Ca were not significant. The limestone rate was significant ($P < 0.05$) in increasing the amount of Ca and Mg on the exchange complex, with the full rate of limestone increasing the amount of Ca and Mg about $0.1 \text{ cmol}_e \text{ kg}^{-1}$ soil more than the $\frac{1}{2}$ rate of limestone. There was significantly more Mg ($P < 0.001$) associated with the 0-7.5 cm depth than the 7.5-15 cm depth, but not a significant difference in Ca present. A legume cover crop significantly decreased the amount of Ca ($P < 0.001$) on the exchange complex as compared to the no cover treatments. There was an increase of Mg with increasing N-rate, however this increase was not significant.

The amount of Ca present on the exchange complex was inversely related to N-rate, with the higher levels of Ca being present in the treatments that received the lower rates of N and no cover (Figure 21). The vetch NT treatment also had significant differences across year within N-rate, however still had differences in 1997 (Figure 21). One explanation for this could be that these treatments had higher levels of acidic cations present and also higher amounts of SOC present, and would be buffered more than the no cover treatments. The only significant increases for Ca within N-rate across year in the NT system were in 67 kg N ha^{-1} no cover and in the 34 kg N ha^{-1} vetch treatments.

Exchangeable Ca in the tilled system was similar to that in the NT system in several aspects (Figure 22). Initially the treatments that received higher rates of N had the lowest amount of exchangeable Ca present. Also, the amount of exchangeable Ca appeared to be more uniform across N-rates in the no cover

treatments after 1995 as compared to the vetch treatments. The vetch tilled treatments had more significant increases in Ca within N-rate and across year as compared to the other treatments. These increases in exchangeable Ca are a direct result of receiving more limestone.

The amount of Na decreased over time ($P < 0.001$), with the greatest decrease occurring from 1996 to 1997, with the average Na content decreasing from 0.090 to 0.067 $\text{cmol}_+ \text{kg}^{-1}$. This decrease could be due to the limestone addition displacing the Na from the exchange complex.

The amount of exchangeable K was influenced by the year variable, with 1996 having a significantly higher exchangeable K content than 1995 and 1997 ($P < 0.001$). Recommended rates of K were added in the spring of 1995, due to a medium soil test, which predicted a possible response to K addition. Tillage did influence the amount of exchangeable K in each system with the tilled system having slightly more exchangeable K than the NT system ($P < 0.05$). When exchangeable K was averaged over all variables, the 0-7.5 cm depth contained significantly more exchangeable K ($P < 0.001$) than the 7.5-15 cm depth, with the 0-7.5 cm depth containing 0.45 $\text{cmol}_+ \text{kg}^{-1}$ of K as compared to the 7.5-15 cm depth (.24 $\text{cmol}_+ \text{kg}^{-1}$).

Conclusions

The effectiveness of surface applied lime was tested against incorporated limestone and found to be as effective at both depths in most systems and at the 0-15 cm average, but did not reach the pH 6.1 cutoff value in the high

nitrogen, NT treatments that received the vetch cover crop. Since most of the acidity appears in the surface it would make sense that surface applied lime would neutralize the acidity created from N applications. In most instances the pH was slower to change to a depth of 15 cm in the NT systems as compared to the tilled systems, however surface applied lime does appear to be effective in raising pH in the NT system. The surface applied lime did increase soil pH and displace most of the acidic cations across all treatments and depths, although incorporation of limestone or a higher lime rate was needed to reach values greater than 6.1 in the high N treatments that received the vetch cover crop in the NT system.

The changes in soil chemical properties as a function of limestone additions were evident. After limestone addition the amount of Al and Mn on the soil exchange complex decreased markedly by 1997. The highest levels of exchangeable Al and Mn throughout the experiment were in the NT vetch treatment that received 101 kg N ha⁻¹. However, by 1997, the exchangeable Al and Mn had significantly decreased, although the pH values of the treatment had not significantly increased. Exchangeable Ca and Mg levels increased after limestone additions. The highest levels of exchangeable Ca were in the plots that received the least amount of N.

The ½ recommended rate of limestone did not differ significantly from the full rate of limestone in its impact on soil properties. However, there was usually a greater and more rapid change in soil properties with the full rate of limestone. The ½ rate of limestone, at both depths, was as effective as the full rate in raising the pH to greater than 6.1. Neither rate increased soil pH to greater than 6.1 in the NT

system that received the highest rates of N, while both rates did in the tilled system.

One reason for using the $\frac{1}{2}$ rate of lime is based in the economics of renting land for short periods of time. A producer could apply $\frac{1}{2}$ the limestone recommended and still have positive benefits from this addition, while reducing the money spent on limestone by one-half.

The Adams and Evans buffer test does appear to be adequate in most NT cotton systems. Indeed, the test appears to overestimate the LR. The only exception being the NT vetch treatments that received N additions higher rates than recommended. For cotton production, the vetch cover and high rates of N are adding more N than is required by the plant, which increases the possibility of nitrate leaching into the groundwater, wastes money on unnecessary N application, and leads to unnecessary acidity. In most production systems, pH values would not be allowed to drop much below 5.5, so they might not incur the same problem as we did in raising pH greater than 6.1 in the NT system. Incorporation of limestone appears to be more effective when pH values reach a very low value, or a higher LR might need to be employed for very acidic NT soils. The Adams and Evans buffer test appears to over-estimate LR for NT cotton production on loess-derived soils, especially when proper N fertilizer practices are followed and account for recycled legume cover crop nitrogen and to avoid excessive nitrogen in the system.

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Table 1. Analysis of variances (Observed Prob>F) for all soil data for all main effects and interactions for all three years†.

Variable	pH	TC	Al	Mn	CEC	Ca	Mg	K	Na
Year (Y)	0.001	0.001	0.001	0.001	- ‡	0.001	0.001	0.001	0.001
N-rate (N)	0.001	NS	NS	0.001	NS	0.008	NS	NS	NS
Y*N	0.001	0.001	0.001	0.001	-	0.001	0.001	0.047	0.003
Cover (C)	0.001	0.001	NS	0.001	NS	0.001	NS	NS	NS
Y*C	0.001	NS	0.036	0.001	-	0.001	0.001	NS	NS
N*C	0.019	NS	NS	NS	NS	NS	NS	NS	NS
Y*N*C	0.001	NS	0.004	NS	-	0.001	NS	0.011	NS
Tillage (T)	0.001	NS	NS	0.019	0.002	NS	0.001	0.024	NS
Y*T	0.001	NS	NS	0.013	-	NS	0.001	NS	NS
N*T	0.001	NS	0.026	0.014	NS	NS	0.044	NS	NS
Y*N*T	0.002	NS	0.001	NS	-	NS	0.009	NS	NS
C*T	0.002	NS	NS	0.021	NS	0.049	NS	NS	NS
Y*C*T	0.005	NS	NS	NS	-	NS	NS	NS	NS
N*C*T	0.016	NS	NS	NS	NS	NS	NS	NS	NS
Depth (D)	0.001	0.001	NS	0.001	0.001	NS	0.001	0.001	NS
Y*D	0.001	0.001	NS	0.001	-	0.001	0.001	0.001	0.012
N*D	0.001	0.007	NS	NS	0.001	0.001	BS	NS	NS
Y*N*D	0.001	NS	0.016	NS	-	0.033	0.001	NS	NS
C*D	NS ††	0.001	NS	NS	0.040	0.003	0.001	NS	0.038
Y*C*D	NS	NS	NS	0.007	-	0.007	0.001	NS	NS
N*C*D	NS	NS	NS	NS	NS	NS	NS	NS	NS
T*D	NS	0.001	NS	NS	0.001	0.001	0.001	NS	NS
Y*T*D	0.025	NS	NS	NS	-	NS	0.001	NS	NS
N*T*D	0.032	0.003	NS	NS	0.010	NS	NS	NS	NS
C*T*D	0.049	0.026	NS	NS	0.001	0.001	NS	NS	NS
Limerate (L)	NS	NS	NS	0.005	-	0.006	0.001	NS	NS
Y*L	NS	NS	NS	NS	-	NS	0.001	NS	NS
Y*N*L	NS	NS	NS	NS	-	NS	0.031	NS	NS
C*L	NS	NS	NS	NS	-	NS	NS	NS	NS
Y*C*L	NS	NS	NS	NS	-	NS	NS	NS	NS
N*C*L	0.006	NS	NS	NS	-	0.004	NS	NS	NS
T*L	NS	NS	NS	NS	-	NS	NS	NS	NS
Y*T*L	NS	NS	NS	NS	-	NS	NS	NS	NS
N*T*L	0.002	NS	NS	NS	-	NS	NS	NS	NS
C*T*L	0.037	NS	NS	NS	-	NS	NS	NS	NS
L*D	NS	NS	NS	NS	-	NS	NS	NS	NS
Y*L*D	NS	NS	NS	NS	-	NS	NS	NS	NS
N*L*D	NS	NS	NS	NS	-	NS	NS	NS	NS
C*L*D	NS	NS	NS	NS	-	NS	NS	NS	NS
T*L*D	NS	NS	NS	NS	-	NS	NS	NS	NS

† pH of 1:1, soil : deionized-distilled water; TC, total carbon by combustion; KCl-Al, 1M KCl extractable Al; NH₄-Mn, NH₄-acetate (pH 7) extractable Mn; CEC, cation exchange capacity by NH₄-acetate (pH 7) method; exchangeable bases, NH₄-acetate (pH 7) extractable

†† All effects labeled NS were not significant at $P \leq 0.05$

‡ CEC was measured for 1995 only and is not included in the year or lime rate variable.

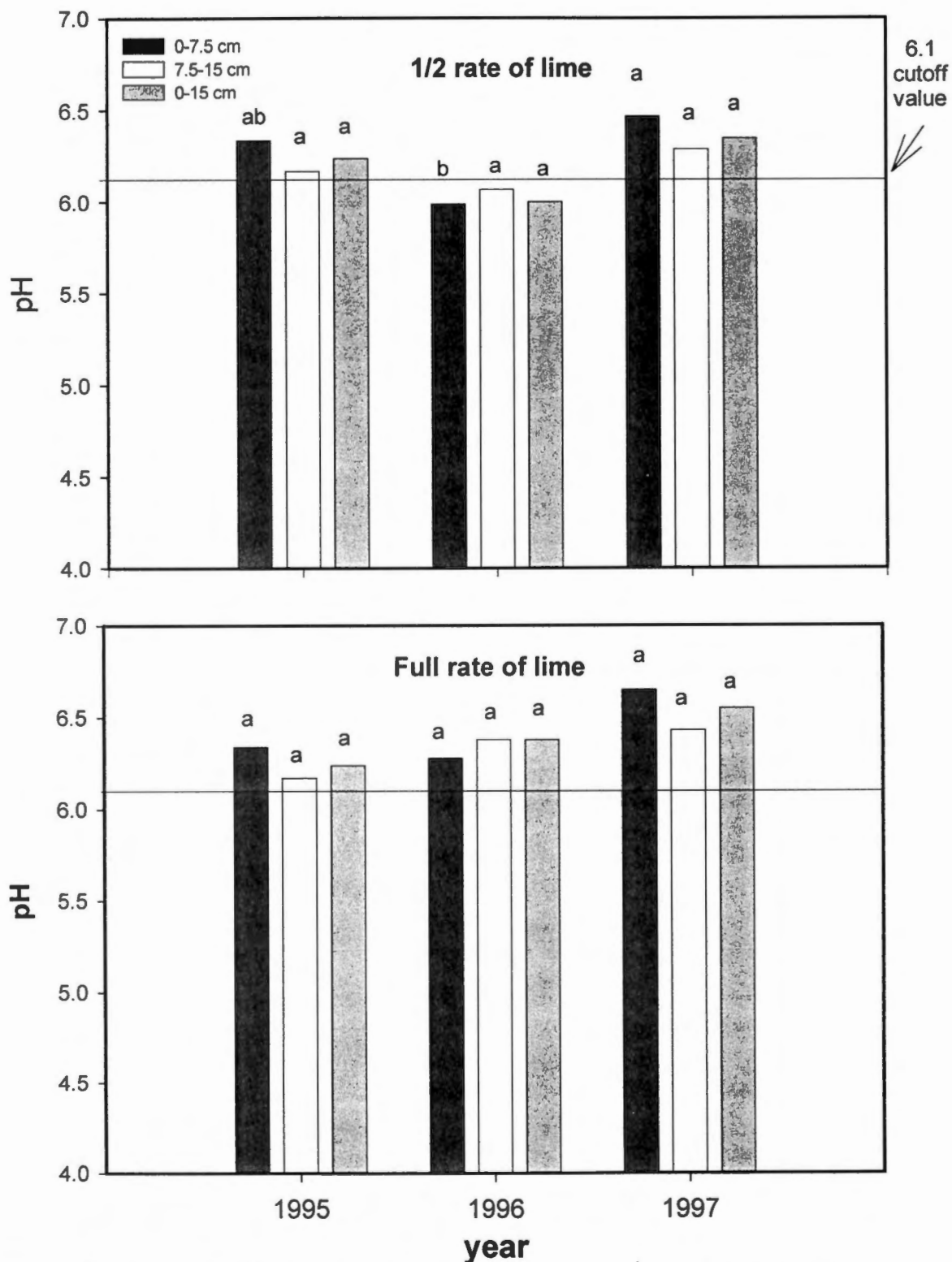


Figure1. The effect of both rates of lime on the 0 kg N ha⁻¹ NT treatments with no cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

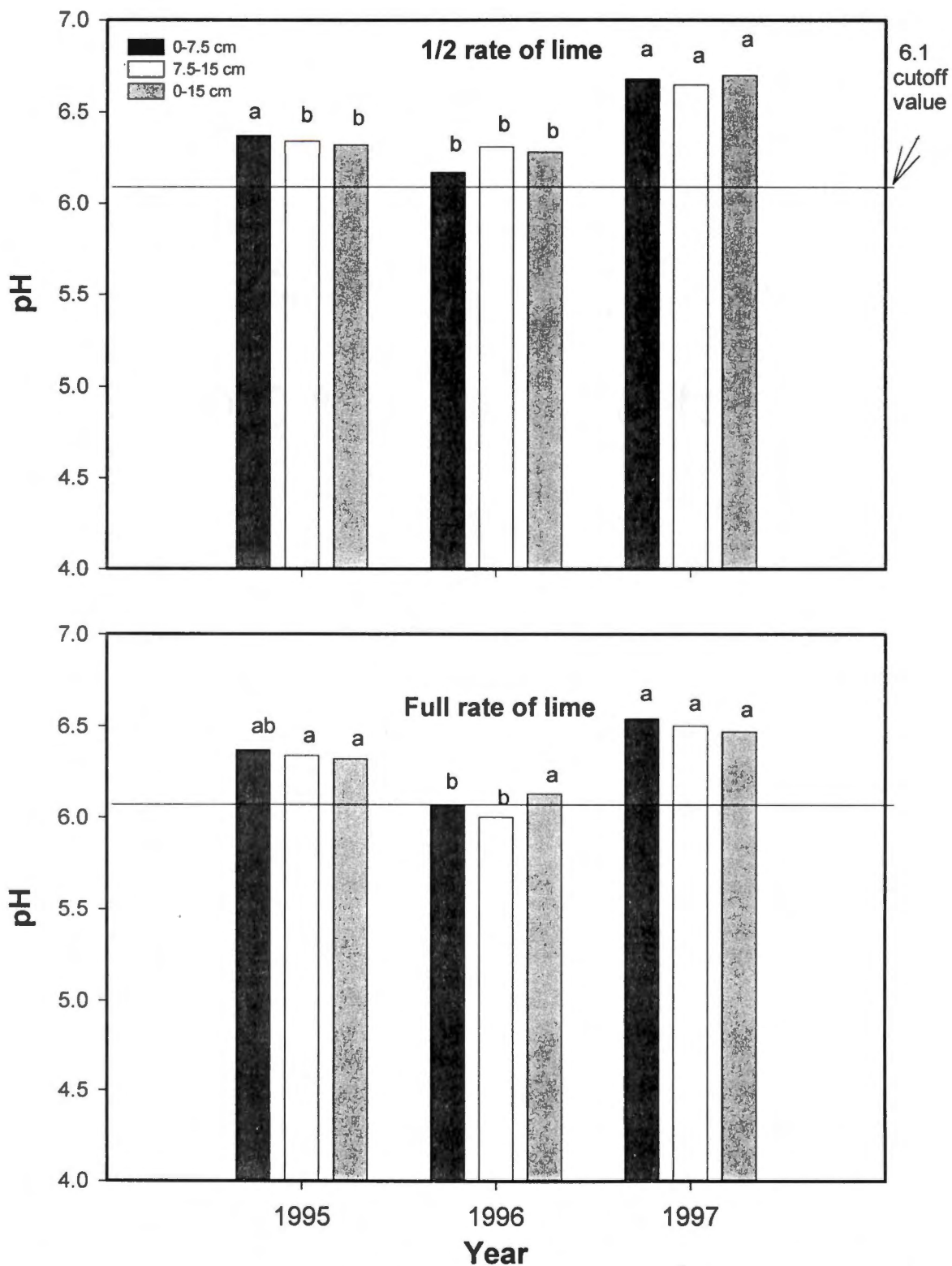


Figure 2. The effect of both rates of lime on the 0 kg N ha⁻¹ tilled treatments with no cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

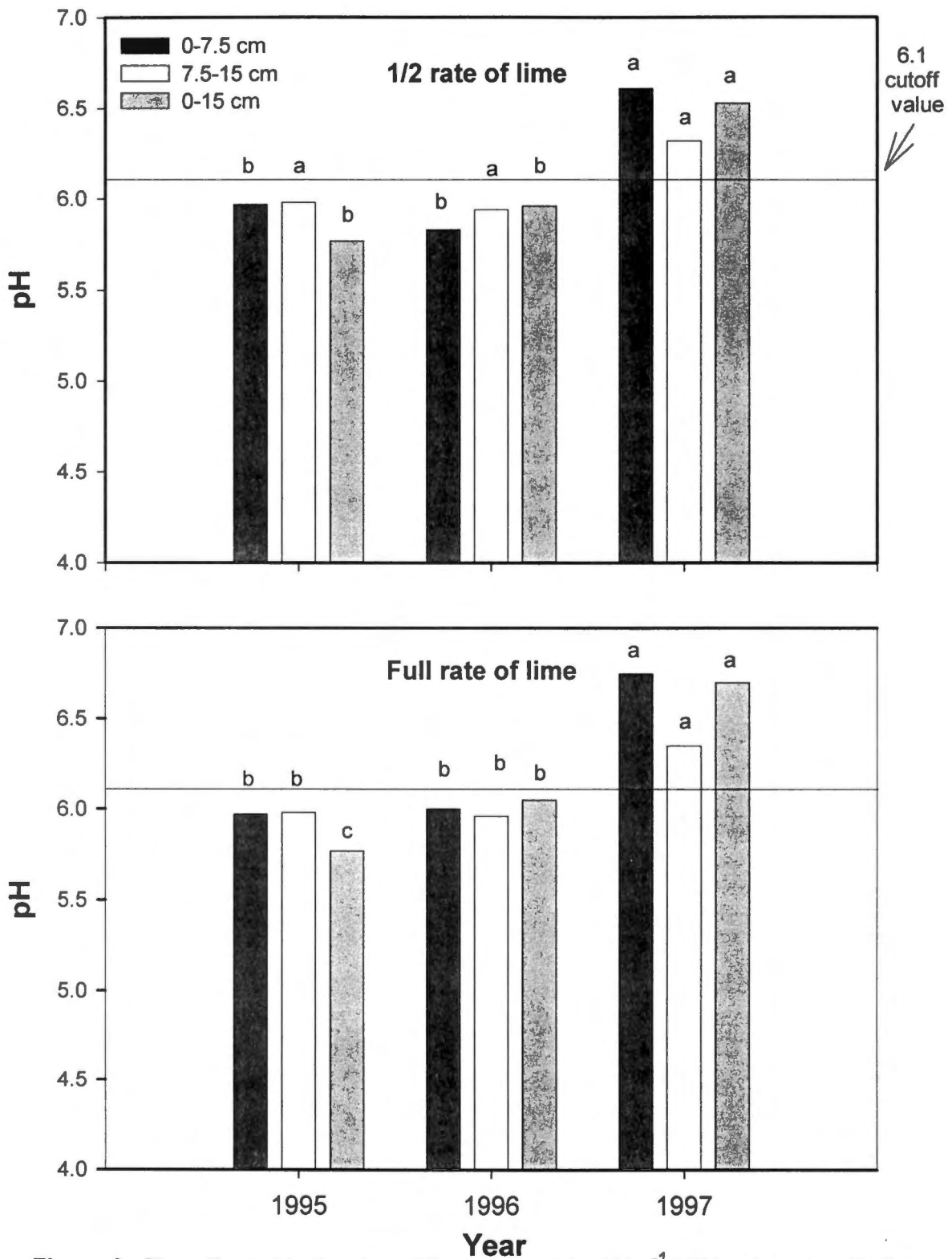


Figure 3. The effect of both rates of lime on the 0 kg N ha⁻¹ NT treatments with the vetch cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

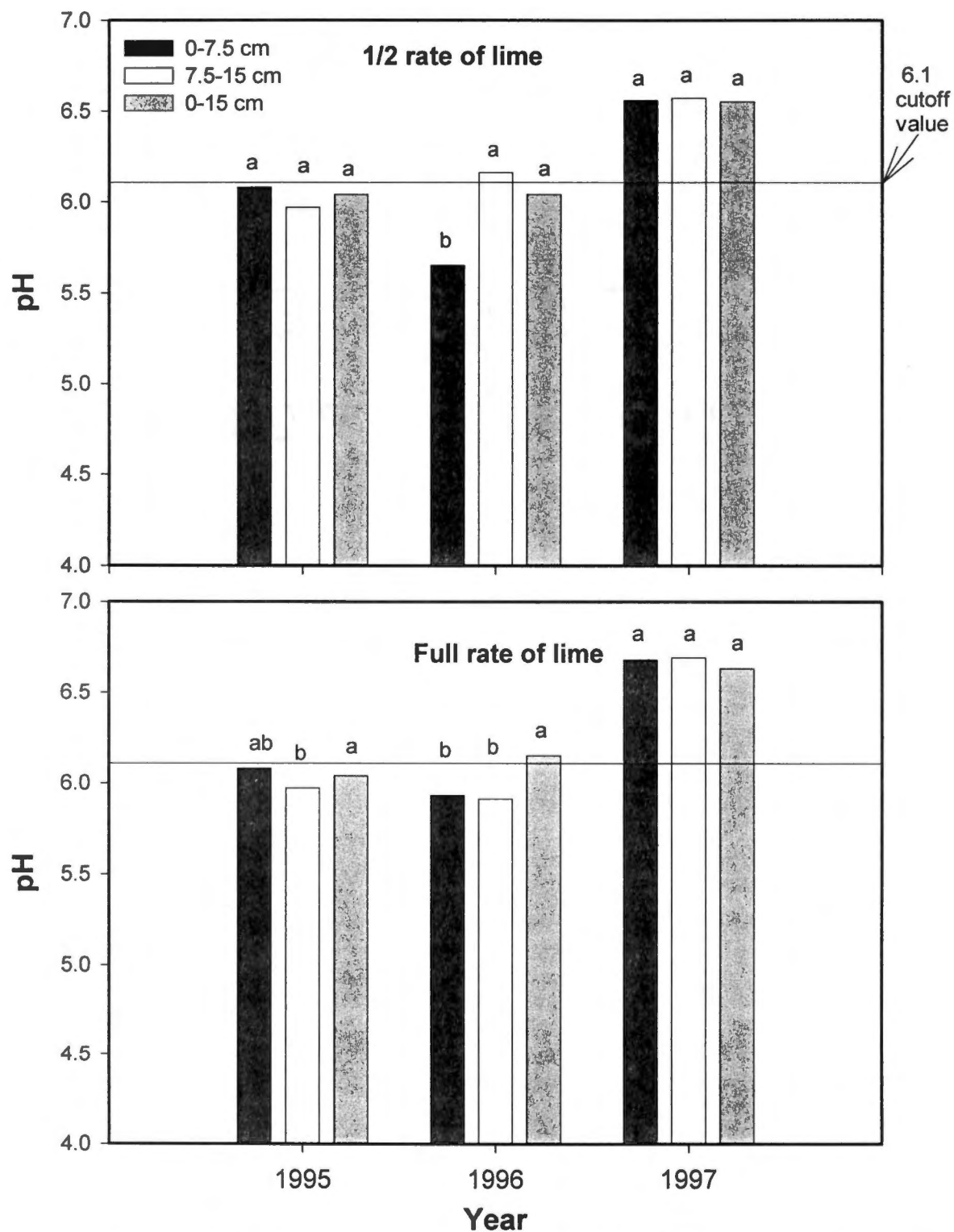


Figure 4. The effect of both rates of lime on the 0 kg N ha⁻¹ tilled treatments with the vetch cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

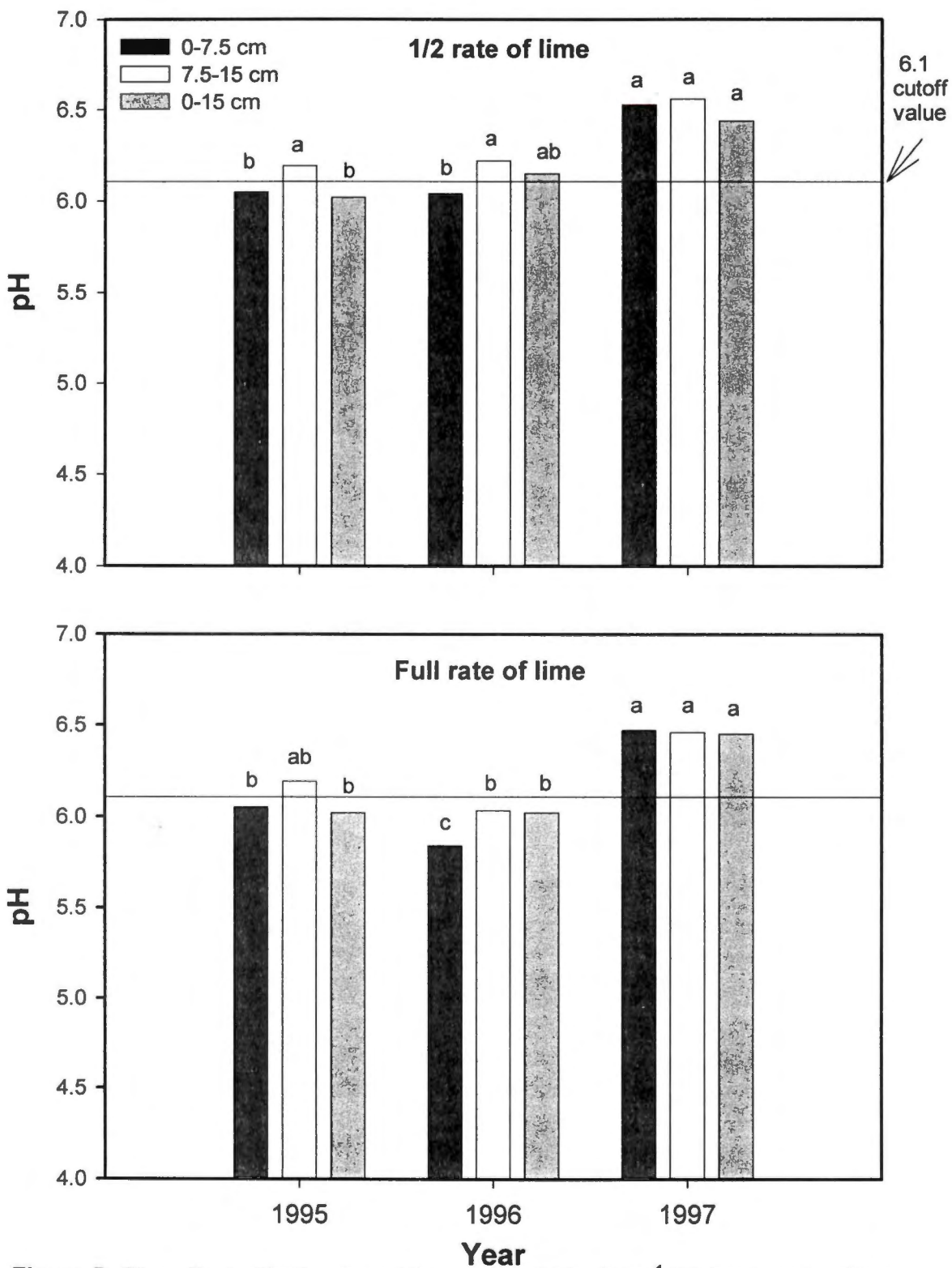


Figure 5. The effect of both rates of lime on the 34 kg N ha⁻¹ NT treatments with no cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

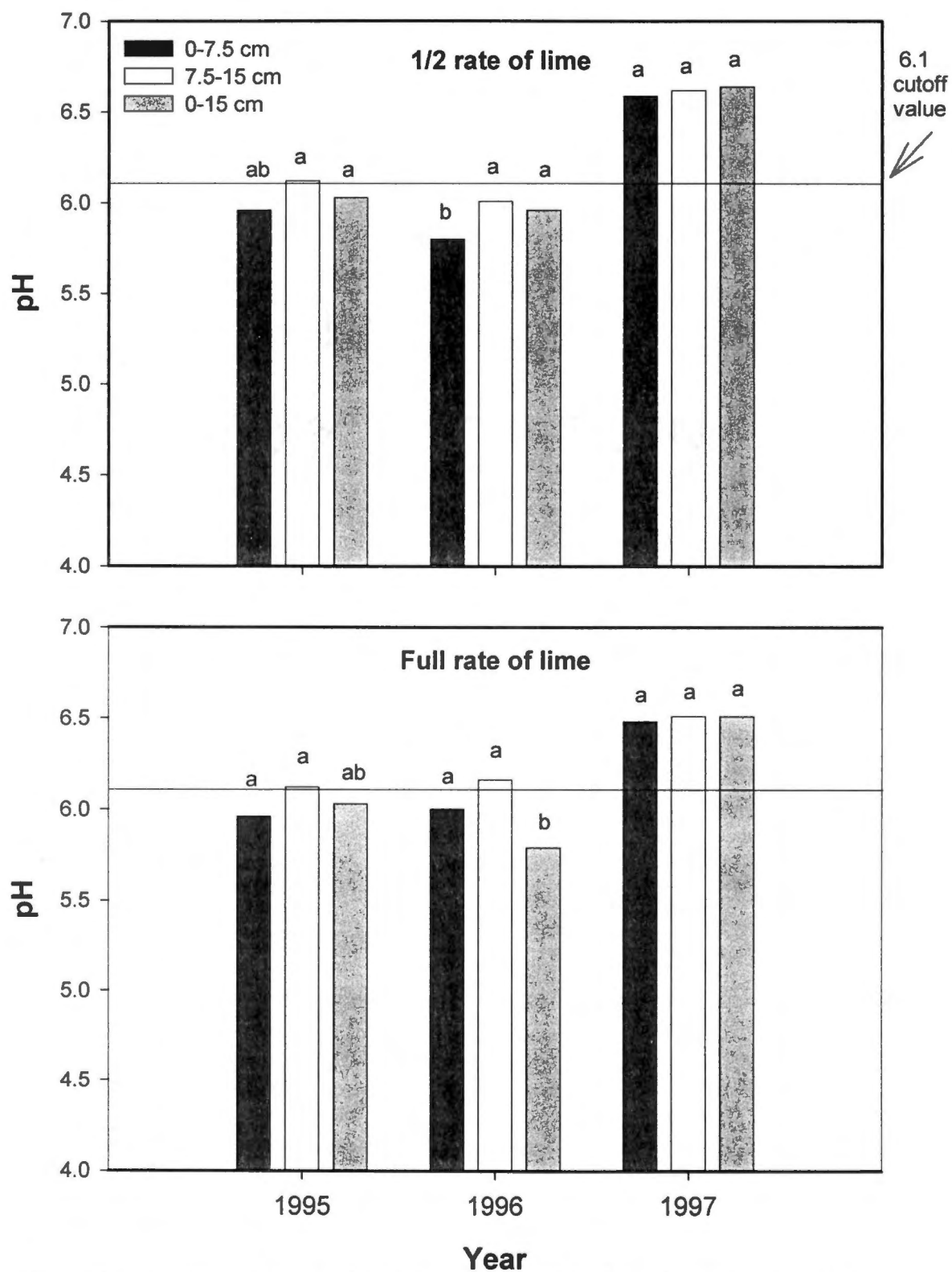


Figure 6. The effect of both rates of lime on the 34 kg N ha⁻¹ tilled treatments with no cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

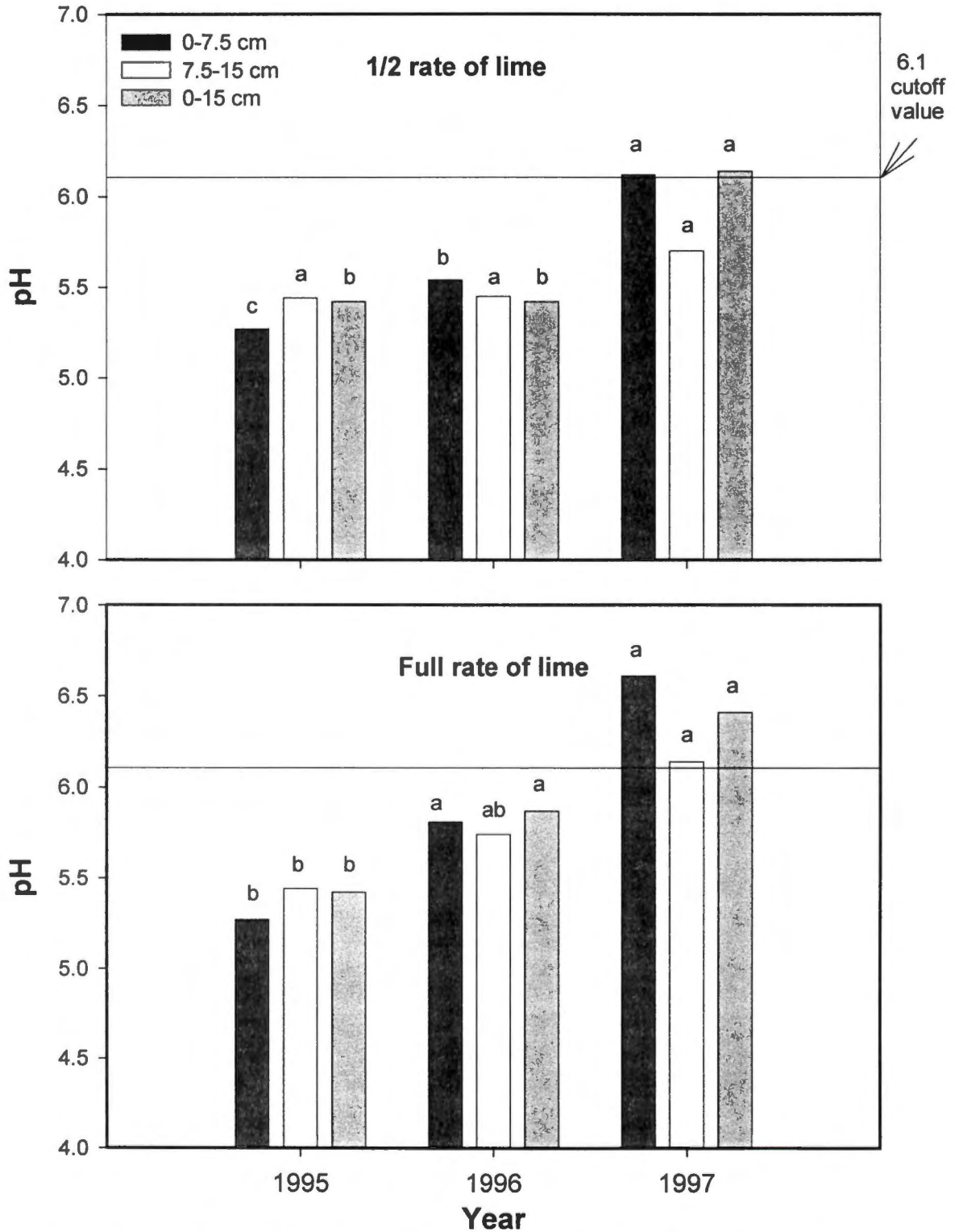


Figure 7. The effect of both rates of lime on the 34 kg N ha⁻¹ NT treatments with the vetch cover crop. Different letters represent different at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would receive limestone.

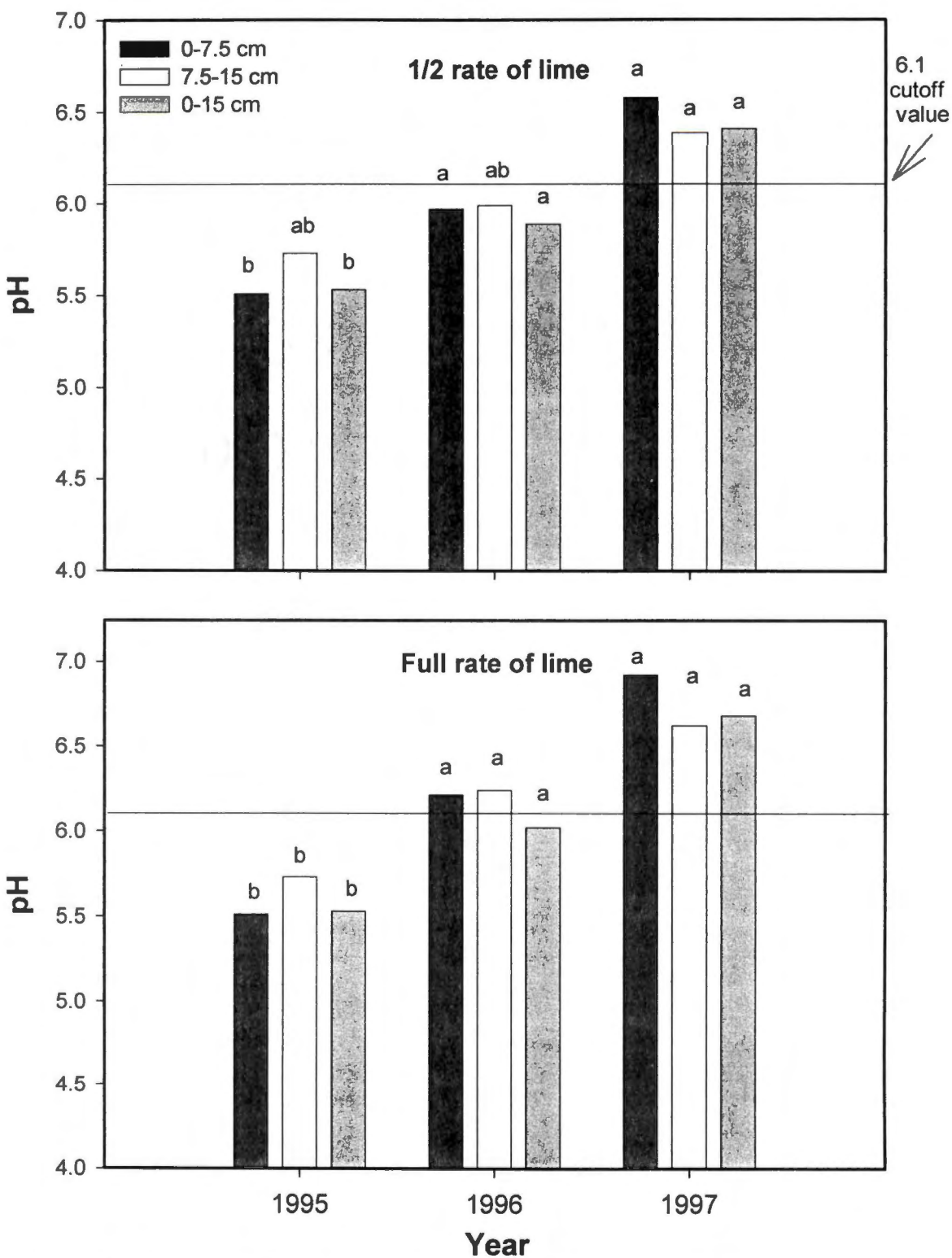


Figure 8. The effect of both rates of lime on the 34 kg N ha⁻¹ tilled treatments with the vetch cover crop. Different letters represent differences at the $\alpha=0.05$ level within each limerate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

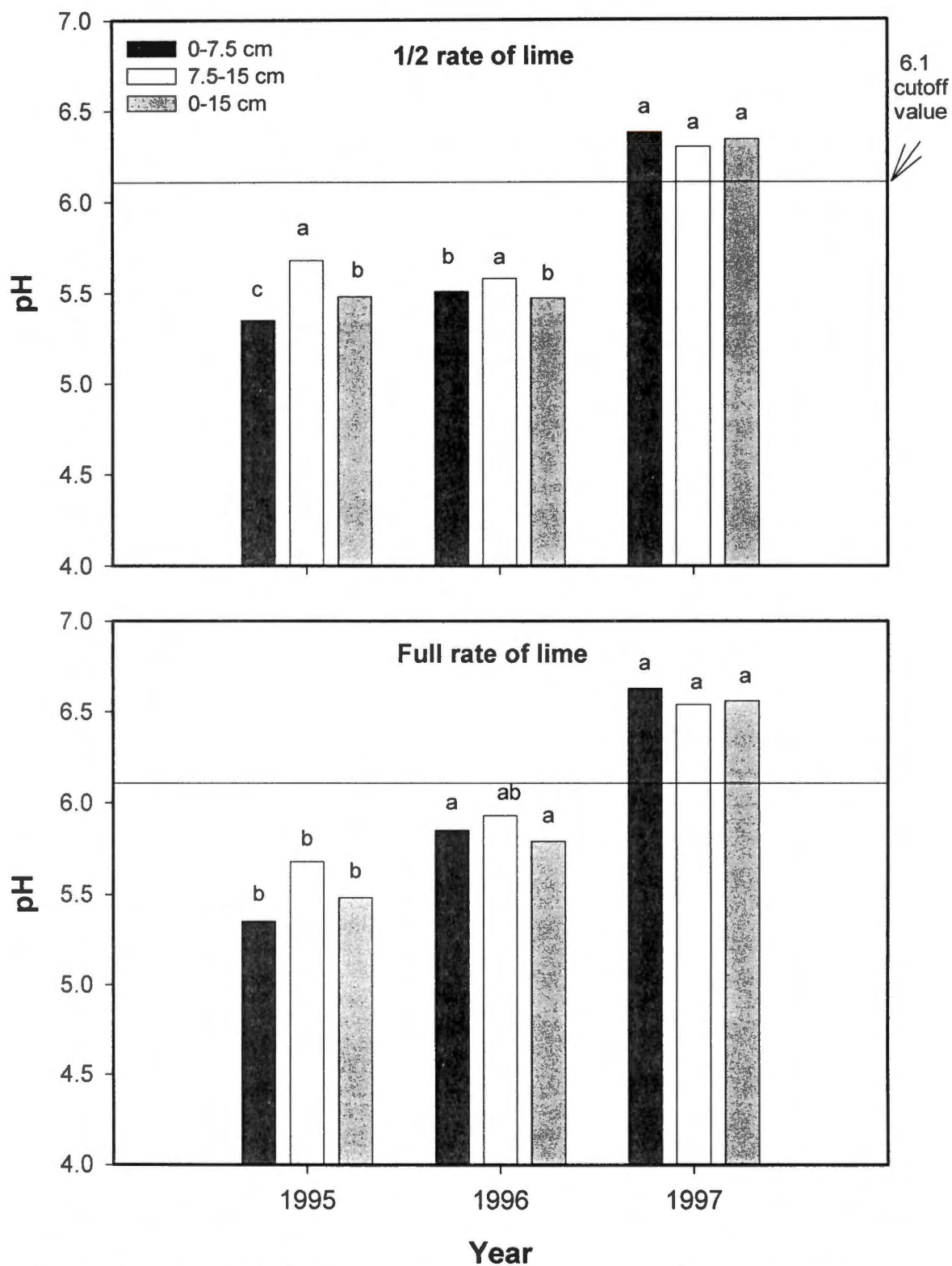


Figure 9. The effect of both rates of lime on the 67 kg N ha⁻¹ NT treatments with no cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

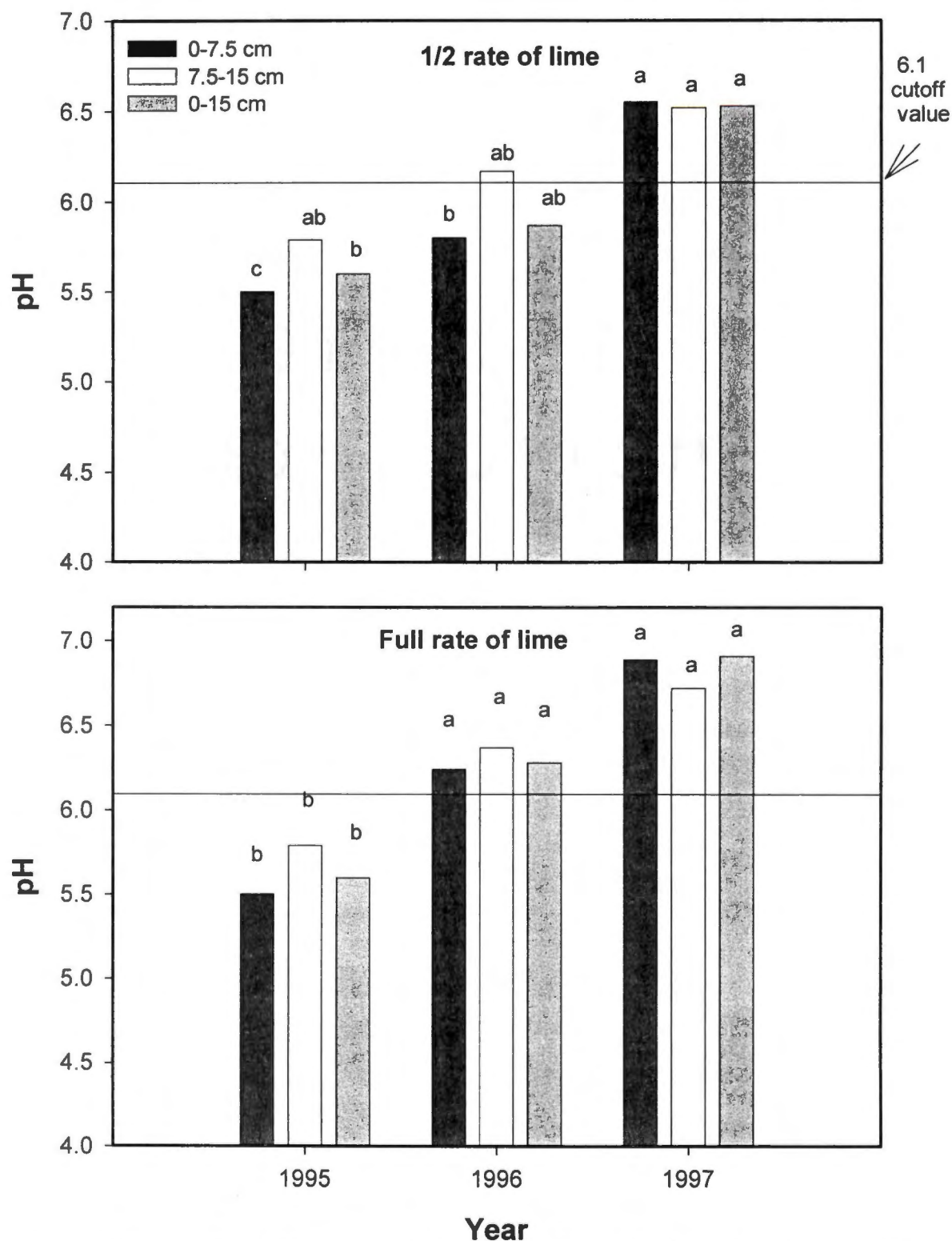


Figure 10. The effect of both rates of lime on the 67 kg N ha⁻¹ tilled treatments with no cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

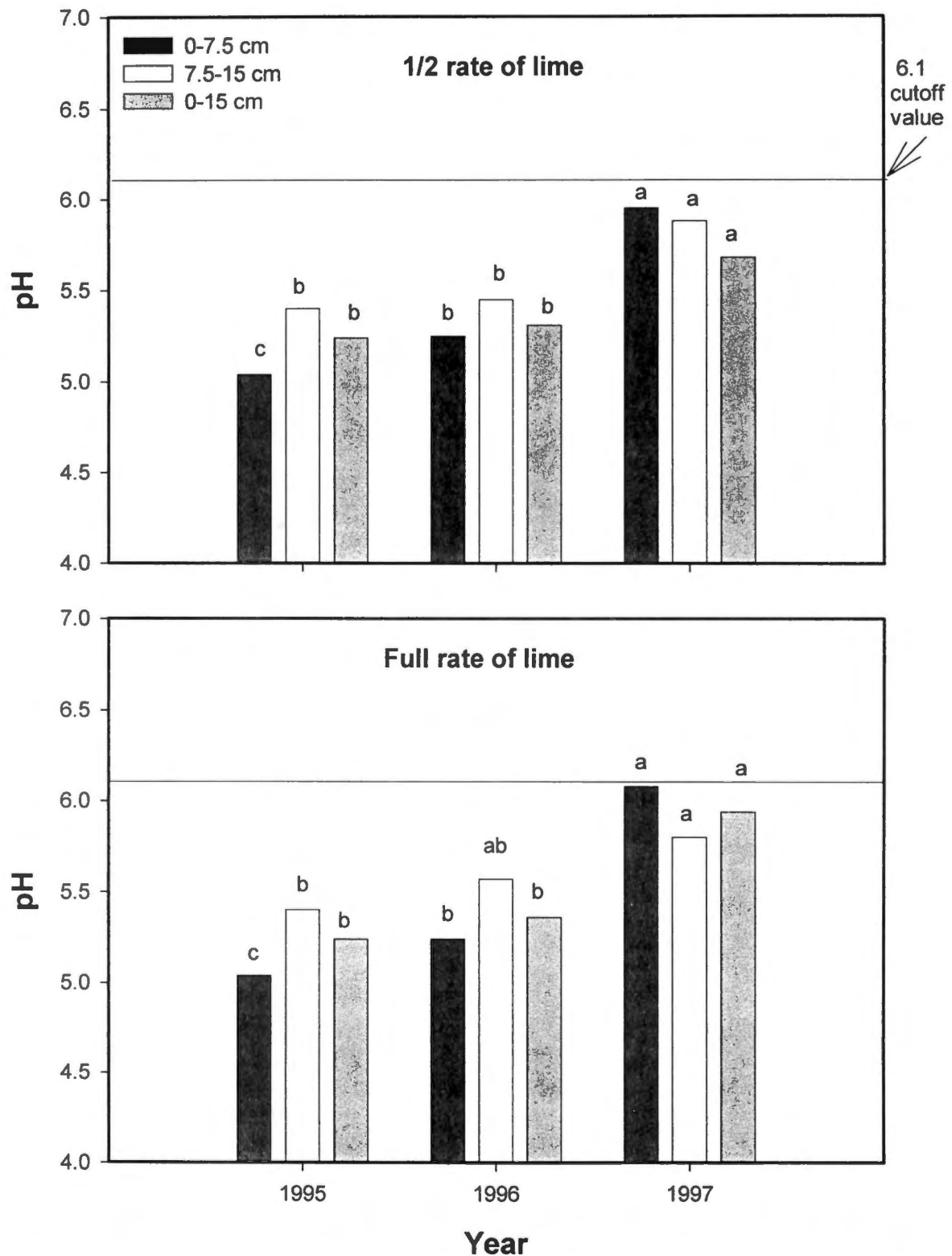


Figure 11. The effect of both rates of lime on the 67 kg N ha⁻¹ NT treatments with the vetch cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff represents the minimum pH value that would not received limestone.

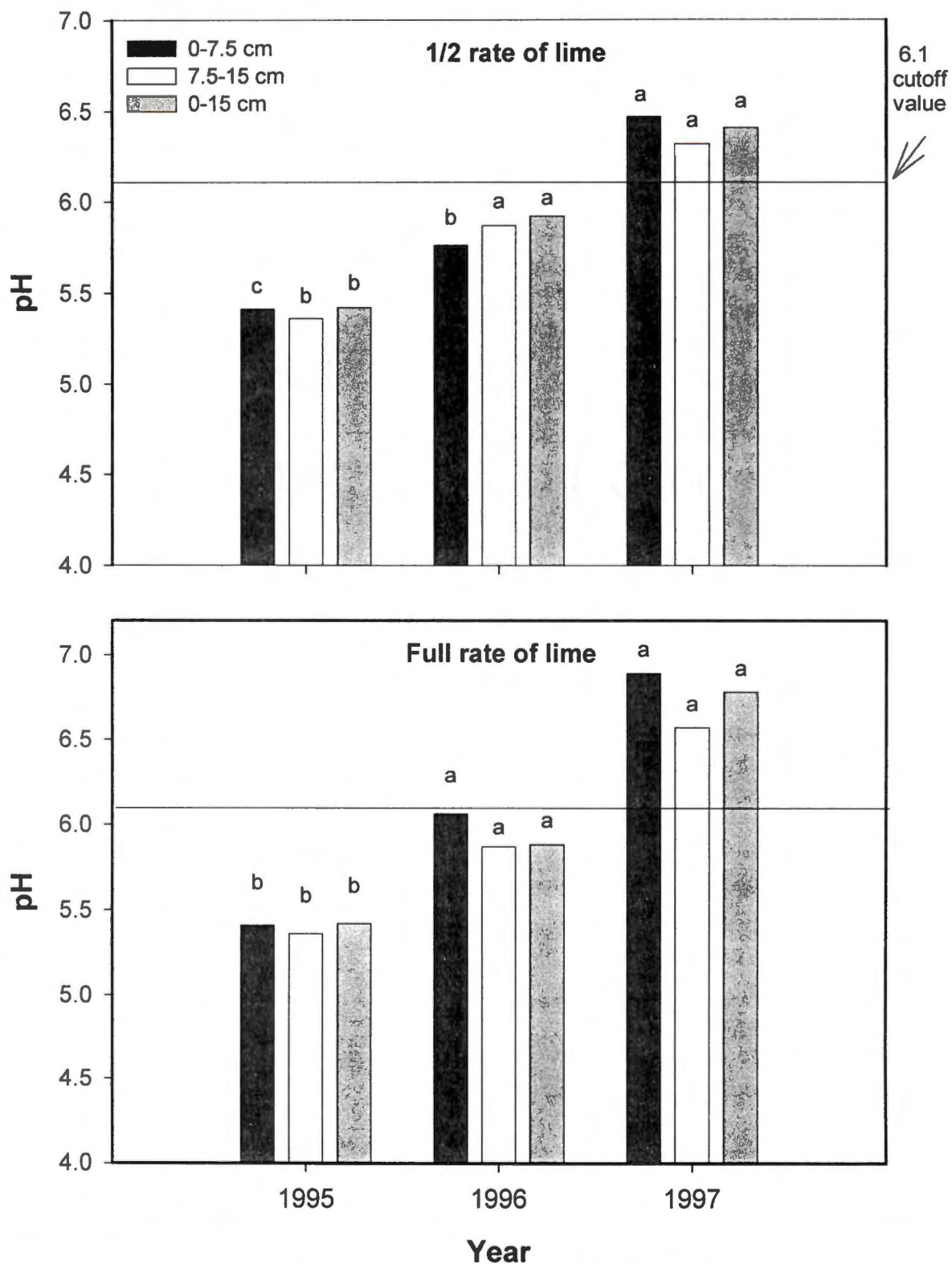


Figure 12. The effect of both rates of lime on the 67 kg N ha⁻¹ tilled treatments with a vetch cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

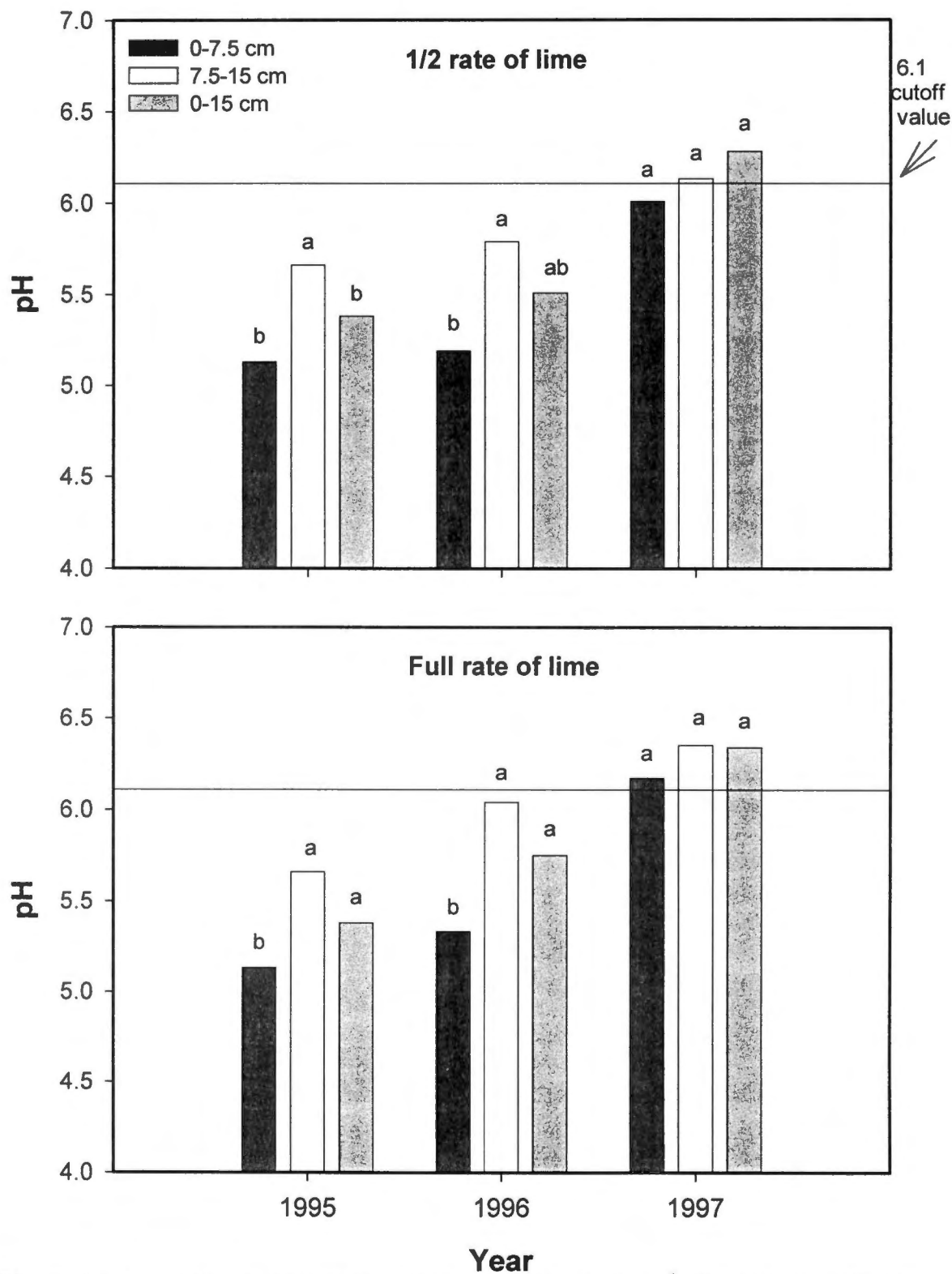


Figure 13. The effect of both rates of lime on the 101 kg N ha⁻¹ NT treatment with no cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

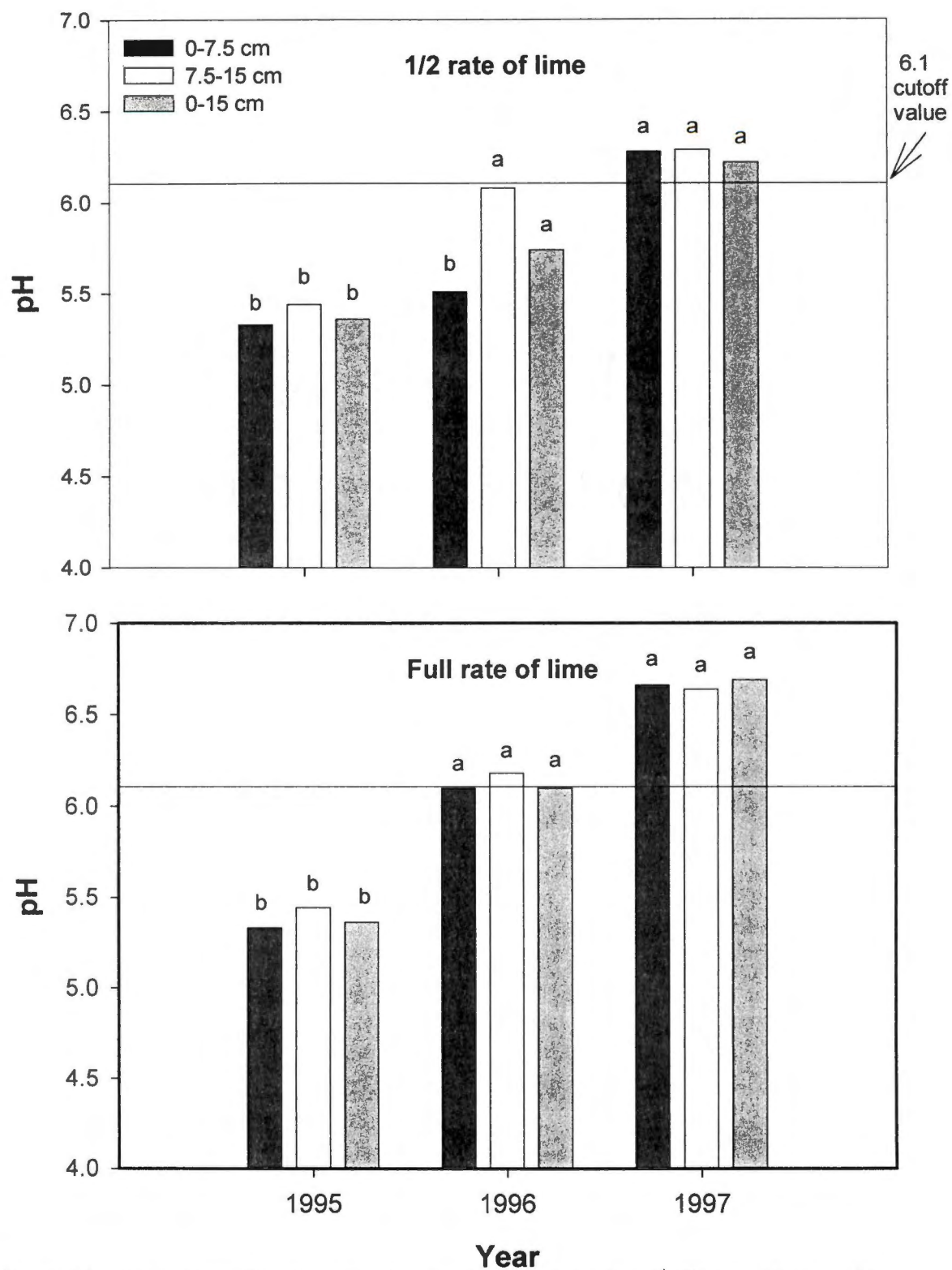


Figure 14. The effect of both rates of lime on the 101 kg N ha⁻¹ tilled treatment with no cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone

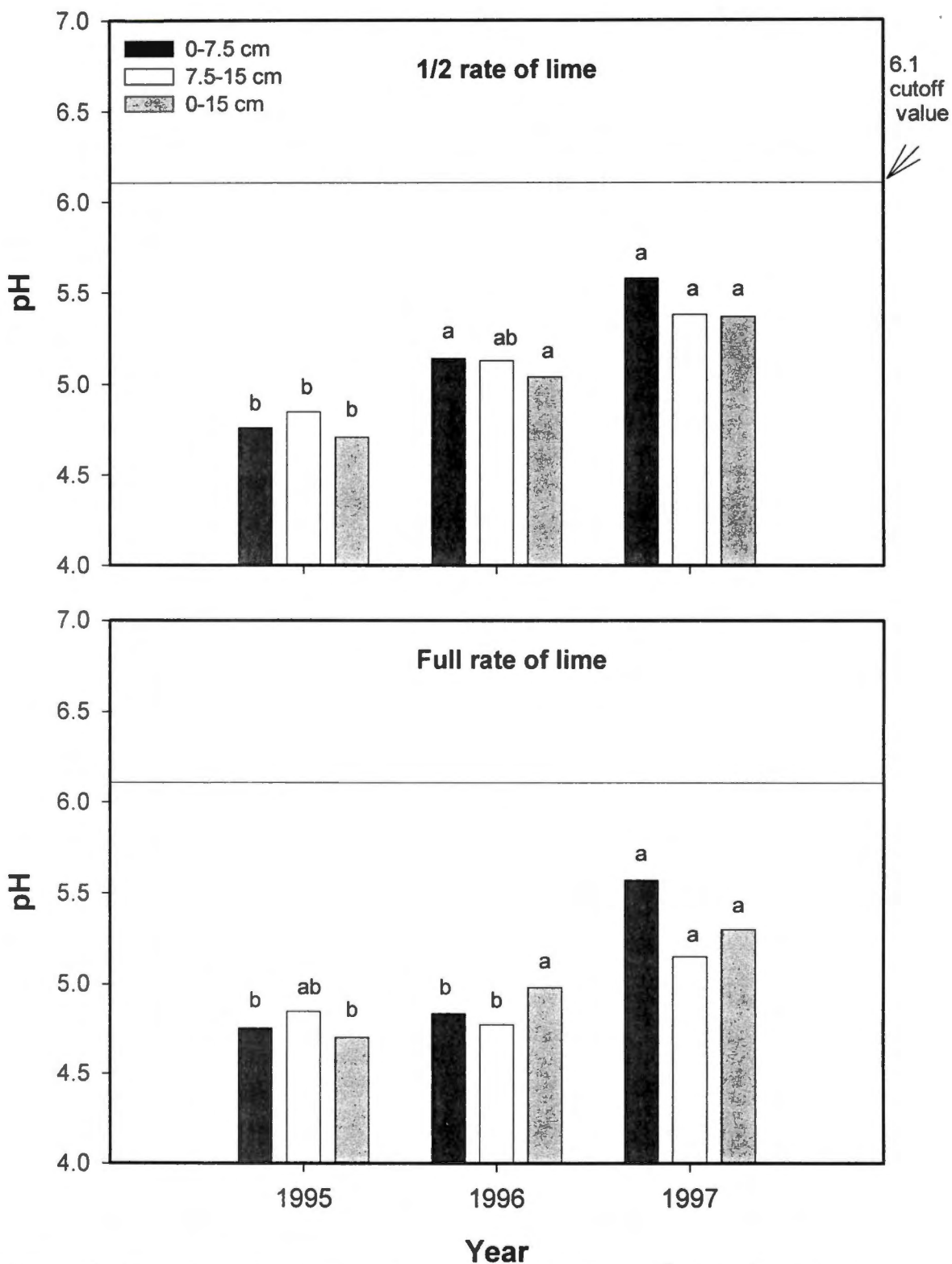


Figure 15. The effect of both rates of lime on the 101 kg N ha⁻¹ NT treatments with the vetch cover crop. Different letters represent differences at $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

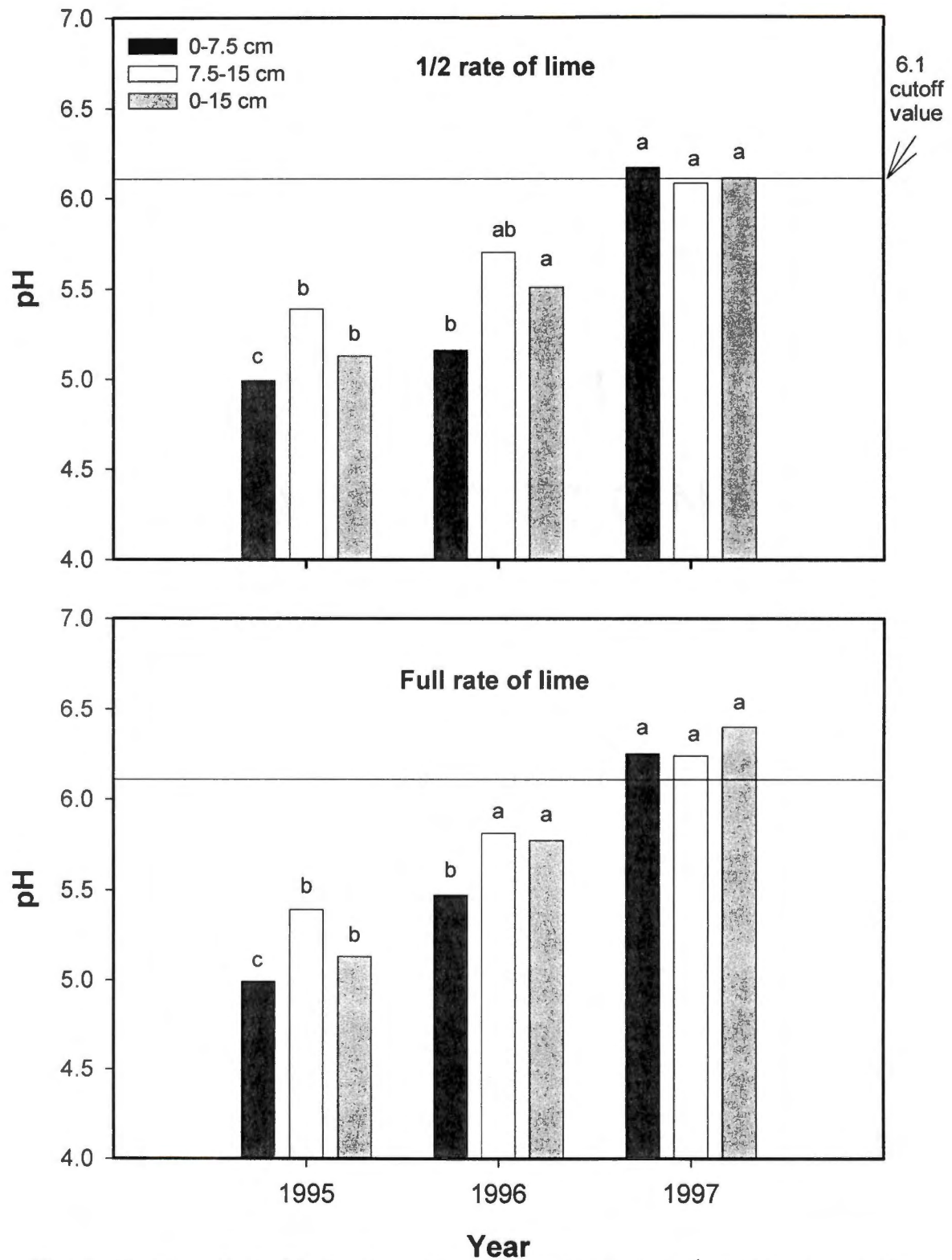


Figure 16. The effect of both rates of lime on the 101 kg N ha⁻¹ tilled treatment with vetch cover crop. Different letters represent differences at the $\alpha=0.05$ level within each lime rate for individual depths. The 6.1 cutoff value represents the minimum pH value that would not receive limestone.

<u>Treatment</u>	<u>LSD Grouping</u>
1995 NT 0 kg N/ha	cdefgh
1995 Till 0 kg N/ha	cdefgh
1995 NT 34 kg N/ha	bcd
1995 Till 34 kg N/ha	bcdefg
1995 NT 67 kg N/ha	bce
1995 Till 67 kg N/ha	bcdef
1995 NT 101 kg N/ha	a
1995 Till 101 kg N/ha	b
1996 NT 0 kg N/ha	fgh
1996 Till 0 kg N/ha	gh
1996 NT 34 kg N/ha	h
1996 Till 34 kg N/ha	efghi
1996 NT 67 kg N/ha	dfghi
1996 Till 67 kg N/ha	gh
1996 NT 101 kg N/ha	cdefgh
1996 Till 101 kg N/ha	cdefgh
1997 NT 0 kg N/ha	gh
1997 Till 0 kg N/ha	gh
1997 NT 34 kg N/ha	h
1997 Till 34 kg N/ha	fgh
1997 NT 67 kg N/ha	cdefgh
1997 Till 67 kg N/ha	gh
1997 NT 101 kg N/ha	cdefgh
1997 Till 101 kg N/ha	fgh

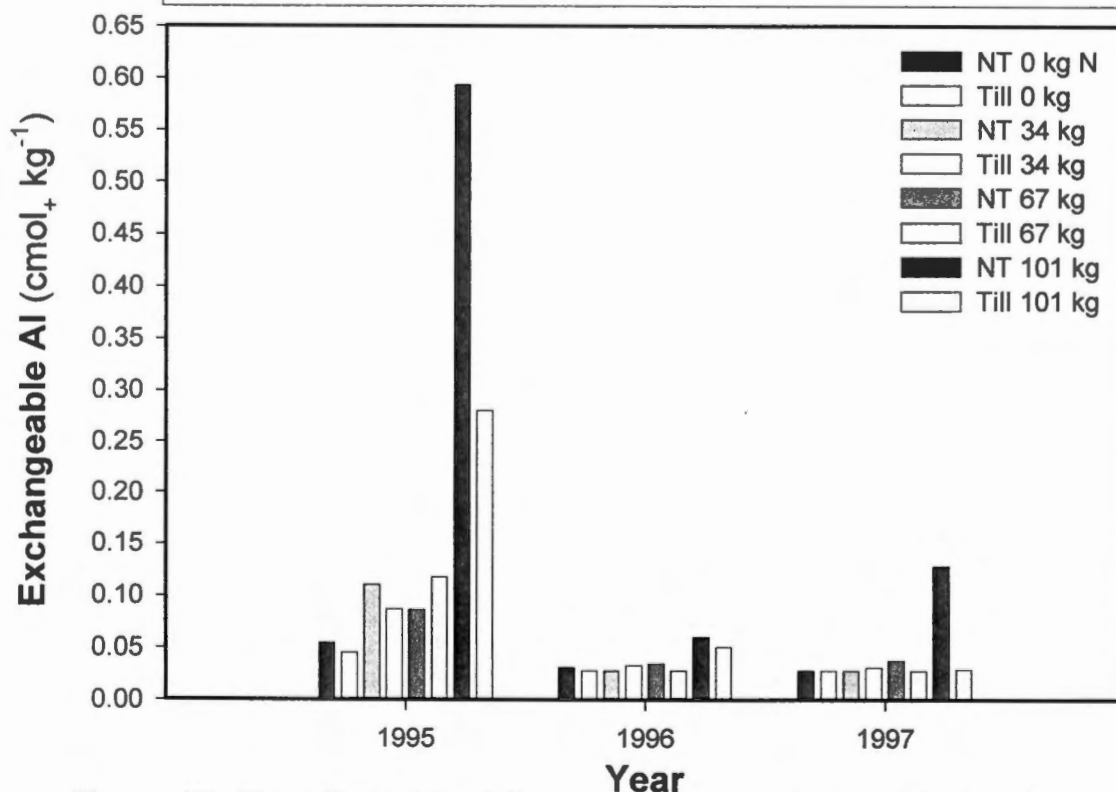


Figure 17. The effect of the full rate of lime on exchangeable Al values for all treatments in the vetch system at the 0-7.5 cm depth.

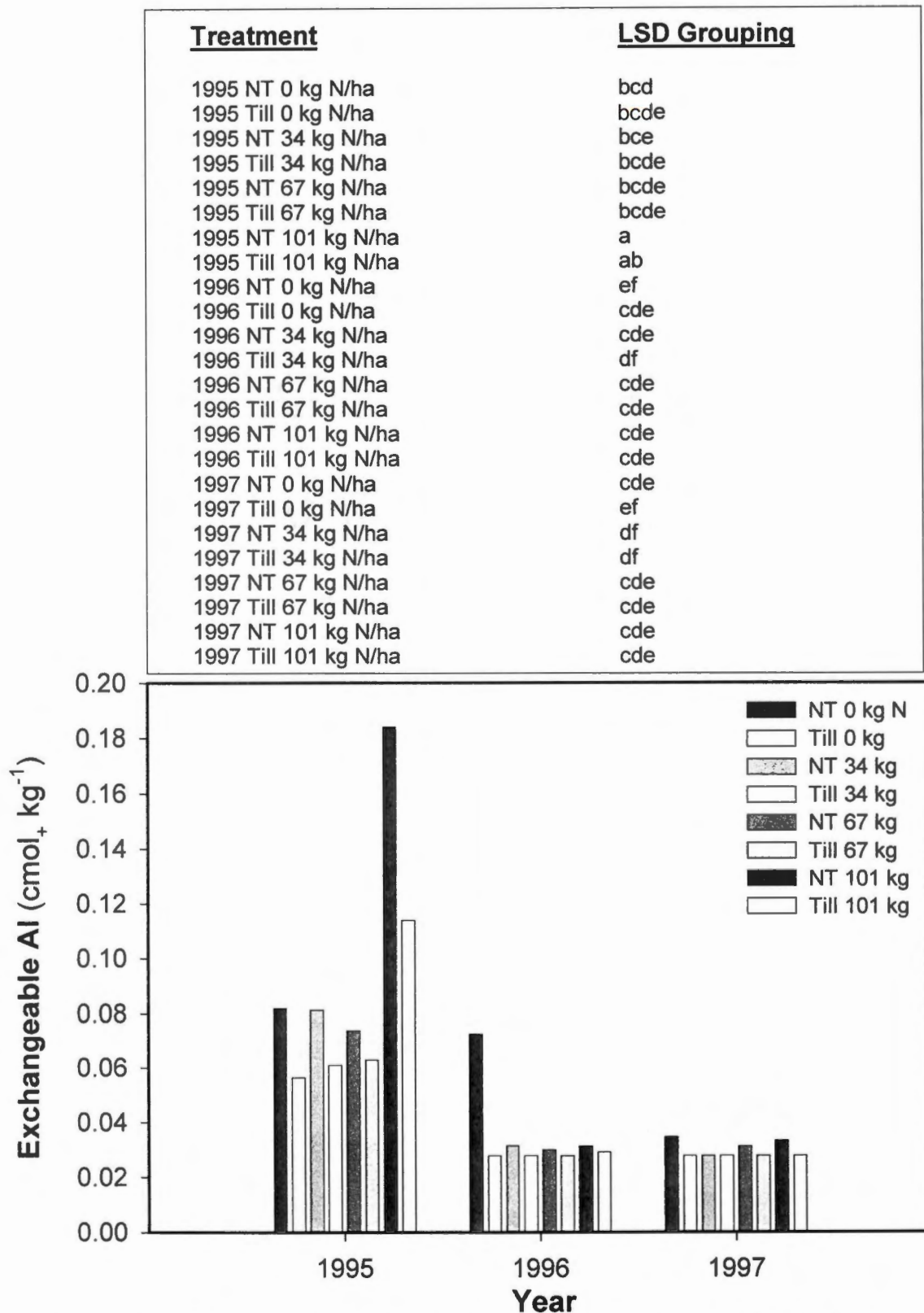


Figure 18. The effect of the full rate of limestone on exchangeable Al values for all treatments in the no cover system at the 0-7.5 cm depth.

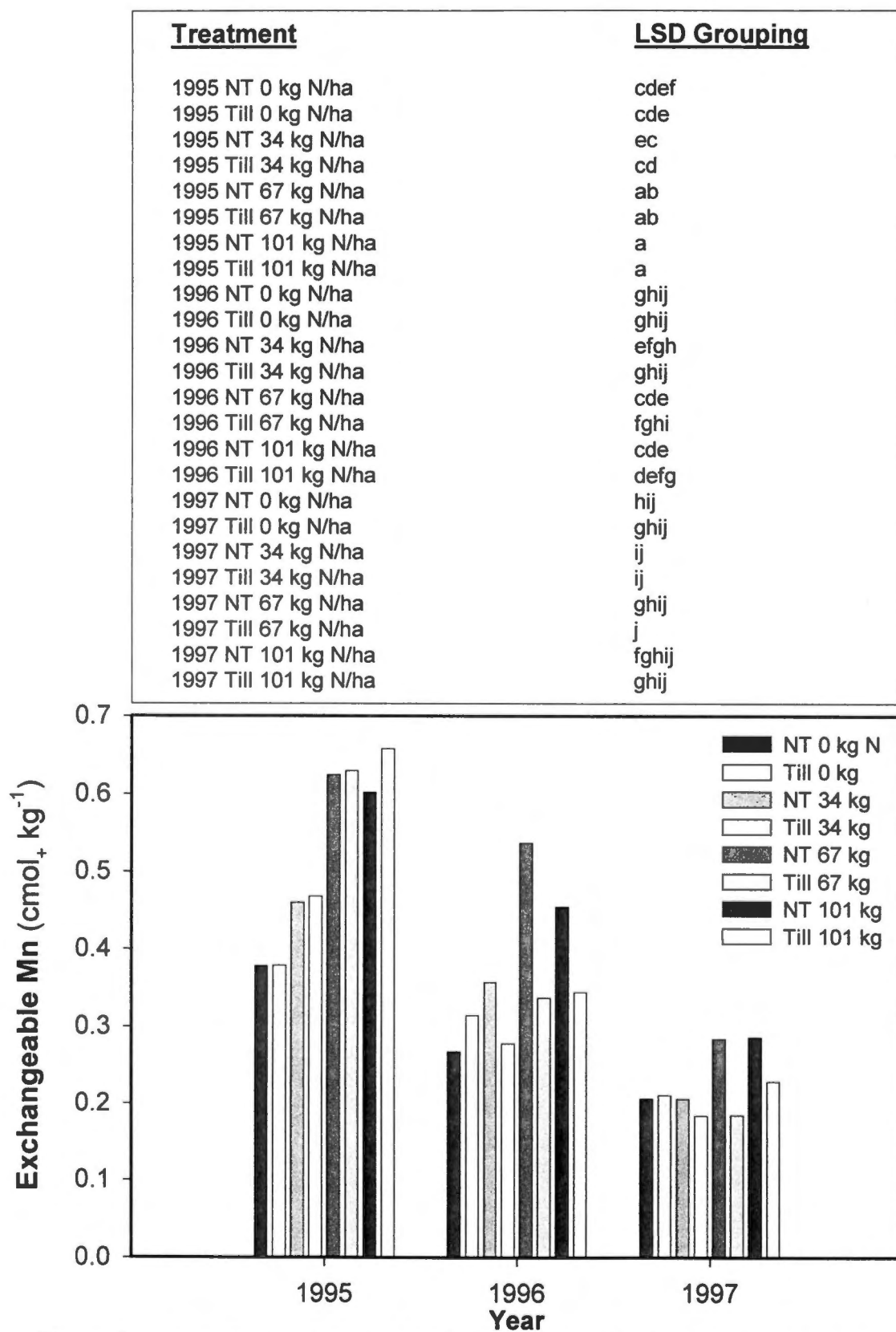


Figure 19. The effect of the full rate of limestone on NH_4OAc (pH 7) Mn values for all treatments in the vetch system at the 0-7.5 cm depth.

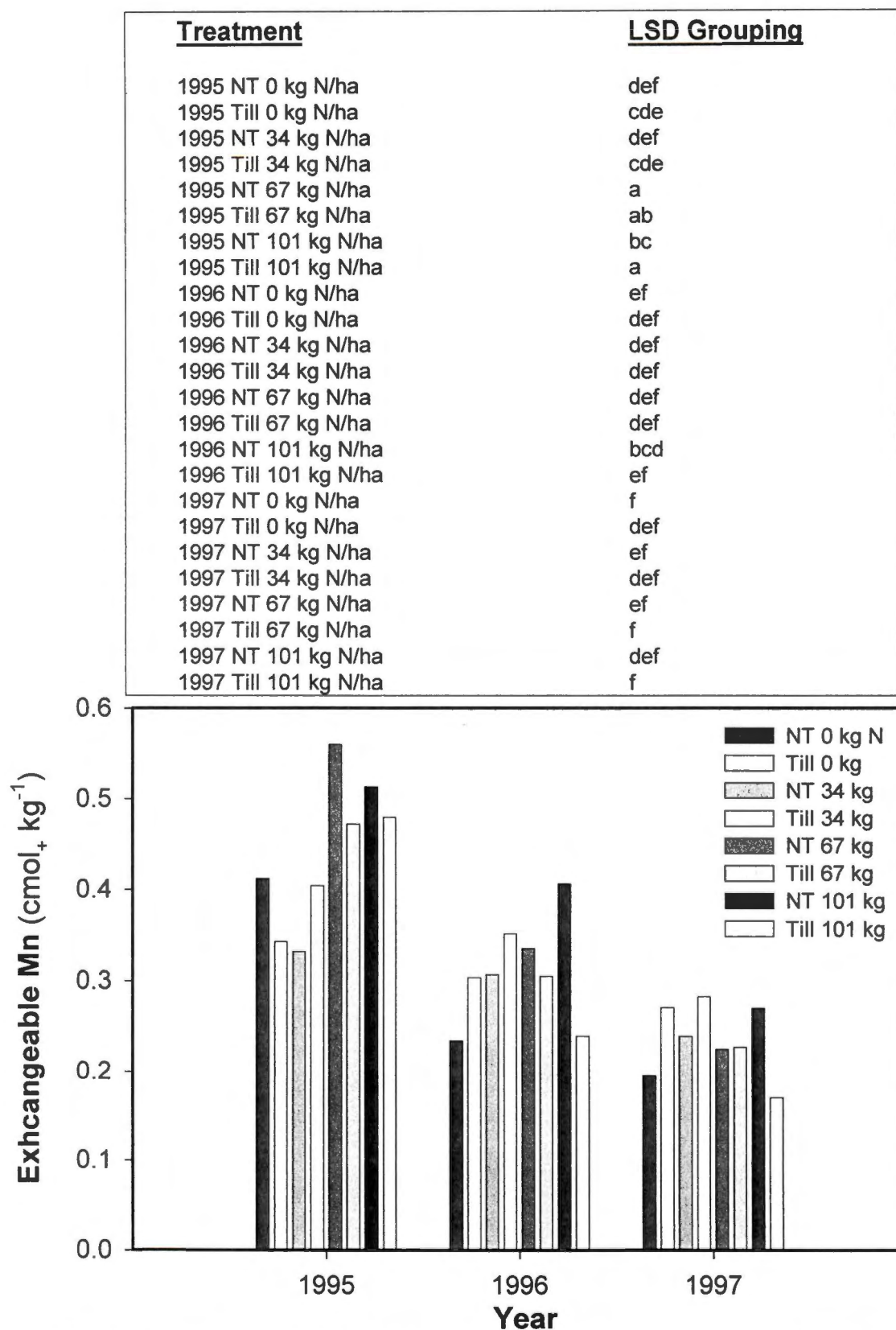


Figure 20. The effect of the full rate of limestone on NH_4OAc (pH 7) Mn values for all treatments in the no cover system at the 0-7.5 cm depth.

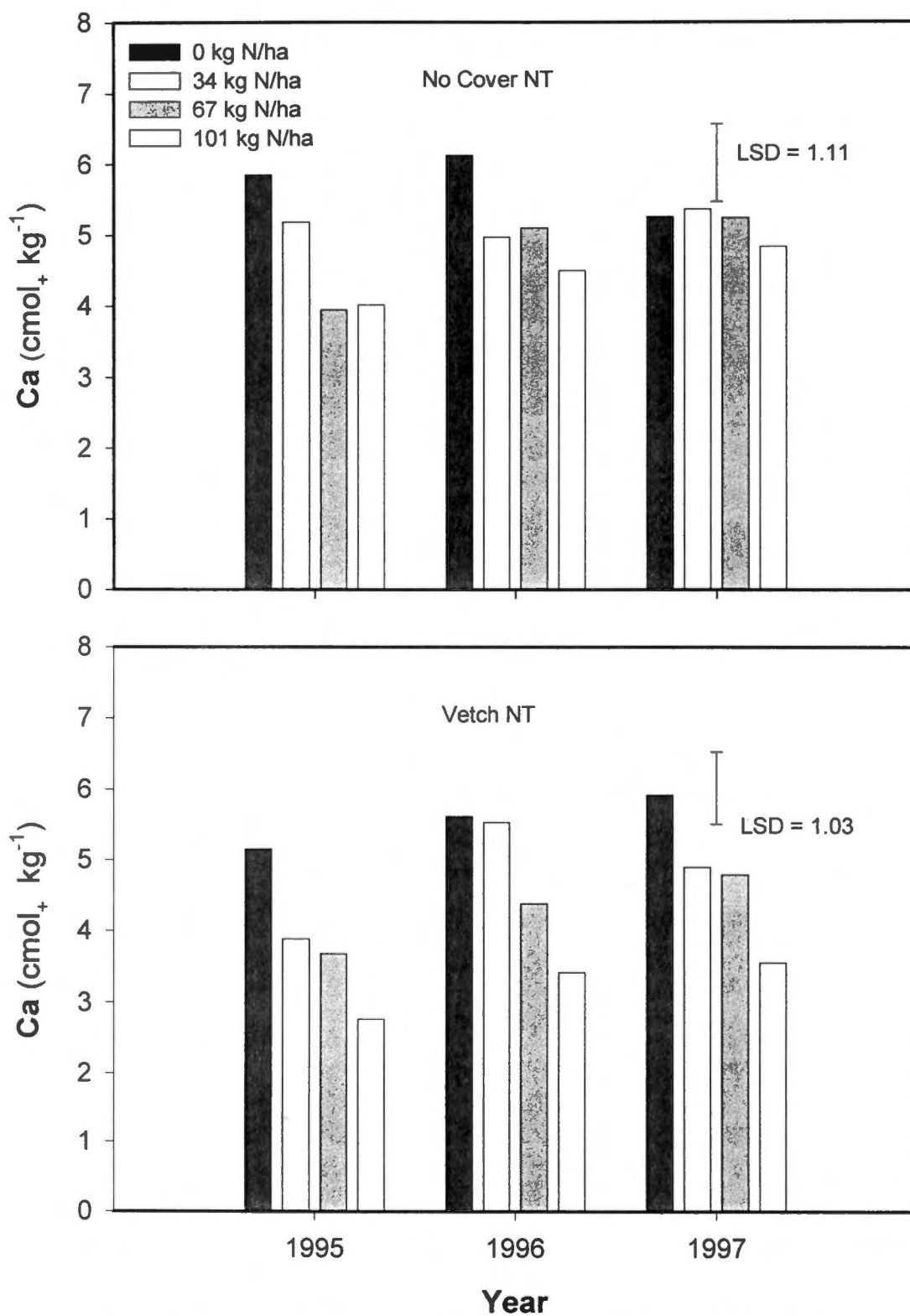


Figure 21. The effect of the full rate of limestone on Ca in the no cover and vetch NT systems at the 0-7.5 cm depth. LSD values represent differences at the $\alpha=0.05$ level within each cover.

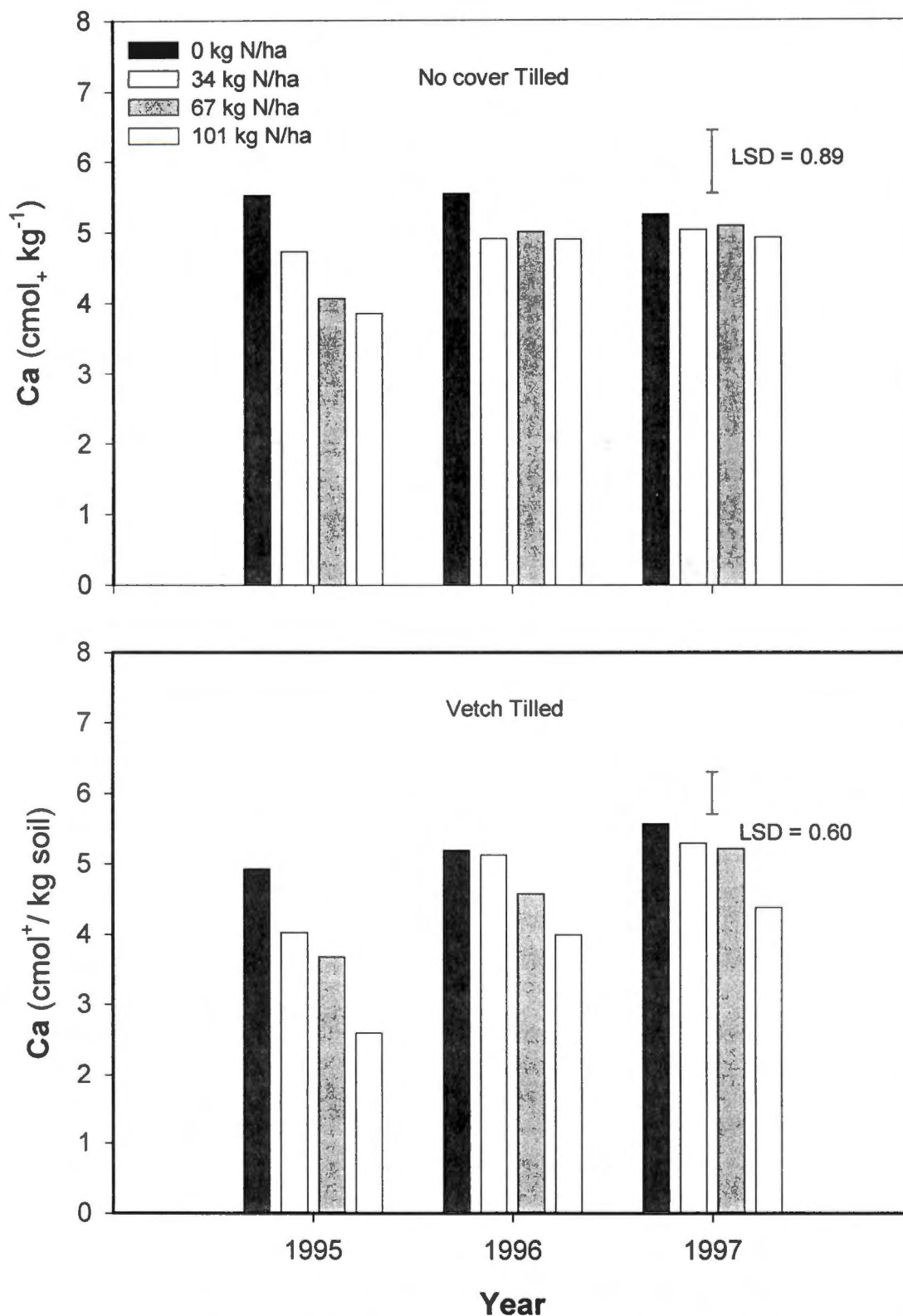


Figure 22. The effect of the full rate of limestone on Ca in the no cover and vetch tilled systems at the 0-7.5 cm depth. LSD values represent differences at the $\alpha=0.05$ level within each cover.

Appendix

List of Codes and Abbreviations

N-rate

0 = 0 kg N ha⁻¹
1 = 34 kg N ha⁻¹
2 = 67 kg N ha⁻¹
3 = 101 kg N ha⁻¹

Cover

0 = no cover
1 = vetch cover

Tillage

0 = no tillage
1 = disk tillage

Depth

1 = 0-7.5 cm
2 = 7.5-15 cm
3 = 0-15 cm

Lime rate

0 = ½ rate of limestone
1 = full rate of limestone

nd = no data

Table A1. 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
										cmol, kg ⁻¹		%	
1	0	0	0	0	1	69	1	7.516	1.187	0.358	0.086	12.603	72.579
1	0	0	0	0	1	69	2	7.427	1.011	0.297	0.103	13.233	66.783
1	0	0	0	1	1	70	1	7.516	1.187	0.358	0.086	12.603	72.579
1	0	0	0	1	1	70	2	7.427	1.011	0.297	0.103	13.233	66.783
1	0	0	0	0	2	125	1	4.689	0.761	0.425	0.104	11.244	53.174
1	0	0	0	0	2	125	2	5.463	0.561	0.217	0.139	10.447	61.074
1	0	0	0	1	2	126	1	4.689	0.761	0.425	0.104	11.244	53.174
1	0	0	0	1	2	126	2	5.463	0.561	0.217	0.139	10.447	61.074
1	0	0	0	0	3	175	1	5.451	0.866	0.732	0.049	12.409	57.206
1	0	0	0	0	3	175	2	4.378	0.593	0.461	0.055	12.241	44.817
1	0	0	0	1	3	176	1	5.451	0.866	0.732	0.049	12.409	57.206
1	0	0	0	1	3	176	2	4.378	0.593	0.461	0.055	12.241	44.817
1	0	0	0	0	4	213	1	5.749	0.835	0.404	0.056	9.880	71.291
1	0	0	0	0	4	213	2	5.793	0.553	0.172	0.052	9.219	71.249
1	0	0	0	1	4	214	1	5.749	0.835	0.404	0.056	9.880	71.291
1	0	0	0	1	4	214	2	5.793	0.553	0.172	0.052	9.219	71.249
3	0	0	1	0	1	71	1	6.330	1.191	0.436	0.063	10.981	73.048
3	0	0	1	0	1	71	2	6.717	1.048	0.323	0.067	11.676	69.843
3	0	0	1	1	1	72	1	6.330	1.191	0.436	0.063	10.981	73.048
3	0	0	1	1	1	72	2	6.717	1.048	0.323	0.067	11.676	69.843
3	0	0	1	0	2	127	1	5.348	0.843	0.361	0.096	11.063	60.104
3	0	0	1	0	2	127	2	5.583	0.654	0.217	0.124	9.678	67.974
3	0	0	1	1	2	128	1	5.348	0.843	0.361	0.096	11.063	60.104
3	0	0	1	1	2	128	2	5.583	0.654	0.217	0.124	9.678	67.974
3	0	0	1	0	3	173	1	5.202	0.745	0.578	0.043	12.131	54.141
3	0	0	1	0	3	173	2	4.645	0.500	0.280	0.041	11.082	49.328

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol.kg ⁻¹				%	
3	0	0	1	1	3	174	1	5.202	0.745	0.578	0.043	12.131	54.141
3	0	0	1	1	3	174	2	4.645	0.500	0.280	0.041	11.082	49.328
3	0	0	1	0	4	215	1	5.209	0.723	0.452	0.154	10.278	63.602
3	0	0	1	0	4	215	2	5.248	0.581	0.280	0.086	9.823	63.064
3	0	0	1	1	4	216	1	5.209	0.723	0.452	0.154	10.278	63.602
3	0	0	1	1	4	216	2	5.248	0.581	0.280	0.086	9.823	63.064
5	1	0	0	0	1	2	1	5.086	0.737	0.367	0.168	9.984	63.680
5	1	0	0	0	1	2	2	5.308	0.522	0.262	0.137	9.005	69.179
5	1	0	0	1	1	1	1	5.086	0.737	0.367	0.168	9.984	63.680
5	1	0	0	1	1	1	2	5.308	0.522	0.262	0.137	9.005	69.179
5	1	0	0	0	2	95	1	5.100	0.944	0.410	0.078	9.832	66.444
5	1	0	0	0	2	95	2	5.725	0.680	0.288	0.084	9.495	71.379
5	1	0	0	1	2	96	1	5.100	0.944	0.410	0.078	9.832	66.444
5	1	0	0	1	2	96	2	5.725	0.680	0.288	0.084	9.495	71.379
5	1	0	0	0	3	208	1	5.004	0.772	0.488	0.074	12.518	50.631
5	1	0	0	0	3	208	2	5.064	0.505	0.217	0.065	12.722	45.996
5	1	0	0	1	3	207	1	5.004	0.772	0.488	0.074	12.518	50.631
5	1	0	0	1	3	207	2	5.064	0.505	0.217	0.065	12.722	45.996
5	1	0	0	0	4	241	1	5.532	0.874	0.339	0.064	8.568	79.485
5	1	0	0	0	4	241	2	5.637	0.665	0.217	0.076	8.947	73.702
5	1	0	0	1	4	242	1	5.532	0.874	0.343	0.064	8.568	79.538
5	1	0	0	1	4	242	2	5.637	0.665	0.282	0.076	8.947	74.434
7	1	0	1	0	1	4	1	4.000	0.798	0.393	0.156	9.175	58.274
7	1	0	1	0	1	4	2	4.639	0.697	0.253	0.135	9.521	60.128
7	1	0	1	1	1	3	1	4.000	0.798	0.393	0.156	9.175	58.274
7	1	0	1	1	1	3	2	4.639	0.697	0.253	0.135	9.521	60.128

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol _c kg ⁻¹ -----				%	
7	1	0	1	0	2	93	1	4.568	0.927	0.393	0.146	9.326	64.700
7	1	0	1	0	2	93	2	5.580	0.628	0.262	0.130	8.840	74.664
7	1	0	1	1	2	94	1	4.568	0.927	0.393	0.146	9.326	64.700
7	1	0	1	1	2	94	2	5.580	0.628	0.262	0.130	8.840	74.664
7	1	0	1	0	3	205	1	4.671	0.687	0.361	0.064	10.951	52.813
7	1	0	1	0	3	205	2	5.814	0.580	0.226	0.094	11.376	59.020
7	1	0	1	1	3	206	1	4.671	0.687	0.361	0.064	10.951	52.813
7	1	0	1	1	3	206	2	5.814	0.580	0.226	0.094	11.376	59.020
7	1	0	1	0	4	243	1	5.644	0.870	0.352	0.065	10.006	69.267
7	1	0	1	0	4	243	2	5.428	0.652	0.226	0.064	8.604	74.030
7	1	0	1	1	4	244	1	5.644	0.870	0.352	0.065	10.006	69.267
7	1	0	1	1	4	244	2	5.428	0.652	0.226	0.064	8.604	74.030
9	2	0	0	0	1	112	1	3.512	0.732	0.380	0.075	9.738	48.253
9	2	0	0	0	1	112	2	3.347	0.489	0.226	0.086	8.462	49.019
9	2	0	0	1	1	111	1	3.512	0.732	0.380	0.075	9.738	48.253
9	2	0	0	1	1	111	2	3.347	0.489	0.226	0.086	8.462	49.019
9	2	0	0	0	2	17	1	4.137	0.907	0.410	0.181	11.029	51.093
9	2	0	0	0	2	17	2	4.452	0.633	0.288	0.143	9.815	56.205
9	2	0	0	1	2	18	1	4.137	0.907	0.410	0.181	11.029	51.093
9	2	0	0	1	2	18	2	4.452	0.633	0.288	0.143	9.815	56.205
9	2	0	0	0	3	233	1	4.844	0.553	0.289	0.101	10.945	52.865
9	2	0	0	0	3	233	2	5.888	0.391	0.127	0.087	9.781	66.379
9	2	0	0	1	3	234	1	4.844	0.553	0.289	0.101	10.945	52.865
9	2	0	0	1	3	234	2	5.888	0.391	0.127	0.087	9.781	66.379
9	2	0	0	0	4	153	1	3.310	0.640	0.371	0.070	10.096	43.486
9	2	0	0	0	4	153	2	4.558	0.611	0.208	0.065	9.285	58.605

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol _c kg ⁻¹					%
9	2	0	0	1	4	154	1	3.310	0.640	0.371	0.070	10.096	43.486
9	2	0	0	1	4	154	2	4.558	0.611	0.208	0.065	9.285	58.605
11	2	0	1	0	1	109	1	3.272	0.708	0.343	0.097	9.038	48.899
11	2	0	1	0	1	109	2	3.890	0.571	0.172	0.077	8.792	53.566
11	2	0	1	1	1	110	1	3.272	0.708	0.343	0.097	9.038	48.899
11	2	0	1	1	1	110	2	3.890	0.571	0.172	0.077	8.792	53.566
11	2	0	1	0	2	20	1	4.138	0.834	0.419	0.140	10.196	54.253
11	2	0	1	0	2	20	2	4.989	0.680	0.297	0.161	9.661	63.412
11	2	0	1	1	2	19	1	4.138	0.834	0.419	0.140	10.196	54.253
11	2	0	1	1	2	19	2	4.989	0.680	0.297	0.161	9.661	63.412
11	2	0	1	0	3	236	1	4.026	0.605	0.398	0.101	8.734	58.724
11	2	0	1	0	3	236	2	4.899	0.458	0.217	0.095	7.852	72.191
11	2	0	1	1	3	235	1	4.026	0.605	0.398	0.101	8.734	58.724
11	2	0	1	1	3	235	2	4.899	0.458	0.217	0.095	7.852	72.191
11	2	0	1	0	4	156	1	4.830	0.772	0.235	0.161	10.142	59.144
11	2	0	1	0	4	156	2	4.816	0.601	0.127	0.111	9.449	59.850
11	2	0	1	1	4	155	1	4.830	0.772	0.235	0.161	10.142	59.144
11	2	0	1	1	4	155	2	4.816	0.601	0.127	0.111	9.449	59.850
13	3	0	0	0	1	41	1	3.046	0.763	0.393	0.095	12.599	34.108
13	3	0	0	0	1	41	2	4.882	0.879	0.288	0.091	12.450	49.318
13	3	0	0	1	1	42	1	3.046	0.763	0.393	0.095	12.599	34.108
13	3	0	0	1	1	42	2	4.882	0.879	0.288	0.091	12.450	49.318
13	3	0	0	0	2	57	1	4.806	1.069	0.454	0.103	11.536	55.757
13	3	0	0	0	2	57	2	6.745	0.806	0.271	0.097	12.444	63.631
13	3	0	0	1	2	58	1	4.806	1.069	0.454	0.103	11.536	55.757
13	3	0	0	1	2	58	2	6.745	0.806	0.271	0.097	12.444	63.631

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
										cmol. kg ⁻¹			
													%
13	3	0	0	0	3	139	1	3.297	0.750	0.316	0.077	12.024	36.935
13	3	0	0	0	3	139	2	3.981	0.812	0.208	0.087	11.198	45.438
13	3	0	0	1	3	140	1	3.297	0.750	0.316	0.077	12.024	36.935
13	3	0	0	1	3	140	2	3.981	0.812	0.208	0.087	11.198	45.438
13	3	0	0	0	4	192	1	4.920	0.588	0.199	0.056	10.592	54.417
13	3	0	0	0	4	192	2	3.268	0.630	0.307	0.047	11.010	38.628
13	3	0	0	1	4	191	1	4.920	0.588	0.199	0.056	10.592	54.417
13	3	0	0	1	4	191	2	3.268	0.630	0.307	0.047	11.010	38.628
15	3	0	1	0	1	44	1	3.136	0.968	0.463	0.107	11.023	42.402
15	3	0	1	0	1	44	2	4.126	0.786	0.288	0.110	10.962	48.447
15	3	0	1	1	1	43	1	3.136	0.968	0.463	0.107	11.023	42.402
15	3	0	1	1	1	43	2	4.126	0.786	0.288	0.110	10.962	48.447
15	3	0	1	0	2	60	1	3.920	0.970	0.471	0.117	10.748	50.973
15	3	0	1	0	2	60	2	5.149	0.715	0.288	0.155	10.162	62.067
15	3	0	1	1	2	59	1	3.920	0.970	0.471	0.117	10.748	50.973
15	3	0	1	1	2	59	2	5.149	0.715	0.288	0.155	10.162	62.067
15	3	0	1	0	3	137	1	3.339	0.653	0.470	0.063	12.157	37.220
15	3	0	1	0	3	137	2	3.734	0.497	0.217	0.059	11.026	40.881
15	3	0	1	1	3	138	1	3.339	0.653	0.470	0.063	12.157	37.220
15	3	0	1	1	3	138	2	3.734	0.497	0.217	0.059	11.026	40.881
15	3	0	1	0	4	190	1	5.059	0.617	0.199	0.066	10.226	58.095
15	3	0	1	0	4	190	2	3.319	0.692	0.389	0.052	10.195	43.657
15	3	0	1	1	4	189	1	5.059	0.617	0.199	0.066	10.226	58.095
15	3	0	1	1	4	189	2	3.319	0.692	0.389	0.052	10.195	43.657
16	0	1	0	0	1	73	1	5.612	1.250	0.384	0.071	12.907	56.691
16	0	1	0	0	1	73	2	6.097	0.880	0.244	0.073	11.528	63.276

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol _c kg ⁻¹ -----					%
16	0	1	0	1	1	74	1	5.612	1.250	0.384	0.071	12.907	56.691
16	0	1	0	1	1	74	2	6.097	0.880	0.244	0.073	11.528	63.276
16	0	1	0	0	2	123	1	3.808	0.501	0.172	0.077	9.639	47.288
16	0	1	0	0	2	123	2	4.275	0.690	0.298	0.083	9.713	55.044
16	0	1	0	1	2	124	1	3.808	0.501	0.172	0.077	9.639	47.288
16	0	1	0	1	2	124	2	4.275	0.690	0.298	0.083	9.713	55.044
16	0	1	0	0	3	166	1	5.520	0.738	0.380	0.047	12.865	51.964
16	0	1	0	0	3	166	2	4.880	0.485	0.244	0.113	11.153	51.305
16	0	1	0	1	3	165	1	5.520	0.738	0.380	0.047	12.865	51.964
16	0	1	0	1	3	165	2	4.880	0.485	0.244	0.113	11.153	51.305
16	0	1	0	0	4	224	1	5.650	0.798	0.343	0.135	11.980	57.812
16	0	1	0	0	4	224	2	5.808	0.499	0.217	0.161	10.992	60.819
16	0	1	0	1	4	223	1	5.650	0.798	0.343	0.135	11.980	57.812
16	0	1	0	1	4	223	2	5.808	0.499	0.217	0.161	10.992	60.819
18	0	1	1	0	1	75	1	5.446	1.221	0.419	0.097	10.580	67.883
18	0	1	1	0	1	75	2	5.433	0.913	0.297	0.076	10.898	61.655
18	0	1	1	1	1	76	1	5.446	1.221	0.419	0.097	10.580	67.883
18	0	1	1	1	1	76	2	5.433	0.913	0.297	0.076	10.898	61.655
18	0	1	1	0	2	121	1	4.440	0.851	0.443	0.073	9.639	60.240
18	0	1	1	0	2	121	2	4.389	0.620	0.244	0.103	9.713	55.146
18	0	1	1	1	2	122	1	4.440	0.851	0.443	0.073	9.639	60.240
18	0	1	1	1	2	122	2	4.389	0.620	0.244	0.103	9.713	55.146
18	0	1	1	0	3	168	1	4.668	0.614	0.434	0.049	12.596	45.767
18	0	1	1	0	3	168	2	4.935	0.491	0.253	0.049	12.748	44.930
18	0	1	1	1	3	167	1	4.668	0.614	0.434	0.049	12.596	45.767
18	0	1	1	1	3	167	2	4.935	0.491	0.253	0.049	12.748	44.930

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol _c kg ⁻¹ -----				%	
18	0	1	1	0	4	221	1	5.138	0.858	0.488	0.092	11.777	55.835
18	0	1	1	0	4	221	2	5.258	0.651	0.280	0.099	11.023	57.050
18	0	1	1	1	4	222	1	5.138	0.858	0.488	0.092	11.777	55.835
18	0	1	1	1	4	222	2	5.258	0.651	0.280	0.099	11.023	57.050
19	1	1	0	0	1	7	1	3.800	0.728	0.436	0.115	9.844	51.592
19	1	1	0	0	1	7	2	3.430	0.525	0.314	0.144	8.099	54.479
19	1	1	0	1	1	8	1	3.800	0.728	0.436	0.115	9.844	51.592
19	1	1	0	1	1	8	2	3.430	0.525	0.314	0.144	8.099	54.479
19	1	1	0	0	2	81	1	3.556	0.889	0.410	0.084	11.362	43.470
19	1	1	0	0	2	81	2	3.893	0.646	0.279	0.083	10.207	48.014
19	1	1	0	1	2	82	1	3.556	0.889	0.410	0.084	11.362	43.470
19	1	1	0	1	2	82	2	3.893	0.646	0.279	0.083	10.207	48.014
19	1	1	0	0	3	202	1	4.009	0.679	0.262	0.048	12.042	41.504
19	1	1	0	0	3	202	2	4.883	0.449	0.117	0.064	10.557	52.221
19	1	1	0	1	3	201	1	4.009	0.679	0.262	0.048	12.042	41.504
19	1	1	0	1	3	201	2	4.883	0.449	0.117	0.064	10.557	52.221
19	1	1	0	0	4	251	1	4.200	0.709	0.443	0.076	10.443	51.972
19	1	1	0	0	4	251	2	4.009	0.513	0.230	0.069	9.030	53.400
19	1	1	0	1	4	252	1	4.200	0.709	0.443	0.076	10.443	51.972
19	1	1	0	1	4	252	2	4.009	0.513	0.230	0.069	9.030	53.400
20	1	1	1	0	1	6	1	3.420	0.848	0.445	0.149	9.173	53.011
20	1	1	1	0	1	6	2	3.588	0.735	0.340	0.161	9.037	53.388
20	1	1	1	1	1	5	1	3.420	0.848	0.445	0.149	9.173	53.011
20	1	1	1	1	1	5	2	3.588	0.735	0.340	0.161	9.037	53.388
20	1	1	1	0	2	83	1	4.409	1.081	0.393	0.074	10.714	55.607
20	1	1	1	0	2	83	2	5.217	0.874	0.271	0.074	11.062	58.181

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol. kg ⁻¹					%
20	1	1	1	1	2	84	1	4.409	1.081	0.393	0.074	10.714	55.607
20	1	1	1	1	2	84	2	5.217	0.874	0.271	0.074	11.062	58.181
20	1	1	1	0	3	203	1	3.533	0.693	0.398	0.067	10.960	42.793
20	1	1	1	0	3	203	2	3.882	0.485	0.199	0.065	11.062	41.859
20	1	1	1	1	3	204	1	3.533	0.693	0.398	0.067	10.960	42.793
20	1	1	1	1	3	204	2	3.882	0.485	0.199	0.065	11.062	41.859
20	1	1	1	0	4	250	1	4.725	0.758	0.443	0.069	9.702	61.791
20	1	1	1	0	4	250	2	4.795	0.640	0.262	0.079	9.050	63.820
20	1	1	1	1	4	249	1	4.725	0.758	0.438	0.069	9.702	61.745
20	1	1	1	1	4	249	2	4.795	0.640	0.262	0.079	9.050	63.820
21	2	1	0	0	1	101	1	4.115	0.730	0.340	0.081	12.779	41.207
21	2	1	0	0	1	101	2	4.523	0.639	0.288	0.093	9.890	56.047
21	2	1	0	1	1	102	1	4.115	0.730	0.340	0.081	12.779	41.207
21	2	1	0	1	1	102	2	4.523	0.639	0.288	0.093	9.890	56.047
21	2	1	0	0	2	31	1	3.691	0.740	0.489	0.136	11.950	42.304
21	2	1	0	0	2	31	2	4.301	0.646	0.306	0.125	9.771	55.040
21	2	1	0	1	2	32	1	3.691	0.740	0.489	0.136	11.950	42.304
21	2	1	0	1	2	32	2	4.301	0.646	0.306	0.125	9.771	55.040
21	2	1	0	0	3	240	1	3.777	0.687	0.283	0.108	9.008	53.905
21	2	1	0	0	3	240	2	4.442	0.515	0.163	0.095	7.870	66.262
21	2	1	0	1	3	239	1	3.777	0.687	0.283	0.102	9.008	53.829
21	2	1	0	1	3	239	2	4.442	0.515	0.163	0.095	7.870	66.262
21	2	1	0	0	4	157	1	3.126	0.694	0.322	0.121	10.292	41.426
21	2	1	0	0	4	157	2	3.605	0.555	0.181	0.105	8.924	49.826
21	2	1	0	1	4	158	1	3.092	0.694	0.322	0.121	10.292	41.093
21	2	1	0	1	4	158	2	3.605	0.555	0.181	0.105	8.924	49.826

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol. kg ⁻¹				%	
22	2	1	1	0	1	104	1	3.441	1.035	0.425	0.108	9.714	51.559
22	2	1	1	0	1	104	2	4.790	0.750	0.253	0.193	9.036	66.245
22	2	1	1	1	1	103	1	3.441	1.035	0.425	0.108	9.714	51.559
22	2	1	1	1	1	103	2	4.790	0.750	0.253	0.193	9.036	66.245
22	2	1	1	0	2	30	1	3.966	0.834	0.524	0.119	10.458	52.043
22	2	1	1	0	2	30	2	4.298	0.605	0.314	0.098	10.022	53.039
22	2	1	1	1	2	29	1	3.966	0.834	0.524	0.119	10.458	52.043
22	2	1	1	1	2	29	2	4.298	0.605	0.314	0.098	10.022	53.039
22	2	1	1	0	3	237	1	nd	0.002	0.036	0.016	8.887	nd
22	2	1	1	0	3	237	2	3.758	0.494	0.244	0.112	8.281	55.656
22	2	1	1	1	3	238	1	nd	0.002	0.036	0.016	8.887	nd
22	2	1	1	1	3	238	2	3.758	0.494	0.244	0.112	8.281	55.656
22	2	1	1	0	4	159	1	3.636	0.803	0.416	0.085	10.578	46.692
22	2	1	1	0	4	159	2	4.408	0.603	0.181	0.069	10.065	52.266
22	2	1	1	1	4	160	1	3.636	0.803	0.416	0.085	10.578	46.692
22	2	1	1	1	4	160	2	4.408	0.603	0.181	0.069	10.065	52.266
23	3	1	0	0	1	35	1	3.466	0.943	0.471	0.104	12.372	40.289
23	3	1	0	0	1	35	2	3.301	0.738	0.306	0.084	15.642	28.307
23	3	1	0	1	1	36	1	3.466	0.943	0.471	0.104	12.372	40.289
23	3	1	0	1	1	36	2	3.301	0.738	0.306	0.084	15.642	28.307
23	3	1	0	0	2	50	1	2.001	0.515	0.436	0.096	11.871	25.677
23	3	1	0	0	2	50	2	2.572	0.542	0.375	0.090	11.760	30.427
23	3	1	0	1	2	49	1	2.001	0.515	0.436	0.096	11.871	25.677
23	3	1	0	1	2	49	2	2.572	0.542	0.375	0.090	11.760	30.427
23	3	1	0	0	3	131	1	3.417	0.615	0.587	0.085	13.243	35.527
23	3	1	0	0	3	131	2	2.823	0.374	0.325	0.065	10.730	33.435

Table A1 (cont.) 1995 cation exchange capacity and percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol. kg ⁻¹ -----				%	
23	3	1	0	1	3	132	1	3.417	0.615	0.587	0.085	13.243	35.527
23	3	1	0	1	3	132	2	2.823	0.374	0.325	0.065	10.730	33.435
23	3	1	0	0	4	184	1	2.182	0.443	0.380	0.061	11.148	27.491
23	3	1	0	0	4	184	2	3.276	0.458	0.190	0.062	9.591	41.564
23	3	1	0	1	4	183	1	2.182	0.443	0.380	0.061	11.148	27.491
23	3	1	0	1	4	183	2	3.276	0.458	0.190	0.062	9.591	41.564
24	3	1	1	0	1	33	1	2.821	0.893	0.454	0.116	12.053	35.540
24	3	1	1	0	1	33	2	4.422	0.809	0.323	0.116	12.383	45.780
24	3	1	1	1	1	34	1	2.821	0.893	0.454	0.116	12.053	35.540
24	3	1	1	1	1	34	2	4.422	0.809	0.323	0.116	12.383	45.780
24	3	1	1	0	2	52	1	2.739	1.047	0.463	0.105	11.529	37.756
24	3	1	1	0	2	52	2	5.132	0.936	0.297	0.195	11.984	54.735
24	3	1	1	1	2	51	1	2.739	1.047	0.463	0.105	11.529	37.756
24	3	1	1	1	2	51	2	5.132	0.936	0.297	0.195	11.984	54.735
24	3	1	1	0	3	129	1	2.360	0.628	0.452	0.065	10.316	33.973
24	3	1	1	0	3	129	2	2.980	0.386	0.253	0.081	9.617	38.477
24	3	1	1	1	3	130	1	2.360	0.628	0.452	0.065	10.316	33.973
24	3	1	1	1	3	130	2	2.980	0.386	0.253	0.081	9.617	38.477
24	3	1	1	0	4	181	1	2.458	0.628	0.479	0.044	10.227	35.292
24	3	1	1	0	4	181	2	3.843	0.516	0.226	0.053	9.656	48.029
24	3	1	1	1	4	182	1	2.458	0.628	0.479	0.044	10.227	35.292
24	3	1	1	1	4	182	2	3.843	0.516	0.226	0.053	9.656	48.029

Table A2. 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol, kg ⁻¹ -----				%	
1	0	0	0	0	1	69	1	6.089	1.201	0.387	0.081	12.603	61.559
1	0	0	0	0	1	69	2	6.652	1.081	0.199	0.078	13.233	60.539
1	0	0	0	1	1	70	1	6.361	1.120	0.338	0.070	12.603	62.592
1	0	0	0	1	1	70	2	6.825	0.971	0.217	0.076	13.233	61.125
1	0	0	0	0	2	125	1	4.720	0.855	0.562	0.085	11.244	55.334
1	0	0	0	0	2	125	2	4.601	0.637	0.184	0.064	10.447	52.513
1	0	0	0	1	2	126	1	5.016	0.806	0.674	0.084	11.244	58.520
1	0	0	0	1	2	126	2	5.388	0.618	0.233	0.116	10.447	60.834
1	0	0	0	0	3	175	1	5.278	1.122	0.656	0.116	12.409	57.794
1	0	0	0	0	3	175	2	4.791	0.670	0.303	0.116	12.241	48.038
1	0	0	0	1	3	176	1	7.581	1.634	0.877	0.161	12.409	82.631
1	0	0	0	1	3	176	2	5.105	1.161	0.615	0.122	12.241	57.203
1	0	0	0	0	4	213	1	6.134	0.914	0.591	0.166	9.880	79.005
1	0	0	0	0	4	213	2	6.350	0.657	0.242	0.073	9.219	79.427
1	0	0	0	1	4	214	1	5.544	0.850	0.592	0.058	9.880	71.302
1	0	0	0	1	4	214	2	5.101	0.689	0.309	0.060	9.219	66.815
3	0	0	1	0	1	71	1	6.274	1.226	0.416	0.072	10.981	72.739
3	0	0	1	0	1	71	2	6.598	1.252	0.277	0.074	11.676	70.242
3	0	0	1	1	1	72	1	6.151	1.192	0.407	0.078	10.981	71.286
3	0	0	1	1	1	72	2	6.371	1.185	0.286	0.080	11.676	67.846
3	0	0	1	0	2	127	1	6.429	0.842	0.562	0.175	11.063	72.377
3	0	0	1	0	2	127	2	5.661	0.744	0.225	0.072	9.678	69.238
3	0	0	1	1	2	128	1	5.365	0.848	0.613	0.080	11.063	62.426
3	0	0	1	1	2	128	2	5.543	0.778	0.224	0.077	9.678	68.424
3	0	0	1	0	3	173	1	nd	nd	nd	nd	12.131	nd
3	0	0	1	0	3	173	2	nd	nd	nd	nd	11.082	nd

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
										-----cmol _c kg ⁻¹ -----			
													%
3	0	0	1	1	3	174	1	nd	nd	nd	nd	12.131	nd
3	0	0	1	1	3	174	2	nd	nd	nd	nd	11.082	nd
3	0	0	1	0	4	215	1	5.389	0.829	0.673	0.081	10.278	67.834
3	0	0	1	0	4	215	2	5.518	0.709	0.323	0.069	9.823	67.379
3	0	0	1	1	4	216	1	5.125	0.810	0.793	0.092	10.278	66.351
3	0	0	1	1	4	216	2	5.195	0.719	0.412	0.095	9.823	65.368
5	1	0	0	0	1	2	1	4.956	1.165	0.574	0.081	9.984	67.870
5	1	0	0	0	1	2	2	nd	nd	nd	nd	9.005	nd
5	1	0	0	1	1	1	1	4.842	1.179	0.513	0.064	9.984	66.089
5	1	0	0	1	1	1	2	4.531	0.718	0.246	0.053	9.005	61.614
5	1	0	0	0	2	95	1	4.727	0.833	0.497	0.083	9.832	62.448
5	1	0	0	0	2	95	2	5.760	0.764	0.269	0.089	9.495	72.484
5	1	0	0	1	2	96	1	4.758	0.991	0.572	0.093	9.832	65.247
5	1	0	0	1	2	96	2	5.800	0.779	0.199	0.085	9.495	72.274
5	1	0	0	0	3	208	1	5.912	1.437	0.753	0.070	12.518	65.281
5	1	0	0	0	3	208	2	5.157	0.826	0.390	0.086	12.722	50.772
5	1	0	0	1	3	207	1	4.992	1.222	0.605	0.080	12.518	55.108
5	1	0	0	1	3	207	2	4.676	0.651	0.228	0.074	12.722	44.247
5	1	0	0	0	4	241	1	5.875	0.927	0.443	0.087	8.568	85.567
5	1	0	0	0	4	241	2	5.784	0.639	0.208	0.080	8.947	75.002
5	1	0	0	1	4	242	1	5.282	0.876	0.587	0.123	8.568	80.156
5	1	0	0	1	4	242	2	5.361	0.745	0.235	0.068	8.947	71.624
7	1	0	1	0	1	4	1	4.470	1.273	0.564	0.068	9.175	69.482
7	1	0	1	0	1	4	2	4.425	1.115	0.298	0.061	9.521	61.954
7	1	0	1	1	1	3	1	5.106	1.341	0.636	0.060	9.175	77.840
7	1	0	1	1	1	3	2	nd	nd	nd	nd	9.521	nd

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol. kg ⁻¹				%	
7	1	0	1	0	2	93	1	5.325	0.894	0.580	0.158	9.326	74.594
7	1	0	1	0	2	93	2	4.906	0.770	0.225	0.069	8.840	67.546
7	1	0	1	1	2	94	1	4.938	0.883	0.615	0.091	9.326	69.974
7	1	0	1	1	2	94	2	4.994	0.793	0.225	0.074	8.840	68.841
7	1	0	1	0	3	205	1	4.657	0.955	0.631	0.091	10.951	57.838
7	1	0	1	0	3	205	2	4.763	0.827	0.282	0.087	11.376	52.385
7	1	0	1	1	3	206	1	4.766	0.801	0.578	0.086	10.951	56.895
7	1	0	1	1	3	206	2	4.694	0.686	0.417	0.086	11.376	51.712
7	1	0	1	0	4	243	1	5.079	0.880	0.614	0.072	10.006	66.409
7	1	0	1	0	4	243	2	nd	nd	nd	nd	8.604	nd
7	1	0	1	1	4	244	1	4.819	0.811	0.561	0.104	10.006	62.911
7	1	0	1	1	4	244	2	4.783	0.777	0.261	0.082	8.604	68.608
9	2	0	0	0	1	112	1	3.616	1.041	0.483	0.061	9.738	53.408
9	2	0	0	0	1	112	2	3.410	0.597	0.155	0.076	8.462	50.096
9	2	0	0	1	1	111	1	4.687	1.468	0.380	0.072	9.738	67.847
9	2	0	0	1	1	111	2	3.515	0.774	0.207	0.138	8.462	54.772
9	2	0	0	0	2	17	1	3.841	1.198	0.494	0.071	11.029	50.806
9	2	0	0	0	2	17	2	3.679	0.749	0.221	0.068	9.815	48.063
9	2	0	0	1	2	18	1	5.335	1.508	0.537	0.074	11.029	67.577
9	2	0	0	1	2	18	2	5.146	0.873	0.239	0.080	9.815	64.578
9	2	0	0	0	3	233	1	5.294	0.905	0.390	0.109	10.945	61.198
9	2	0	0	0	3	233	2	5.813	0.533	0.175	0.064	9.781	67.322
9	2	0	0	1	3	234	1	6.031	1.442	0.592	0.070	10.945	74.317
9	2	0	0	1	3	234	2	5.789	0.696	0.215	0.063	9.781	69.141
9	2	0	0	0	4	153	1	4.232	0.953	0.409	0.073	10.096	56.129
9	2	0	0	0	4	153	2	4.430	0.608	0.131	0.075	9.285	56.482

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol _c kg ⁻¹ -----				%	
9	2	0	0	1	4	154	1	4.350	1.161	0.525	0.076	10.096	60.532
9	2	0	0	1	4	154	2	4.207	0.693	0.180	0.077	9.285	55.549
11	2	0	1	0	1	109	1	4.462	1.174	0.406	0.122	9.038	68.200
11	2	0	1	0	1	109	2	4.210	0.733	0.078	0.075	8.792	57.947
11	2	0	1	1	1	110	1	4.736	1.438	0.414	0.078	9.038	73.770
11	2	0	1	1	1	110	2	4.359	0.938	0.121	0.072	8.792	62.430
11	2	0	1	0	2	20	1	5.785	1.541	0.579	0.075	10.196	78.258
11	2	0	1	0	2	20	2	7.315	1.177	0.222	0.188	9.661	92.137
11	2	0	1	1	2	19	1	5.550	1.104	0.290	0.157	10.196	69.638
11	2	0	1	1	2	19	2	5.813	1.262	0.179	0.081	9.661	75.915
11	2	0	1	0	3	236	1	4.528	1.120	0.686	0.082	8.734	73.461
11	2	0	1	0	3	236	2	4.915	0.808	0.269	0.066	7.852	77.150
11	2	0	1	1	3	235	1	5.585	1.303	0.713	0.078	8.734	87.920
11	2	0	1	1	3	235	2	5.531	0.943	0.242	0.065	7.852	86.356
11	2	0	1	0	4	156	1	3.539	1.095	0.543	0.107	10.142	52.099
11	2	0	1	0	4	156	2	3.732	0.866	0.205	0.073	9.449	51.594
11	2	0	1	1	4	155	1	4.162	1.117	0.541	0.123	10.142	58.599
11	2	0	1	1	4	155	2	nd	nd	nd	nd	9.449	nd
13	3	0	0	0	1	41	1	3.718	1.021	0.327	0.111	12.599	41.087
13	3	0	0	0	1	41	2	4.988	0.728	0.173	0.110	12.450	48.181
13	3	0	0	1	1	42	1	3.451	1.252	0.519	0.093	12.599	42.186
13	3	0	0	1	1	42	2	4.988	0.746	0.163	0.092	12.450	48.110
13	3	0	0	0	2	57	1	5.519	1.398	0.531	0.116	11.536	65.562
13	3	0	0	0	2	57	2	6.102	0.968	0.228	0.079	12.444	59.279
13	3	0	0	1	2	58	1	5.202	1.314	0.549	0.071	11.536	61.861
13	3	0	0	1	2	58	2	5.941	0.918	0.202	0.079	12.444	57.381

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol _c kg ⁻¹ -----				%	
13	3	0	0	0	3	139	1	3.208	0.841	0.483	0.076	12.024	38.327
13	3	0	0	0	3	139	2	4.216	0.516	0.238	0.066	11.198	44.958
13	3	0	0	1	3	140	1	4.424	1.204	0.385	0.065	12.024	50.543
13	3	0	0	1	3	140	2	4.464	0.669	0.180	0.059	11.198	47.975
13	3	0	0	0	4	192	1	4.008	1.127	0.663	0.115	10.592	55.821
13	3	0	0	0	4	192	2	4.677	0.764	0.213	0.081	11.010	52.091
13	3	0	0	1	4	191	1	4.919	1.032	0.450	0.104	10.592	61.420
13	3	0	0	1	4	191	2	5.640	0.611	0.188	0.111	11.010	59.501
15	3	0	1	0	1	44	1	5.173	1.266	0.307	0.176	11.023	62.797
15	3	0	1	0	1	44	2	6.052	1.133	0.212	0.103	10.962	68.409
15	3	0	1	1	1	43	1	5.077	1.396	0.355	0.096	11.023	62.811
15	3	0	1	1	1	43	2	5.084	1.070	0.211	0.099	10.962	58.967
15	3	0	1	0	2	60	1	4.765	1.348	0.582	0.080	10.748	63.036
15	3	0	1	0	2	60	2	4.896	0.920	0.228	0.077	10.162	60.240
15	3	0	1	1	2	59	1	5.577	1.612	0.523	0.076	10.748	72.462
15	3	0	1	1	2	59	2	5.358	0.998	0.245	0.091	10.162	65.847
15	3	0	1	0	3	137	1	3.850	0.957	0.570	0.107	12.157	45.106
15	3	0	1	0	3	137	2	4.045	0.691	0.216	0.062	11.026	45.482
15	3	0	1	1	3	138	1	4.526	1.384	0.639	0.082	12.157	54.541
15	3	0	1	1	3	138	2	4.290	0.987	0.254	0.068	11.026	50.789
15	3	0	1	0	4	190	1	3.982	1.083	0.712	0.104	10.226	57.515
15	3	0	1	0	4	190	2	4.677	0.771	0.238	0.091	10.195	56.659
15	3	0	1	1	4	189	1	4.594	1.535	0.606	0.090	10.226	66.751
15	3	0	1	1	4	189	2	4.565	0.860	0.229	0.106	10.195	56.496
16	0	1	0	0	1	73	1	6.705	1.471	0.441	0.156	12.907	67.966
16	0	1	0	0	1	73	2	6.252	1.003	0.190	0.090	11.528	65.368

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol _c kg ⁻¹ -----				%	
16	0	1	0	1	1	74	1	6.135	1.598	0.485	0.081	12.907	64.291
16	0	1	0	1	1	74	2	6.124	1.052	0.165	0.072	11.528	64.308
16	0	1	0	0	2	123	1	4.435	0.989	0.354	0.068	9.639	60.655
16	0	1	0	0	2	123	2	3.671	0.637	0.173	0.063	9.713	46.779
16	0	1	0	1	2	124	1	4.260	1.079	0.466	0.066	9.639	60.917
16	0	1	0	1	2	124	2	4.029	0.627	0.138	0.067	9.713	50.049
16	0	1	0	0	3	166	1	6.329	1.265	0.590	0.054	12.865	64.030
16	0	1	0	0	3	166	2	4.522	0.530	0.205	0.077	11.153	47.825
16	0	1	0	1	3	165	1	6.505	1.212	0.491	0.178	12.865	65.187
16	0	1	0	1	3	165	2	4.443	0.560	0.205	0.074	11.153	47.356
16	0	1	0	0	4	224	1	5.745	1.261	0.565	0.056	11.980	63.664
16	0	1	0	0	4	224	2	5.340	0.819	0.323	0.067	10.992	59.578
16	0	1	0	1	4	223	1	5.589	1.101	0.565	0.056	11.980	61.037
16	0	1	0	1	4	223	2	6.040	0.740	0.228	0.165	10.992	65.257
18	0	1	1	0	1	75	1	6.588	1.538	0.433	0.189	10.580	82.687
18	0	1	1	0	1	75	2	5.221	1.167	0.234	0.079	10.898	61.485
18	0	1	1	1	1	76	1	5.706	1.512	0.471	0.100	10.580	73.618
18	0	1	1	1	1	76	2	6.067	1.226	0.225	0.130	10.898	70.177
18	0	1	1	0	2	121	1	4.368	0.757	0.543	0.087	9.639	59.704
18	0	1	1	0	2	121	2	4.163	0.673	0.242	0.065	9.713	52.949
18	0	1	1	1	2	122	1	4.332	0.795	0.587	0.085	9.639	60.166
18	0	1	1	1	2	122	2	4.472	0.624	0.164	0.064	9.713	54.822
18	0	1	1	0	3	168	1	5.514	1.152	0.688	0.066	12.596	58.909
18	0	1	1	0	3	168	2	5.301	0.803	0.295	0.058	12.748	50.656
18	0	1	1	1	3	167	1	5.702	1.502	0.549	0.081	12.596	62.197
18	0	1	1	1	3	167	2	4.951	0.928	0.254	0.071	12.748	48.670

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol _c kg ⁻¹				%	
18	0	1	1	0	4	221	1	5.636	0.867	0.538	0.096	11.777	60.606
18	0	1	1	0	4	221	2	5.378	0.733	0.309	0.077	11.023	58.940
18	0	1	1	1	4	222	1	5.014	0.843	0.618	0.096	11.777	55.798
18	0	1	1	1	4	222	2	4.844	0.648	0.229	0.066	11.023	52.490
19	1	1	0	0	1	7	1	4.648	1.269	0.513	0.066	9.844	65.991
19	1	1	0	0	1	7	2	3.731	0.711	0.195	0.110	8.099	58.606
19	1	1	0	1	1	8	1	5.914	1.399	0.434	0.059	9.844	79.293
19	1	1	0	1	1	8	2	4.022	0.709	0.196	0.060	8.099	61.581
19	1	1	0	0	2	81	1	4.850	1.309	0.503	0.119	11.362	59.680
19	1	1	0	0	2	81	2	4.370	0.842	0.243	0.126	10.207	54.668
19	1	1	0	1	2	82	1	4.766	1.520	0.485	0.075	11.362	60.259
19	1	1	0	1	2	82	2	4.543	1.069	0.243	0.070	10.207	58.048
19	1	1	0	0	3	202	1	5.107	1.202	0.672	0.066	12.042	58.515
19	1	1	0	0	3	202	2	4.446	0.682	0.172	0.069	10.557	50.864
19	1	1	0	1	3	201	1	5.371	1.209	0.361	0.090	12.042	58.383
19	1	1	0	1	3	201	2	4.471	0.608	0.123	0.080	10.557	50.036
19	1	1	0	0	4	251	1	4.410	0.922	0.548	0.058	10.443	56.866
19	1	1	0	0	4	251	2	4.638	0.633	0.222	0.140	9.030	62.387
19	1	1	0	1	4	252	1	6.067	1.394	0.535	0.131	10.443	77.819
19	1	1	0	1	4	252	2	4.347	0.784	0.203	0.049	9.030	59.616
20	1	1	1	0	1	6	1	4.860	1.433	0.472	0.141	9.173	75.279
20	1	1	1	0	1	6	2	nd	nd	nd	nd	9.037	nd
20	1	1	1	1	1	5	1	4.231	1.655	0.338	0.076	9.173	68.688
20	1	1	1	1	1	5	2	nd	nd	nd	nd	9.037	nd
20	1	1	1	0	2	83	1	4.491	1.504	0.537	0.074	10.714	61.659
20	1	1	1	0	2	83	2	4.915	1.286	0.286	0.070	11.062	59.275

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol _c kg ⁻¹				%	
20	1	1	1	1	2	84	1	5.316	1.548	0.520	0.144	10.714	70.269
20	1	1	1	1	2	84	2	4.982	1.188	0.225	0.072	11.062	58.475
20	1	1	1	0	3	203	1	4.225	1.101	0.508	0.109	10.960	54.218
20	1	1	1	0	3	203	2	4.182	0.733	0.197	0.084	11.062	46.964
20	1	1	1	1	3	204	1	5.511	1.387	0.524	0.156	10.960	69.138
20	1	1	1	1	3	204	2	5.387	1.102	0.270	0.091	11.062	61.931
20	1	1	1	0	4	250	1	4.774	1.067	0.678	0.068	9.702	67.899
20	1	1	1	0	4	250	2	4.865	0.813	0.274	0.127	9.050	67.163
20	1	1	1	1	4	249	1	5.401	1.357	0.730	0.073	9.702	77.935
20	1	1	1	1	4	249	2	5.758	1.012	0.339	0.172	9.050	80.458
21	2	1	0	0	1	101	1	3.889	1.019	0.320	0.090	12.779	41.618
21	2	1	0	0	1	101	2	4.936	1.275	0.338	0.107	9.890	67.310
21	2	1	0	1	1	102	1	6.459	2.132	0.744	0.158	12.779	74.285
21	2	1	0	1	1	102	2	4.436	0.860	0.160	0.109	9.890	56.271
21	2	1	0	0	2	31	1	nd	nd	nd	nd	nd	nd
21	2	1	0	0	2	31	2	4.037	0.710	0.183	0.072	9.771	51.187
21	2	1	0	1	2	32	1	nd	nd	nd	nd	11.950	nd
21	2	1	0	1	2	32	2	3.316	0.905	0.192	0.071	9.771	45.893
21	2	1	0	0	3	240	1	4.485	1.245	0.404	0.066	9.008	68.830
21	2	1	0	0	3	240	2	4.930	0.724	0.144	0.067	7.870	74.526
21	2	1	0	1	3	239	1	3.805	1.175	0.496	0.088	9.008	61.763
21	2	1	0	1	3	239	2	3.588	0.676	0.235	0.076	7.870	58.130
21	2	1	0	0	4	157	1	nd	nd	nd	nd	10.292	nd
21	2	1	0	0	4	157	2	2.675	0.679	0.319	0.075	8.924	41.996
21	2	1	0	1	4	158	1	3.886	1.215	0.540	0.090	10.292	55.679
21	2	1	0	1	4	158	2	3.935	0.763	0.238	0.081	8.924	56.222

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol _c kg ⁻¹ -----					%
22	2	1	1	0	1	104	1	nd	nd	nd	nd	9.714	nd
22	2	1	1	0	1	104	2	4.787	0.992	0.158	0.092	9.036	66.719
22	2	1	1	1	1	103	1	4.466	1.710	0.481	0.108	9.714	69.652
22	2	1	1	1	1	103	2	4.239	1.088	0.211	0.096	9.036	62.345
22	2	1	1	0	2	30	1	4.515	1.211	0.615	0.058	10.458	61.189
22	2	1	1	0	2	30	2	nd	nd	nd	nd	10.022	nd
22	2	1	1	1	2	29	1	4.883	1.748	0.625	0.060	10.458	69.963
22	2	1	1	1	2	29	2	4.677	0.945	0.221	0.056	10.022	58.863
22	2	1	1	0	3	237	1	4.045	1.034	0.646	0.097	8.887	65.517
22	2	1	1	0	3	237	2	4.424	0.654	0.248	0.162	8.281	66.273
22	2	1	1	1	3	238	1	4.469	1.427	0.626	0.077	8.887	74.249
22	2	1	1	1	3	238	2	3.873	0.838	0.222	0.077	8.281	60.496
22	2	1	1	0	4	159	1	4.181	1.266	0.483	0.077	10.578	56.791
22	2	1	1	0	4	159	2	4.054	0.815	0.164	0.067	10.065	50.666
22	2	1	1	1	4	160	1	4.473	1.396	0.549	0.095	10.578	61.564
22	2	1	1	1	4	160	2	4.609	0.980	0.196	0.075	10.065	58.221
23	3	1	0	0	1	35	1	3.830	1.358	0.538	0.053	12.372	46.710
23	3	1	0	0	1	35	2	3.756	0.855	0.240	0.063	15.642	31.418
23	3	1	0	1	1	36	1	3.259	1.368	0.519	0.065	12.372	42.116
23	3	1	0	1	1	36	2	5.578	0.783	0.250	0.156	15.642	43.263
23	3	1	0	0	2	50	1	4.111	1.701	0.633	0.109	11.871	55.222
23	3	1	0	0	2	50	2	4.292	1.021	0.269	0.147	11.760	48.711
23	3	1	0	1	2	49	1	4.708	1.817	0.568	0.158	11.871	61.080
23	3	1	0	1	2	49	2	2.799	0.820	0.272	0.086	11.760	33.817
23	3	1	0	0	3	131	1	4.166	1.076	0.561	0.062	13.243	44.285
23	3	1	0	0	3	131	2	3.038	0.526	0.311	0.067	10.730	36.725

Table A2 (cont.) 1996 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol _c kg ⁻¹				%	
23	3	1	0	1	3	132	1	2.815	0.863	0.509	0.082	13.243	32.231
23	3	1	0	1	3	132	2	1.894	0.425	0.343	0.068	10.730	25.442
23	3	1	0	0	4	184	1	3.557	1.029	0.516	0.109	11.148	46.753
23	3	1	0	0	4	184	2	2.996	0.622	0.279	0.076	9.591	41.417
23	3	1	0	1	4	183	1	2.909	1.105	0.565	0.266	11.148	43.470
23	3	1	0	1	4	183	2	2.139	0.444	0.246	0.131	9.591	30.864
24	3	1	1	0	1	33	1	nd	nd	nd	nd	12.053	nd
24	3	1	1	0	1	33	2	4.730	0.987	0.173	0.070	12.383	48.126
24	3	1	1	1	1	34	1	4.155	1.679	0.528	0.063	12.053	53.310
24	3	1	1	1	1	34	2	4.410	1.300	0.250	0.053	12.383	48.560
24	3	1	1	0	2	52	1	3.536	1.400	0.586	0.088	11.529	48.668
24	3	1	1	0	2	52	2	4.959	1.231	0.211	0.158	11.984	54.726
24	3	1	1	1	2	51	1	3.995	1.709	0.442	0.087	11.529	54.057
24	3	1	1	1	2	51	2	6.388	1.584	0.202	0.191	11.984	69.796
24	3	1	1	0	3	129	1	2.677	1.079	0.466	0.094	10.316	41.836
24	3	1	1	0	3	129	2	2.982	0.783	0.138	0.061	9.617	41.220
24	3	1	1	1	3	130	1	4.072	1.373	0.708	0.101	10.316	60.622
24	3	1	1	1	3	130	2	3.770	0.945	0.225	0.068	9.617	52.068
24	3	1	1	0	4	181	1	3.628	1.341	0.582	0.093	10.227	55.186
24	3	1	1	0	4	181	2	4.113	0.990	0.213	0.092	9.656	56.005
24	3	1	1	1	4	182	1	3.722	1.327	0.623	0.105	10.227	56.487
24	3	1	1	1	4	182	2	4.521	0.874	0.205	0.171	9.656	59.761

Table A3. 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
-----cmol. kg ⁻¹ -----													%
1	0	0	0	0	1	69	1	5.952	1.246	0.346	0.082	12.603	60.518
1	0	0	0	0	1	69	2	6.359	1.113	0.183	0.089	13.233	58.522
1	0	0	0	1	1	70	1	6.513	1.076	0.317	0.078	12.603	63.353
1	0	0	0	1	1	70	2	6.940	0.934	0.096	0.085	13.233	60.872
1	0	0	0	0	2	125	1	3.104	1.187	0.394	0.066	11.244	42.255
1	0	0	0	0	2	125	2	3.439	1.047	0.212	0.058	10.447	45.515
1	0	0	0	1	2	126	1	3.490	1.057	0.192	0.060	11.244	42.683
1	0	0	0	1	2	126	2	3.450	1.041	0.211	0.065	10.447	45.632
1	0	0	0	0	3	175	1	5.271	1.330	0.630	0.048	12.409	58.670
1	0	0	0	0	3	175	2	4.223	0.581	0.288	0.046	12.241	41.967
1	0	0	0	1	3	176	1	5.706	1.615	0.598	0.036	12.409	64.105
1	0	0	0	1	3	176	2	4.230	0.774	0.354	0.051	12.241	44.181
1	0	0	0	0	4	213	1	5.400	0.796	0.443	0.055	9.880	67.750
1	0	0	0	0	4	213	2	5.624	0.587	0.199	0.053	9.219	70.108
1	0	0	0	1	4	214	1	5.335	0.762	0.432	0.048	9.880	66.569
1	0	0	0	1	4	214	2	5.142	0.584	0.221	0.057	9.219	65.125
3	0	0	1	0	1	71	1	6.140	1.185	0.355	0.075	10.981	70.619
3	0	0	1	0	1	71	2	7.338	1.319	0.154	0.091	11.676	76.242
3	0	0	1	1	1	72	1	6.207	1.170	0.298	0.071	10.981	70.528
3	0	0	1	1	1	72	2	6.695	1.178	0.173	0.080	11.676	69.603
3	0	0	1	0	2	127	1	4.495	1.430	0.298	0.058	11.063	56.775
3	0	0	1	0	2	127	2	4.490	1.134	0.173	0.056	9.678	60.477
3	0	0	1	1	2	128	1	5.004	1.721	0.394	0.042	11.063	64.725
3	0	0	1	1	2	128	2	4.953	1.300	0.202	0.057	9.678	67.277
3	0	0	1	0	3	173	1	4.977	0.907	0.542	0.045	12.131	53.352
3	0	0	1	0	3	173	2	4.824	0.638	0.310	0.047	11.082	52.507

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol _c kg ⁻¹				%	
3	0	0	1	1	3	174	1	4.662	0.764	0.465	0.058	12.131	49.048
3	0	0	1	1	3	174	2	4.736	0.638	0.299	0.055	11.082	51.684
3	0	0	1	0	4	215	1	5.633	0.813	0.576	0.131	10.278	69.596
3	0	0	1	0	4	215	2	5.263	0.687	0.388	0.043	9.823	64.961
3	0	0	1	1	4	216	1	5.135	0.839	0.642	0.049	10.278	64.840
3	0	0	1	1	4	216	2	4.938	0.673	0.421	0.097	9.823	62.392
5	1	0	0	0	1	2	1	5.698	1.560	0.531	0.066	9.984	78.674
5	1	0	0	0	1	2	2	nd	nd	nd	nd	9.005	nd
5	1	0	0	1	1	1	1	5.020	1.321	0.444	0.077	9.984	68.737
5	1	0	0	1	1	1	2	4.872	0.892	0.249	0.123	9.005	68.149
5	1	0	0	0	2	95	1	5.172	0.832	0.346	0.066	9.832	65.250
5	1	0	0	0	2	95	2	5.508	0.641	0.192	0.076	9.495	67.584
5	1	0	0	1	2	96	1	5.311	1.007	0.461	0.125	9.832	70.217
5	1	0	0	1	2	96	2	5.268	0.775	0.211	0.072	9.495	66.632
5	1	0	0	0	3	208	1	5.517	1.515	0.476	0.041	12.518	60.301
5	1	0	0	0	3	208	2	5.217	0.814	0.232	0.050	12.722	49.621
5	1	0	0	1	3	207	1	6.029	1.770	0.487	0.052	12.518	66.610
5	1	0	0	1	3	207	2	5.115	0.784	0.277	0.055	12.722	48.981
5	1	0	0	0	4	241	1	5.073	0.844	0.355	0.046	8.568	73.734
5	1	0	0	0	4	241	2	5.374	0.655	0.209	0.061	8.947	70.391
5	1	0	0	1	4	242	1	5.073	0.841	0.459	0.056	8.568	75.042
5	1	0	0	1	4	242	2	5.502	0.681	0.240	0.055	8.947	72.397
7	1	0	1	0	1	4	1	4.870	1.463	0.422	0.067	9.175	74.364
7	1	0	1	0	1	4	2	5.236	1.346	0.238	0.109	9.521	72.778
7	1	0	1	1	1	3	1	5.955	1.845	0.596	0.057	9.175	92.125
7	1	0	1	1	1	3	2	5.611	1.382	0.423	0.054	9.521	78.461

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol, kg ⁻¹				%	
7	1	0	1	0	2	93	1	4.529	0.809	0.423	0.064	9.326	62.466
7	1	0	1	0	2	93	2	4.883	0.721	0.212	0.064	8.840	66.521
7	1	0	1	1	2	94	1	4.837	0.882	0.394	0.062	9.326	66.211
7	1	0	1	1	2	94	2	5.001	0.702	0.224	0.075	8.840	67.898
7	1	0	1	0	3	205	1	4.787	1.157	0.443	0.049	10.951	58.763
7	1	0	1	0	3	205	2	4.735	0.852	0.243	0.056	11.376	51.744
7	1	0	1	1	3	206	1	4.485	0.712	0.409	0.051	10.951	51.658
7	1	0	1	1	3	206	2	5.010	0.639	0.232	0.120	11.376	52.754
7	1	0	1	0	4	243	1	5.150	0.869	0.532	0.050	10.006	65.978
7	1	0	1	0	4	243	2	5.031	0.741	0.271	0.070	8.604	71.062
7	1	0	1	1	4	244	1	4.827	0.848	0.469	0.047	10.006	61.878
7	1	0	1	1	4	244	2	4.793	0.773	0.292	0.052	8.604	68.696
9	2	0	0	0	1	112	1	5.805	1.483	0.375	0.068	9.738	79.378
9	2	0	0	0	1	112	2	4.111	0.743	0.240	0.065	8.462	60.963
9	2	0	0	1	1	111	1	4.406	1.107	0.356	0.073	9.738	61.018
9	2	0	0	1	1	111	2	3.595	0.665	0.192	0.064	8.462	53.373
9	2	0	0	0	2	17	1	3.883	1.361	0.452	0.054	11.029	52.141
9	2	0	0	0	2	17	2	2.839	0.641	0.259	0.065	9.815	38.762
9	2	0	0	1	2	18	1	5.606	1.934	0.356	0.102	11.029	72.522
9	2	0	0	1	2	18	2	5.323	1.164	0.221	0.083	9.815	69.184
9	2	0	0	0	3	233	1	5.703	1.467	0.313	0.042	10.945	68.748
9	2	0	0	0	3	233	2	4.870	0.687	0.198	0.041	9.781	59.255
9	2	0	0	1	3	234	1	5.520	1.394	0.365	0.108	10.945	67.488
9	2	0	0	1	3	234	2	5.617	0.603	0.198	0.071	9.781	66.345
9	2	0	0	0	4	153	1	4.184	1.033	0.384	0.055	10.096	56.017
9	2	0	0	0	4	153	2	4.970	1.313	0.407	0.057	9.285	72.664

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol. kg ⁻¹				%	
9	2	0	0	1	4	154	1	5.423	0.821	0.244	0.067	10.096	64.934
9	2	0	0	1	4	154	2	4.599	0.857	0.256	0.057	9.285	62.120
11	2	0	1	0	1	109	1	4.508	0.755	0.375	0.071	9.038	63.169
11	2	0	1	0	1	109	2	4.550	0.652	0.221	0.086	8.792	62.653
11	2	0	1	1	1	110	1	5.006	0.845	0.394	0.086	9.038	70.055
11	2	0	1	1	1	110	2	4.943	0.685	0.250	0.066	8.792	67.616
11	2	0	1	0	2	20	1	4.551	1.520	0.327	0.051	10.196	63.242
11	2	0	1	0	2	20	2	4.908	1.072	0.202	0.062	9.661	64.616
11	2	0	1	1	2	19	1	5.231	1.848	0.403	0.051	10.196	73.889
11	2	0	1	1	2	19	2	5.404	1.404	0.211	0.079	9.661	73.461
11	2	0	1	0	3	236	1	4.721	1.288	0.428	0.051	8.734	74.284
11	2	0	1	0	3	236	2	5.212	0.928	0.240	0.111	7.852	82.664
11	2	0	1	1	3	235	1	5.882	1.741	0.428	0.051	8.734	92.746
11	2	0	1	1	3	235	2	5.589	1.203	0.292	0.104	7.852	91.543
11	2	0	1	0	4	156	1	3.745	1.221	0.418	0.051	10.142	53.585
11	2	0	1	0	4	156	2	4.100	1.002	0.248	0.052	9.449	57.168
11	2	0	1	1	4	155	1	4.238	1.382	0.418	0.044	10.142	59.965
11	2	0	1	1	4	155	2	4.042	1.029	0.232	0.052	9.449	56.668
13	3	0	0	0	1	41	1	4.402	1.690	0.366	0.090	12.599	51.966
13	3	0	0	0	1	41	2	4.389	0.792	0.183	0.066	12.450	43.620
13	3	0	0	1	1	42	1	3.989	1.746	0.365	0.061	12.599	48.904
13	3	0	0	1	1	42	2	4.575	1.048	0.182	0.075	12.450	47.232
13	3	0	0	0	2	57	1	5.944	1.678	0.394	0.054	11.536	69.956
13	3	0	0	0	2	57	2	6.302	1.051	0.211	0.069	12.444	61.343
13	3	0	0	1	2	58	1	5.173	1.549	0.404	0.055	11.536	62.244
13	3	0	0	1	2	58	2	5.846	0.890	0.202	0.052	12.444	56.166

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol _c kg ⁻¹				%	
13	3	0	0	0	3	139	1	4.227	1.211	0.395	0.063	12.024	49.038
13	3	0	0	0	3	139	2	4.399	0.633	0.232	0.071	11.198	47.647
13	3	0	0	1	3	140	1	5.451	1.793	0.418	0.072	12.024	64.322
13	3	0	0	1	3	140	2	4.700	0.903	0.267	0.088	11.198	53.206
13	3	0	0	0	4	192	1	4.220	1.341	0.421	0.063	10.592	57.071
13	3	0	0	0	4	192	2	5.296	0.738	0.232	0.072	11.010	57.581
13	3	0	0	1	4	191	1	4.728	1.315	0.365	0.059	10.592	61.064
13	3	0	0	1	4	191	2	5.669	0.754	0.221	0.069	11.010	60.974
15	3	0	1	0	1	44	1	4.279	1.555	0.384	0.060	11.023	56.953
15	3	0	1	0	1	44	2	5.062	1.266	0.211	0.084	10.962	60.428
15	3	0	1	1	1	43	1	4.431	1.788	0.327	0.058	11.023	59.906
15	3	0	1	1	1	43	2	5.149	1.315	0.173	0.067	10.962	61.160
15	3	0	1	0	2	60	1	4.855	1.361	0.346	0.062	10.748	61.621
15	3	0	1	0	2	60	2	4.789	1.497	0.462	0.070	10.162	67.085
15	3	0	1	1	2	59	1	5.522	1.911	0.420	0.077	10.748	73.781
15	3	0	1	1	2	59	2	5.501	1.336	0.202	0.082	10.162	70.070
15	3	0	1	0	3	137	1	3.908	1.156	0.500	0.066	12.157	46.312
15	3	0	1	0	3	137	2	4.454	0.890	0.308	0.078	11.026	51.960
15	3	0	1	1	3	138	1	4.999	1.814	0.407	0.057	12.157	59.854
15	3	0	1	1	3	138	2	4.612	1.393	0.221	0.069	11.026	57.092
15	3	0	1	0	4	190	1	4.253	1.481	0.554	0.063	10.226	62.102
15	3	0	1	0	4	190	2	4.257	1.042	0.343	0.060	10.195	55.925
15	3	0	1	1	4	189	1	4.736	1.811	0.476	0.061	10.226	69.274
15	3	0	1	1	4	189	2	4.908	1.210	0.233	0.062	10.195	62.895
16	0	1	0	0	1	73	1	6.388	1.686	0.355	0.065	12.907	65.818
16	0	1	0	0	1	73	2	6.466	0.988	0.134	0.090	11.528	66.611

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
cmol _c kg ⁻¹													%
16	0	1	0	1	1	74	1	6.876	2.020	0.337	0.072	12.907	72.083
16	0	1	0	1	1	74	2	6.904	1.236	0.154	0.092	11.528	72.748
16	0	1	0	0	2	123	1	5.097	0.875	0.481	0.058	9.639	67.547
16	0	1	0	0	2	123	2	5.375	0.769	0.307	0.061	9.713	67.050
16	0	1	0	1	2	124	1	4.888	0.815	0.433	0.075	9.639	64.437
16	0	1	0	1	2	124	2	5.180	0.741	0.240	0.060	9.713	64.052
16	0	1	0	0	3	166	1	5.816	1.261	0.407	0.046	12.865	58.533
16	0	1	0	0	3	166	2	4.742	0.518	0.198	0.048	11.153	49.374
16	0	1	0	1	3	165	1	6.370	1.576	0.371	0.045	12.865	65.001
16	0	1	0	1	3	165	2	4.525	0.629	0.198	0.053	11.153	48.464
16	0	1	0	0	4	224	1	6.382	1.414	0.480	0.046	11.980	69.470
16	0	1	0	0	4	224	2	5.355	0.756	0.302	0.039	10.992	58.694
16	0	1	0	1	4	223	1	6.124	1.284	0.409	0.050	11.980	65.684
16	0	1	0	1	4	223	2	5.628	0.715	0.277	0.073	10.992	60.885
18	0	1	1	0	1	75	1	5.897	1.692	0.404	0.072	10.580	76.226
18	0	1	1	0	1	75	2	5.894	1.167	0.115	0.092	10.898	66.693
18	0	1	1	1	1	76	1	5.803	1.638	0.269	0.074	10.580	73.575
18	0	1	1	1	1	76	2	nd	nd	nd	nd	10.898	nd
18	0	1	1	0	2	121	1	5.529	0.863	0.538	0.061	9.639	72.524
18	0	1	1	0	2	121	2	5.318	0.557	0.211	0.065	9.713	63.337
18	0	1	1	1	2	122	1	4.836	0.700	0.413	0.067	9.639	62.411
18	0	1	1	1	2	122	2	6.117	0.642	0.221	0.144	9.713	73.340
18	0	1	1	0	3	168	1	5.744	1.427	0.531	0.063	12.596	61.648
18	0	1	1	0	3	168	2	5.142	0.852	0.332	0.055	12.748	50.054
18	0	1	1	1	3	167	1	6.215	1.926	0.441	0.050	12.596	68.533
18	0	1	1	1	3	167	2	5.180	1.161	0.267	0.046	12.748	52.199

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
										cmol _c kg ⁻¹			
													%
18	0	1	1	0	4	221	1	5.007	0.858	0.542	0.059	11.777	54.900
18	0	1	1	0	4	221	2	5.278	0.643	0.343	0.070	11.023	57.465
18	0	1	1	1	4	222	1	5.403	0.921	0.598	0.051	11.777	59.205
18	0	1	1	1	4	222	2	5.919	0.698	0.332	0.115	11.023	64.088
19	1	1	0	0	1	7	1	4.401	1.334	0.356	0.059	9.844	62.465
19	1	1	0	0	1	7	2	2.863	0.662	0.173	0.060	8.099	46.398
19	1	1	0	1	1	8	1	5.677	1.581	0.336	0.053	9.844	77.676
19	1	1	0	1	1	8	2	4.170	0.728	0.202	0.077	8.099	63.905
19	1	1	0	0	2	81	1	4.467	1.482	0.337	0.071	11.362	55.951
19	1	1	0	0	2	81	2	3.743	0.800	0.183	0.066	10.207	46.940
19	1	1	0	1	2	82	1	5.828	2.096	0.327	0.061	11.362	73.155
19	1	1	0	1	2	82	2	4.694	1.157	0.173	0.066	10.207	59.661
19	1	1	0	0	3	202	1	5.175	1.454	0.299	0.058	12.042	58.017
19	1	1	0	0	3	202	2	4.410	0.716	0.155	0.060	10.557	50.586
19	1	1	0	1	3	201	1	5.995	1.790	0.388	0.046	12.042	68.253
19	1	1	0	1	3	201	2	4.341	0.849	0.177	0.061	10.557	51.413
19	1	1	0	0	4	251	1	5.564	1.356	0.480	0.057	10.443	71.405
19	1	1	0	0	4	251	2	3.959	0.566	0.261	0.061	9.030	53.674
19	1	1	0	1	4	252	1	5.540	1.572	0.501	0.040	10.443	73.277
19	1	1	0	1	4	252	2	3.983	0.737	0.323	0.045	9.030	56.359
20	1	1	1	0	1	6	1	4.718	1.775	0.477	0.078	9.173	76.818
20	1	1	1	0	1	6	2	3.793	1.241	0.212	0.061	9.037	58.726
20	1	1	1	1	1	5	1	5.039	1.956	0.509	0.071	9.173	82.579
20	1	1	1	1	1	5	2	4.651	1.415	0.228	0.065	9.037	70.379
20	1	1	1	0	2	83	1	4.647	1.595	0.355	0.061	10.714	62.151
20	1	1	1	0	2	83	2	4.783	1.225	0.230	0.062	11.062	56.955

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
cmol _c kg ⁻¹													%
20	1	1	1	1	2	84	1	5.363	1.972	0.375	0.072	10.714	72.636
20	1	1	1	1	2	84	2	5.208	1.465	0.221	0.073	11.062	62.987
20	1	1	1	0	3	203	1	4.407	1.359	0.498	0.052	10.960	57.623
20	1	1	1	0	3	203	2	4.167	0.848	0.243	0.062	11.062	48.096
20	1	1	1	1	3	204	1	5.400	1.669	0.454	0.110	10.960	69.650
20	1	1	1	1	3	204	2	4.534	1.032	0.233	0.056	11.062	52.927
20	1	1	1	0	4	250	1	5.122	1.201	0.491	0.036	9.702	70.604
20	1	1	1	0	4	250	2	4.724	0.840	0.355	0.105	9.050	66.569
20	1	1	1	1	4	249	1	5.351	1.438	0.553	0.106	9.702	76.765
20	1	1	1	1	4	249	2	4.626	0.925	0.313	0.053	9.050	65.390
21	2	1	0	0	1	101	1	4.363	1.661	0.288	0.071	12.779	49.958
21	2	1	0	0	1	101	2	4.125	0.791	0.135	0.078	9.890	51.851
21	2	1	0	1	1	102	1	5.002	2.002	0.289	0.078	12.779	57.672
21	2	1	0	1	1	102	2	3.928	0.859	0.125	0.070	9.890	50.376
21	2	1	0	0	2	31	1	4.316	1.210	0.442	0.053	nd	nd
21	2	1	0	0	2	31	2	4.006	0.700	0.240	0.115	9.771	51.805
21	2	1	0	1	2	32	1	3.962	1.265	0.375	0.061	11.950	47.381
21	2	1	0	1	2	32	2	3.954	0.831	0.183	0.067	9.771	51.535
21	2	1	0	0	3	240	1	5.594	1.479	0.365	0.058	9.008	83.224
21	2	1	0	0	3	240	2	4.951	0.806	0.198	0.132	7.870	77.348
21	2	1	0	1	3	239	1	5.434	1.978	0.355	0.052	9.008	86.797
21	2	1	0	1	3	239	2	3.682	0.895	0.209	0.047	7.870	61.404
21	2	1	0	0	4	157	1	4.346	1.391	0.430	0.091	10.292	60.813
21	2	1	0	0	4	157	2	2.833	0.862	0.302	0.047	8.924	45.314
21	2	1	0	1	4	158	1	4.777	1.622	0.337	0.045	10.292	65.882
21	2	1	0	1	4	158	2	3.683	0.898	0.267	0.046	8.924	54.847

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								cmol. kg ⁻¹				%	
22	2	1	1	0	1	104	1	5.063	1.673	0.327	0.074	9.714	73.466
22	2	1	1	0	1	104	2	5.153	1.214	0.144	0.078	9.036	72.911
22	2	1	1	1	1	103	1	4.776	1.999	0.279	0.095	9.714	73.593
22	2	1	1	1	1	103	2	4.937	1.632	0.173	0.100	9.036	75.720
22	2	1	1	0	2	30	1	4.962	1.575	0.471	0.047	10.458	67.462
22	2	1	1	0	2	30	2	4.281	1.013	0.269	0.056	10.022	56.059
22	2	1	1	1	2	29	1	5.507	2.027	0.461	0.090	10.458	77.310
22	2	1	1	1	2	29	2	4.756	1.361	0.269	0.074	10.022	64.464
22	2	1	1	0	3	237	1	4.212	1.295	0.407	0.047	8.887	67.066
22	2	1	1	0	3	237	2	4.137	0.874	0.219	0.047	8.281	63.727
22	2	1	1	1	3	238	1	4.909	1.814	0.428	0.054	8.887	81.078
22	2	1	1	1	3	238	2	4.286	1.372	0.198	0.058	8.281	71.424
22	2	1	1	0	4	159	1	4.543	1.439	0.442	0.048	10.578	61.178
22	2	1	1	0	4	159	2	4.505	0.948	0.256	0.044	10.065	57.159
22	2	1	1	1	4	160	1	5.634	1.880	0.511	0.049	10.578	76.333
22	2	1	1	1	4	160	2	4.759	1.376	0.325	0.048	10.065	64.656
23	3	1	0	0	1	35	1	4.584	1.775	0.461	0.064	12.372	55.638
23	3	1	0	0	1	35	2	3.829	0.811	0.231	0.062	15.642	31.533
23	3	1	0	1	1	36	1	2.788	1.470	0.404	0.066	12.372	38.210
23	3	1	0	1	1	36	2	2.984	0.868	0.221	0.078	15.642	26.539
23	3	1	0	0	2	50	1	3.602	1.665	0.461	0.057	11.871	48.731
23	3	1	0	0	2	50	2	3.685	1.068	0.269	0.069	11.760	43.294
23	3	1	0	1	2	49	1	3.773	1.693	0.423	0.065	11.871	50.158
23	3	1	0	1	2	49	2	2.604	0.778	0.240	0.068	11.760	31.382
23	3	1	0	0	3	131	1	3.784	1.190	0.500	0.066	13.243	41.841
23	3	1	0	0	3	131	2	3.042	0.624	0.356	0.166	10.730	39.035

Table A3 (cont.) 1997 percent base saturation.

trt	N rate	Cover	Tillage	Lime rate	Rep	new plot #	depth	Ca	Mg	K	Na	CEC	Base Sat
								-----cmol, kg ⁻¹ -----				%	
23	3	1	0	1	3	132	1	4.415	1.616	0.528	0.061	13.243	49.993
23	3	1	0	1	3	132	2	1.843	0.591	0.375	0.056	10.730	26.700
23	3	1	0	0	4	184	1	3.709	1.218	0.399	0.120	11.148	48.855
23	3	1	0	0	4	184	2	3.543	0.681	0.277	0.120	9.591	48.170
23	3	1	0	1	4	183	1	3.247	1.347	0.321	0.056	11.148	44.589
23	3	1	0	1	4	183	2	2.301	0.639	0.240	0.053	9.591	33.700
24	3	1	1	0	1	33	1	4.691	2.113	0.385	0.054	12.053	60.095
24	3	1	1	0	1	33	2	5.914	1.673	0.163	0.076	12.383	63.194
24	3	1	1	1	1	34	1	4.422	1.701	0.432	0.055	12.053	54.842
24	3	1	1	1	1	34	2	4.968	1.181	0.211	0.058	12.383	51.834
24	3	1	1	0	2	52	1	3.820	1.766	0.452	0.065	11.529	52.929
24	3	1	1	0	2	52	2	4.410	1.374	0.163	0.087	11.984	50.360
24	3	1	1	1	2	51	1	4.354	2.063	0.452	0.064	11.529	60.131
24	3	1	1	1	2	51	2	5.326	1.455	0.163	0.071	11.984	58.541
24	3	1	1	0	3	129	1	4.870	1.699	0.365	0.046	10.316	67.665
24	3	1	1	0	3	129	2	4.086	1.064	0.253	0.055	9.617	56.753
24	3	1	1	1	3	130	1	4.170	1.701	0.461	0.047	10.316	61.835
24	3	1	1	1	3	130	2	3.775	1.319	0.231	0.061	9.617	55.998
24	3	1	1	0	4	181	1	4.067	1.541	0.454	0.049	10.227	59.751
24	3	1	1	0	4	181	2	4.400	1.278	0.232	0.051	9.656	61.730
24	3	1	1	1	4	182	1	4.558	1.750	0.565	0.045	10.227	67.645
24	3	1	1	1	4	182	2	4.317	1.246	0.310	0.081	9.656	61.659

Table A4. 1995 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
0	0	0	0	1	69	1	3.98e-07	6.4	0.503
0	0	0	0	1	69	2	3.16e-07	6.5	0.459
0	0	0	0	1	69	3	3.16e-07	6.5	nd
0	0	0	1	1	70	1	3.98e-07	6.4	0.503
0	0	0	1	1	70	2	3.16e-07	6.5	0.459
0	0	0	1	1	70	3	3.16e-07	6.5	nd
0	0	0	0	2	125	1	2.51e-07	6.6	0.698
0	0	0	0	2	125	2	2.51e-07	6.6	0.501
0	0	0	0	2	125	3	2.51e-07	6.6	nd
0	0	0	1	2	126	1	2.51e-07	6.6	0.698
0	0	0	1	2	126	2	2.51e-07	6.6	0.501
0	0	0	1	2	126	3	2.51e-07	6.6	nd
0	0	0	0	3	175	1	1.00e-06	6	1.313
0	0	0	0	3	175	2	2.00e-06	5.7	0.780
0	0	0	0	3	175	3	1.58e-06	5.8	nd
0	0	0	1	3	176	1	1.00e-06	6	1.313
0	0	0	1	3	176	2	2.00e-06	5.7	0.780
0	0	0	1	3	176	3	1.58e-06	5.8	nd
0	0	0	0	4	213	1	1.58e-07	6.8	0.800
0	0	0	0	4	213	2	1.26e-07	6.9	0.559
0	0	0	0	4	213	3	1.26e-07	6.9	nd
0	0	0	1	4	214	1	1.58e-07	6.8	0.800
0	0	0	1	4	214	2	1.26e-07	6.9	0.559
0	0	0	1	4	214	3	1.26e-07	6.9	nd
0	0	1	0	1	72	1	2.00e-07	6.7	0.765
0	0	1	0	1	72	2	2.00e-07	6.7	0.571
0	0	1	0	1	72	3	2.51e-07	6.6	nd
0	0	1	1	1	71	1	2.00e-07	6.7	0.765
0	0	1	1	1	71	2	2.00e-07	6.7	0.571
0	0	1	1	1	71	3	2.51e-07	6.6	nd
0	0	1	0	2	127	1	2.00e-07	6.7	0.750
0	0	1	0	2	127	2	2.51e-07	6.6	0.572
0	0	1	0	2	127	3	2.51e-07	6.6	nd
0	0	1	1	2	128	1	2.00e-07	6.7	0.750
0	0	1	1	2	128	2	2.51e-07	6.6	0.571
0	0	1	1	2	128	3	2.51e-07	6.6	nd
0	0	1	0	3	173	1	7.94e-07	6.1	1.165
0	0	1	0	3	173	2	1.00e-06	6	0.682
0	0	1	0	3	173	3	7.94e-07	6.1	nd
0	0	1	1	3	174	1	7.94e-07	6.1	1.165

Table A4 (cont). 1995 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
1	0	0	0	1	2	2	5.01e-07	6.3	0.520
1	0	0	0	1	2	3	1.00e-06	6	nd
1	0	0	1	1	1	1	1.00e-06	6	0.869
1	0	0	1	1	1	2	5.01e-07	6.3	0.520
1	0	0	1	1	1	3	1.00e-06	6	nd
1	0	0	0	2	95	1	5.01e-07	6.3	0.872
1	0	0	0	2	95	2	2.51e-07	6.6	0.538
1	0	0	0	2	95	3	7.94e-07	6.1	nd
1	0	0	1	2	96	1	5.01e-07	6.3	0.872
1	0	0	1	2	96	2	2.51e-07	6.6	0.538
1	0	0	1	2	96	3	7.94e-07	6.1	nd
1	0	0	0	3	208	1	1.58e-06	5.8	1.305
1	0	0	0	3	208	2	1.58e-06	5.8	0.711
1	0	0	0	3	208	3	1.58e-06	5.8	nd
1	0	0	1	3	207	1	1.58e-06	5.8	1.305
1	0	0	1	3	207	2	1.58e-06	5.8	0.711
1	0	0	1	3	207	3	1.58e-06	5.8	nd
1	0	0	0	4	241	1	5.01e-07	6.3	1.179
1	0	0	0	4	241	2	2.51e-07	6.6	0.648
1	0	0	0	4	241	3	3.98e-07	6.4	nd
1	0	0	1	4	242	1	5.01e-07	6.3	1.179
1	0	0	1	4	242	2	2.51e-07	6.6	0.648
1	0	0	1	4	242	3	3.98e-07	6.4	nd
1	0	1	0	1	4	1	2.00e-06	5.7	0.877
1	0	1	0	1	4	2	1.58e-06	5.8	0.556
1	0	1	0	1	4	3	1.58e-06	5.8	nd
1	0	1	1	1	3	1	2.00e-06	5.7	0.877
1	0	1	1	1	3	2	1.58e-06	5.8	0.556
1	0	1	1	1	3	3	1.58e-06	5.8	nd
1	0	1	0	2	93	1	6.31e-07	6.2	0.949
1	0	1	0	2	93	2	3.98e-07	6.4	0.559
1	0	1	0	2	93	3	3.98e-07	6.4	nd
1	0	1	1	2	94	1	6.31e-07	6.2	0.949
1	0	1	1	2	94	2	3.98e-07	6.4	0.559
1	0	1	1	2	94	3	3.98e-07	6.4	nd
1	0	1	0	3	205	1	1.26e-06	5.9	1.018
1	0	1	0	3	205	2	6.31e-07	6.2	0.716
1	0	1	0	3	205	3	1.26e-06	5.9	nd
1	0	1	1	3	206	1	1.26e-06	5.9	1.018
1	0	1	1	3	206	2	6.31e-07	6.2	0.716

Table A4 (cont). 1995 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
2	0	0	0	1	112	3	5.01e-06	5.3	nd
2	0	0	1	1	111	1	5.01e-06	5.3	1.271
2	0	0	1	1	111	2	3.98e-06	5.4	0.537
2	0	0	1	1	111	3	5.01e-06	5.3	nd
2	0	0	0	2	17	1	7.94e-06	5.1	0.923
2	0	0	0	2	17	2	3.16e-06	5.5	0.510
2	0	0	0	2	17	3	5.01e-06	5.3	nd
2	0	0	1	2	18	1	7.94e-06	5.1	0.923
2	0	0	1	2	18	2	3.16e-06	5.5	0.510
2	0	0	1	2	18	3	5.01e-06	5.3	nd
2	0	0	0	3	233	1	1.58e-06	5.8	1.012
2	0	0	0	3	233	2	6.31e-07	6.2	0.693
2	0	0	0	3	233	3	2.00e-06	5.7	nd
2	0	0	1	3	234	1	1.58e-06	5.8	1.012
2	0	0	1	3	234	2	6.31e-07	6.2	0.693
2	0	0	1	3	234	3	2.00e-06	5.7	nd
2	0	0	0	4	153	1	3.16e-06	5.5	0.981
2	0	0	0	4	153	2	5.01e-07	6.3	0.624
2	0	0	0	4	153	3	1.26e-06	5.9	nd
2	0	0	1	4	154	1	3.16e-06	5.5	0.981
2	0	0	1	4	154	2	5.01e-07	6.3	0.624
2	0	0	1	4	154	3	1.26e-06	5.9	nd
2	0	1	0	1	109	1	5.01e-06	5.3	0.923
2	0	1	0	1	109	2	2.51e-06	5.6	0.677
2	0	1	0	1	109	3	3.16e-06	5.5	nd
2	0	1	1	1	110	1	5.01e-06	5.3	0.923
2	0	1	1	1	110	2	2.51e-06	5.6	0.677
2	0	1	1	1	110	3	3.16e-06	5.5	nd
2	0	1	0	2	20	1	3.98e-06	5.4	0.809
2	0	1	0	2	20	2	2.00e-06	5.7	0.621
2	0	1	0	2	20	3	3.98e-06	5.4	nd
2	0	1	1	2	19	1	3.98e-06	5.4	0.809
2	0	1	1	2	19	2	2.00e-06	5.7	0.621
2	0	1	1	2	19	3	3.98e-06	5.4	nd
2	0	1	0	3	236	1	2.51e-06	5.6	0.981
2	0	1	0	3	236	2	1.26e-06	5.9	0.784
2	0	1	0	3	236	3	1.58e-06	5.8	nd
2	0	1	1	3	235	1	2.51e-06	5.6	0.981
2	0	1	1	3	235	2	1.26e-06	5.9	0.784
2	0	1	1	3	235	3	1.58e-06	5.8	nd

Table A4 (cont). 1995 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
3	0	0	1	1	41	1	1.26e-05	4.9	0.929
3	0	0	1	1	41	2	2.00e-06	5.7	0.563
3	0	0	1	1	41	3	3.98e-06	5.4	nd
3	0	0	0	2	57	1	3.16e-06	5.5	1.086
3	0	0	0	2	57	2	2.51e-07	6.6	0.587
3	0	0	0	2	57	3	1.26e-06	5.9	nd
3	0	0	1	2	58	1	3.16e-06	5.5	1.086
3	0	0	1	2	58	2	2.51e-07	6.6	0.587
3	0	0	1	2	58	3	1.26e-06	5.9	nd
3	0	0	0	3	140	1	1.26e-05	4.9	0.900
3	0	0	0	3	140	2	3.98e-06	5.4	0.531
3	0	0	0	3	140	3	6.31e-06	5.2	nd
3	0	0	1	3	139	1	1.26e-05	4.9	0.900
3	0	0	1	3	139	2	3.98e-06	5.4	0.531
3	0	0	1	3	139	3	6.31e-06	5.2	nd
3	0	0	0	4	191	1	1.26e-06	5.9	0.588
3	0	0	0	4	191	2	2.51e-06	5.6	0.934
3	0	0	0	4	191	3	5.01e-06	5.3	nd
3	0	0	1	4	192	1	1.26e-06	5.9	0.588
3	0	0	1	4	192	2	2.51e-06	5.6	0.934
3	0	0	1	4	192	3	5.01e-06	5.3	nd
3	0	1	0	1	43	1	6.31e-06	5.2	0.752
3	0	1	0	1	43	2	3.98e-06	5.4	0.632
3	0	1	0	1	43	3	7.94e-06	5.1	nd
3	0	1	1	1	44	1	6.31e-06	5.2	0.752
3	0	1	1	1	44	2	3.98e-06	5.4	0.632
3	0	1	1	1	44	3	7.94e-06	5.1	nd
3	0	1	0	2	60	1	5.01e-06	5.3	0.937
3	0	1	0	2	60	2	1.00e-06	6	0.676
3	0	1	0	2	60	3	2.00e-06	5.7	nd
3	0	1	1	2	59	1	5.01e-06	5.3	0.937
3	0	1	1	2	59	2	1.00e-06	6	0.676
3	0	1	1	2	59	3	2.00e-06	5.7	nd
3	0	1	0	3	138	1	6.31e-06	5.2	1.115
3	0	1	0	3	138	2	3.16e-06	5.5	0.722
3	0	1	0	3	138	3	5.01e-06	5.3	nd
3	0	1	1	3	137	1	6.31e-06	5.2	1.115
3	0	1	1	3	137	2	3.16e-06	5.5	0.722
3	0	1	1	3	137	3	5.01e-06	5.3	nd
3	0	1	0	4	189	1	1.00e-06	6	0.566

Table A4 (cont). 1995 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
0	1	0	1	1	74	2	1.26e-06	5.9	0.512
0	1	0	1	1	74	3	2.00e-06	5.7	nd
0	1	0	0	2	123	1	1.26e-06	5.9	0.919
0	1	0	0	2	123	2	1.26e-06	5.9	0.580
0	1	0	0	2	123	3	2.51e-06	5.6	nd
0	1	0	1	2	124	1	1.26e-06	5.9	0.919
0	1	0	1	2	124	2	1.26e-06	5.9	0.580
0	1	0	1	2	124	3	2.51e-06	5.6	nd
0	1	0	0	3	165	1	1.00e-06	6	1.319
0	1	0	0	3	165	2	1.00e-06	6	0.776
0	1	0	0	3	165	3	1.26e-06	5.9	nd
0	1	0	1	3	166	1	1.00e-06	6	1.319
0	1	0	1	3	166	2	1.00e-06	6	0.776
0	1	0	1	3	166	3	1.26e-06	5.9	nd
0	1	0	0	4	223	1	7.94e-07	6.1	0.979
0	1	0	0	4	223	2	6.31e-07	6.2	0.588
0	1	0	0	4	223	3	1.00e-06	6	nd
0	1	0	1	4	224	1	7.94e-07	6.1	0.979
0	1	0	1	4	224	2	6.31e-07	6.2	0.588
0	1	0	1	4	224	3	1.00e-06	6	nd
0	1	1	0	1	75	1	6.31e-07	6.2	nd
0	1	1	0	1	75	2	1.58e-06	5.8	nd
0	1	1	0	1	75	3	1.26e-06	5.9	nd
0	1	1	1	1	76	1	6.31e-07	6.2	nd
0	1	1	1	1	76	2	1.58e-06	5.8	nd
0	1	1	1	1	76	3	1.26e-06	5.9	nd
0	1	1	0	2	121	1	7.94e-07	6.1	0.984
0	1	1	0	2	121	2	7.94e-07	6.1	0.758
0	1	1	0	2	121	3	6.31e-07	6.2	nd
0	1	1	1	2	122	1	7.94e-07	6.1	0.984
0	1	1	1	2	122	2	7.94e-07	6.1	0.758
0	1	1	1	2	122	3	6.31e-07	6.2	nd
0	1	1	0	3	167	1	1.26e-06	5.9	1.033
0	1	1	0	3	167	2	1.26e-06	5.9	0.847
0	1	1	0	3	167	3	1.00e-06	6	nd
0	1	1	1	3	168	1	1.26e-06	5.9	1.033
0	1	1	1	3	168	2	1.26e-06	5.9	0.847
0	1	1	1	3	168	3	1.00e-06	6	nd
0	1	1	0	4	221	1	6.31e-07	6.2	1.091
0	1	1	0	4	221	2	6.31e-07	6.2	0.786

Table A4 (cont). 1995 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
1	1	0	1	1	8	3	3.16e-06	5.5	nd
1	1	0	0	2	81	1	1.00e-05	5	1.299
1	1	0	0	2	81	2	6.31e-06	5.2	0.560
1	1	0	0	2	81	3	6.31e-06	5.2	nd
1	1	0	1	2	82	1	1.00e-05	5	1.299
1	1	0	1	2	82	2	6.31e-06	5.2	0.560
1	1	0	1	2	82	3	6.31e-06	5.2	nd
1	1	0	0	3	202	1	3.16e-06	5.5	0.963
1	1	0	0	3	202	2	1.00e-06	6	0.622
1	1	0	0	3	202	3	1.58e-06	5.8	nd
1	1	0	1	3	201	1	3.16e-06	5.5	0.963
1	1	0	1	3	201	2	1.00e-06	6	0.622
1	1	0	1	3	201	3	1.58e-06	5.8	nd
1	1	0	0	4	251	1	3.16e-06	5.5	0.673
1	1	0	0	4	251	2	3.16e-06	5.5	1.132
1	1	0	0	4	251	3	3.98e-06	5.4	nd
1	1	0	1	4	252	1	3.16e-06	5.5	0.673
1	1	0	1	4	252	2	3.16e-06	5.5	1.132
1	1	0	1	4	252	3	3.98e-06	5.4	nd
1	1	1	0	1	6	1	3.98e-06	5.4	1.070
1	1	1	0	1	6	2	1.00e-06	6	0.838
1	1	1	0	1	6	3	3.98e-06	5.4	nd
1	1	1	1	1	5	1	3.98e-06	5.4	1.070
1	1	1	1	1	5	2	1.00e-06	6	0.838
1	1	1	1	1	5	3	3.98e-06	5.4	nd
1	1	1	0	2	83	1	3.98e-06	5.4	0.784
1	1	1	0	2	83	2	2.00e-06	5.7	0.723
1	1	1	0	2	83	3	3.98e-06	5.4	nd
1	1	1	1	2	84	1	3.98e-06	5.4	0.784
1	1	1	1	2	84	2	2.00e-06	5.7	0.723
1	1	1	1	2	84	3	3.98e-06	5.4	nd
1	1	1	0	3	203	1	3.16e-06	5.5	0.943
1	1	1	0	3	203	2	3.16e-06	5.5	0.748
1	1	1	0	3	203	3	2.51e-06	5.6	nd
1	1	1	1	3	204	1	3.16e-06	5.5	0.943
1	1	1	1	3	204	2	3.16e-06	5.5	0.748
1	1	1	1	3	204	3	2.51e-06	5.6	nd
1	1	1	0	4	250	1	1.26e-06	5.9	0.997
1	1	1	0	4	250	2	1.26e-06	5.9	0.753
1	1	1	0	4	250	3	1.26e-06	5.9	nd

Table A4 (cont). 1995 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
2	1	0	0	2	31	1	1.00e-05	5	1.360
2	1	0	0	2	31	2	3.98e-06	5.4	0.640
2	1	0	0	2	31	3	6.31e-06	5.2	nd
2	1	0	1	2	32	1	1.00e-05	5	1.360
2	1	0	1	2	32	2	3.98e-06	5.4	0.640
2	1	0	1	2	32	3	6.31e-06	5.2	nd
2	1	0	0	3	240	1	6.31e-06	5.2	1.156
2	1	0	0	3	240	2	2.51e-06	5.6	0.684
2	1	0	0	3	240	3	3.98e-06	5.4	nd
2	1	0	1	3	239	1	6.31e-06	5.2	1.156
2	1	0	1	3	239	2	2.51e-06	5.6	0.684
2	1	0	1	3	239	3	3.98e-06	5.4	nd
2	1	0	0	4	157	1	7.94e-06	5.1	1.029
2	1	0	0	4	157	2	3.16e-06	5.5	0.548
2	1	0	0	4	157	3	5.01e-06	5.3	nd
2	1	0	1	4	158	1	7.94e-06	5.1	1.029
2	1	0	1	4	158	2	3.16e-06	5.5	0.548
2	1	0	1	4	158	3	5.01e-06	5.3	nd
2	1	1	0	1	104	1	5.01e-06	5.3	0.933
2	1	1	0	1	104	2	6.31e-06	5.2	0.716
2	1	1	0	1	104	3	2.51e-06	5.6	nd
2	1	1	1	1	103	1	5.01e-06	5.3	0.933
2	1	1	1	1	103	2	6.31e-06	5.2	0.716
2	1	1	1	1	103	3	2.51e-06	5.6	nd
2	1	1	0	2	30	1	3.16e-06	5.5	0.959
2	1	1	0	2	30	2	3.98e-06	5.4	0.717
2	1	1	0	2	30	3	5.01e-06	5.3	nd
2	1	1	1	2	29	1	3.16e-06	5.5	0.959
2	1	1	1	2	29	2	3.98e-06	5.4	0.717
2	1	1	1	2	29	3	5.01e-06	5.3	nd
2	1	1	0	3	237	1	5.01e-06	5.3	1.107
2	1	1	0	3	237	2	5.01e-06	5.3	0.767
2	1	1	0	3	237	3	5.01e-06	5.3	nd
2	1	1	1	3	238	1	5.01e-06	5.3	1.107
2	1	1	1	3	238	2	5.01e-06	5.3	0.767
2	1	1	1	3	238	3	5.01e-06	5.3	nd
2	1	1	0	4	159	1	2.51e-06	5.6	0.973
2	1	1	0	4	159	2	2.00e-06	5.7	0.633
2	1	1	0	4	159	3	2.51e-06	5.6	nd
2	1	1	1	4	160	1	2.51e-06	5.6	0.973

Table A4 (cont). 1995 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
3	1	0	0	2	50	2	3.16e-05	4.5	0.516
3	1	0	0	2	50	3	3.98e-05	4.4	nd
3	1	0	1	2	49	1	2.51e-05	4.6	0.802
3	1	0	1	2	49	2	3.16e-05	4.5	0.516
3	1	0	1	2	49	3	3.98e-05	4.4	nd
3	1	0	0	3	131	1	6.31e-06	5.2	1.410
3	1	0	0	3	131	2	6.31e-06	5.2	0.813
3	1	0	0	3	131	3	1.26e-05	4.9	nd
3	1	0	1	3	132	1	6.31e-06	5.2	1.410
3	1	0	1	3	132	2	6.31e-06	5.2	0.813
3	1	0	1	3	132	3	1.26e-05	4.9	nd
3	1	0	0	4	183	1	1.26e-05	4.9	1.120
3	1	0	0	4	183	2	6.31e-06	5.2	0.643
3	1	0	0	4	183	3	6.31e-06	5.2	nd
3	1	0	1	4	184	1	1.26e-05	4.9	1.120
3	1	0	1	4	184	2	6.31e-06	5.2	0.643
3	1	0	1	4	184	3	6.31e-06	5.2	nd
3	1	1	0	1	34	1	1.26e-05	4.9	0.876
3	1	1	0	1	34	2	3.98e-06	5.4	0.631
3	1	1	0	1	34	3	3.98e-06	5.4	nd
3	1	1	1	1	33	1	1.26e-05	4.9	0.876
3	1	1	1	1	33	2	3.98e-06	5.4	0.631
3	1	1	1	1	33	3	3.98e-06	5.4	nd
3	1	1	0	2	52	1	1.26e-05	4.9	1.176
3	1	1	0	2	52	2	3.98e-06	5.4	0.620
3	1	1	0	2	52	3	1.26e-05	4.9	nd
3	1	1	1	2	51	1	1.26e-05	4.9	1.176
3	1	1	1	2	51	2	3.98e-06	5.4	0.620
3	1	1	1	2	51	3	1.26e-05	4.9	nd
3	1	1	0	3	129	1	7.94e-06	5.1	nd
3	1	1	0	3	129	2	5.01e-06	5.3	0.693
3	1	1	0	3	129	3	7.94e-06	5.1	nd
3	1	1	1	3	130	1	7.94e-06	5.1	1.043
3	1	1	1	3	130	2	5.01e-06	5.3	0.693
3	1	1	1	3	130	3	7.94e-06	5.1	nd
3	1	1	0	4	181	1	7.94e-06	5.1	1.037
3	1	1	0	4	181	2	3.16e-06	5.5	0.751
3	1	1	0	4	181	3	5.01e-06	5.3	nd
3	1	1	1	4	182	1	7.94e-06	5.1	1.037
3	1	1	1	4	182	2	3.16e-06	5.5	0.751

Table A5. 1996 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
0	0	0	0	1	69	1	7.94e-07	6.1	0.569
0	0	0	0	1	69	2	7.94e-07	6.1	0.522
0	0	0	0	1	69	3	7.94e-07	6.1	0.546
0	0	0	1	1	70	1	5.01e-07	6.3	0.534
0	0	0	1	1	70	2	3.98e-07	6.4	0.472
0	0	0	1	1	70	3	5.01e-07	6.3	0.567
0	0	0	0	2	125	1	1.58e-06	5.8	0.666
0	0	0	0	2	125	2	5.01e-07	6.3	0.518
0	0	0	0	2	125	3	1.00e-06	6	0.655
0	0	0	1	2	126	1	7.94e-07	6.1	0.736
0	0	0	1	2	126	2	2.51e-07	6.6	0.547
0	0	0	1	2	126	3	2.51e-07	6.6	0.583
0	0	0	0	3	175	1	1.26e-06	5.9	0.981
0	0	0	0	3	175	2	2.00e-06	5.7	0.718
0	0	0	0	3	175	3	1.58e-06	5.8	0.937
0	0	0	1	3	176	1	3.16e-07	6.5	1.341
0	0	0	1	3	176	2	6.31e-07	6.2	0.886
0	0	0	1	3	176	3	3.98e-07	6.4	1.128
0	0	0	0	4	213	1	5.01e-07	6.3	0.776
0	0	0	0	4	213	2	1.26e-07	6.9	0.555
0	0	0	0	4	213	3	6.31e-07	6.2	0.675
0	0	0	1	4	214	1	5.01e-07	6.3	0.952
0	0	0	1	4	214	2	3.98e-07	6.4	0.625
0	0	0	1	4	214	3	5.01e-07	6.3	0.927
0	0	1	0	1	71	1	5.01e-07	6.3	0.585
0	0	1	0	1	71	2	3.16e-07	6.5	0.630
0	0	1	0	1	71	3	3.98e-07	6.4	0.619
0	0	1	1	1	72	1	5.01e-07	6.3	0.933
0	0	1	1	1	72	2	6.31e-07	6.2	0.685
0	0	1	1	1	72	3	6.31e-07	6.2	0.627
0	0	1	0	2	127	1	3.16e-07	6.5	0.878
0	0	1	0	2	127	2	2.51e-07	6.6	0.644
0	0	1	0	2	127	3	2.00e-07	6.7	0.652
0	0	1	1	2	128	1	3.98e-07	6.4	0.761
0	0	1	1	2	128	2	2.00e-07	6.7	0.604
0	0	1	1	2	128	3	2.51e-07	6.6	0.686
0	0	1	0	3	173	1	1.26e-06	5.9	nd
0	0	1	0	3	173	2	1.00e-06	6	nd
0	0	1	0	3	173	3	1.00e-06	6	nd
0	0	1	1	3	174	1	1.26e-06	5.9	nd

Table A5 (cont). 1996 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
1	0	0	0	1	2	2	6.31e-07	6.2	nd
1	0	0	0	1	2	3	6.31e-07	6.2	nd
1	0	0	1	1	1	1	7.94e-07	6.1	0.906
1	0	0	1	1	1	2	5.01e-07	6.3	0.568
1	0	0	1	1	1	3	7.94e-07	6.1	0.792
1	0	0	0	2	95	1	1.26e-06	5.9	0.680
1	0	0	0	2	95	2	3.16e-07	6.5	0.531
1	0	0	0	2	95	3	1.00e-06	6	0.624
1	0	0	1	2	96	1	1.26e-06	5.9	0.834
1	0	0	1	2	96	2	3.16e-07	6.5	0.544
1	0	0	1	2	96	3	7.94e-07	6.1	0.679
1	0	0	0	3	208	1	6.31e-07	6.2	1.253
1	0	0	0	3	208	2	1.26e-06	5.9	0.733
1	0	0	0	3	208	3	7.94e-07	6.1	1.152
1	0	0	1	3	207	1	2.51e-06	5.6	0.982
1	0	0	1	3	207	2	2.51e-06	5.6	0.700
1	0	0	1	3	207	3	1.58e-06	5.8	0.920
1	0	0	0	4	241	1	7.94e-07	6.1	0.854
1	0	0	0	4	241	2	2.00e-07	6.7	0.554
1	0	0	0	4	241	3	3.98e-07	6.4	0.813
1	0	0	1	4	242	1	1.26e-06	5.9	0.832
1	0	0	1	4	242	2	3.98e-07	6.4	0.599
1	0	0	1	4	242	3	6.31e-07	6.2	0.715
1	0	1	0	1	4	1	7.94e-07	6.1	0.729
1	0	1	0	1	4	2	7.94e-07	6.1	0.629
1	0	1	0	1	4	3	6.31e-07	6.2	0.717
1	0	1	1	1	3	1	2.51e-07	6.6	0.806
1	0	1	1	1	3	2	5.01e-07	6.3	nd
1	0	1	1	1	3	3	2.51e-07	6.6	nd
1	0	1	0	2	93	1	3.98e-06	5.4	0.767
1	0	1	0	2	93	2	2.00e-06	5.7	0.634
1	0	1	0	2	93	3	2.00e-06	5.7	0.716
1	0	1	1	2	94	1	1.00e-06	6	0.859
1	0	1	1	2	94	2	7.94e-07	6.1	0.657
1	0	1	1	2	94	3	6.31e-07	6.2	0.708
1	0	1	0	3	205	1	1.00e-06	6	0.872
1	0	1	0	3	205	2	7.94e-07	6.1	0.856
1	0	1	0	3	205	3	1.26e-06	5.9	0.837
1	0	1	1	3	206	1	2.00e-06	5.7	0.878
1	0	1	1	3	206	2	1.00e-06	6	0.794

Table A5 (cont). 1996 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
2	0	0	0	1	112	3	2.51e-06	5.6	0.791
2	0	0	1	1	111	1	7.94e-07	6.1	1.194
2	0	0	1	1	111	2	2.00e-06	5.7	0.660
2	0	0	1	1	111	3	2.51e-06	5.6	1.086
2	0	0	0	2	17	1	6.31e-06	5.2	0.979
2	0	0	0	2	17	2	6.31e-06	5.2	0.518
2	0	0	0	2	17	3	7.94e-06	5.1	0.744
2	0	0	1	2	18	1	2.51e-06	5.6	1.410
2	0	0	1	2	18	2	1.26e-06	5.9	0.586
2	0	0	1	2	18	3	2.00e-06	5.7	0.694
2	0	0	0	3	233	1	1.58e-06	5.8	0.952
2	0	0	0	3	233	2	6.31e-07	6.2	0.727
2	0	0	0	3	233	3	1.58e-06	5.8	1.037
2	0	0	1	3	234	1	7.94e-07	6.1	1.141
2	0	0	1	3	234	2	6.31e-07	6.2	0.833
2	0	0	1	3	234	3	7.94e-07	6.1	1.156
2	0	0	0	4	153	1	2.00e-06	5.7	0.746
2	0	0	0	4	153	2	1.00e-06	6	1.110
2	0	0	0	4	153	3	1.58e-06	5.8	1.065
2	0	0	1	4	154	1	1.58e-06	5.8	1.018
2	0	0	1	4	154	2	7.94e-07	6.1	0.619
2	0	0	1	4	154	3	1.26e-06	5.9	0.864
2	0	1	0	1	109	1	1.26e-06	5.9	0.901
2	0	1	0	1	109	2	7.94e-07	6.1	0.602
2	0	1	0	1	109	3	1.00e-06	6	nd
2	0	1	1	1	110	1	3.16e-07	6.5	0.882
2	0	1	1	1	110	2	3.16e-07	6.5	0.640
2	0	1	1	1	110	3	3.98e-07	6.4	0.803
2	0	1	0	2	20	1	6.31e-07	6.2	0.885
2	0	1	0	2	20	2	3.16e-07	6.5	0.595
2	0	1	0	2	20	3	7.94e-07	6.1	0.823
2	0	1	1	2	19	1	3.98e-07	6.4	0.720
2	0	1	1	2	19	2	5.01e-07	6.3	0.675
2	0	1	1	2	19	3	7.94e-07	6.1	0.750
2	0	1	0	3	236	1	2.00e-06	5.7	1.080
2	0	1	0	3	236	2	7.94e-07	6.1	0.852
2	0	1	0	3	236	3	2.00e-06	5.7	0.883
2	0	1	1	3	235	1	7.94e-07	6.1	1.062
2	0	1	1	3	235	2	3.98e-07	6.4	0.836
2	0	1	1	3	235	3	5.01e-07	6.3	nd

Table A5 (cont). 1996 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
3	0	0	1	1	42	1	1.26e-05	4.9	0.773
3	0	0	1	1	42	2	6.31e-07	6.2	0.478
3	0	0	1	1	42	3	3.98e-06	5.4	0.658
3	0	0	0	2	57	1	3.16e-06	5.5	1.349
3	0	0	0	2	57	2	3.16e-06	5.5	0.563
3	0	0	0	2	57	3	7.94e-07	6.1	0.893
3	0	0	1	2	58	1	5.01e-07	6.3	1.233
3	0	0	1	2	58	2	1.26e-06	5.9	0.608
3	0	0	1	2	58	3	3.16e-07	6.5	0.977
3	0	0	0	3	139	1	5.01e-06	5.3	0.878
3	0	0	0	3	139	2	1.00e-06	6	0.630
3	0	0	0	3	139	3	3.16e-06	5.5	0.857
3	0	0	1	3	140	1	3.16e-06	5.5	1.160
3	0	0	1	3	140	2	1.26e-06	5.9	0.711
3	0	0	1	3	140	3	1.26e-06	5.9	1.033
3	0	0	0	4	192	1	7.94e-06	5.1	1.169
3	0	0	0	4	192	2	1.58e-06	5.8	0.739
3	0	0	0	4	192	3	1.58e-06	5.8	0.763
3	0	0	1	4	191	1	2.51e-06	5.6	0.931
3	0	0	1	4	191	2	5.01e-07	6.3	0.621
3	0	0	1	4	191	3	1.58e-06	5.8	0.793
3	0	1	0	1	44	1	3.98e-06	5.4	0.640
3	0	1	0	1	44	2	6.31e-07	6.2	0.495
3	0	1	0	1	44	3	2.51e-06	5.6	0.655
3	0	1	1	1	43	1	1.58e-06	5.8	0.644
3	0	1	1	1	43	2	1.00e-06	6	0.567
3	0	1	1	1	43	3	1.26e-06	5.9	0.605
3	0	1	0	2	60	1	1.26e-06	5.9	1.104
3	0	1	0	2	60	2	6.31e-07	6.2	0.609
3	0	1	0	2	60	3	1.26e-06	5.9	0.833
3	0	1	1	2	59	1	3.16e-07	6.5	0.879
3	0	1	1	2	59	2	3.98e-07	6.4	0.637
3	0	1	1	2	59	3	3.16e-07	6.5	0.897
3	0	1	0	3	137	1	5.01e-06	5.3	1.013
3	0	1	0	3	137	2	1.26e-06	5.9	0.809
3	0	1	0	3	137	3	1.00e-06	6	1.003
3	0	1	1	3	138	1	1.00e-06	6	1.020
3	0	1	1	3	138	2	6.31e-07	6.2	0.828
3	0	1	1	3	138	3	7.94e-07	6.1	0.975
3	0	1	0	4	190	1	2.00e-06	5.7	0.561

Table A5 (cont). 1996 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
0	1	0	1	1	74	2	1.58e-06	5.8	0.544
0	1	0	1	1	74	3	1.00e-06	6	0.723
0	1	0	0	2	123	1	1.58e-06	5.8	1.110
0	1	0	0	2	123	2	1.26e-06	5.9	0.655
0	1	0	0	2	123	3	2.00e-06	5.7	0.779
0	1	0	1	2	124	1	1.00e-06	6	0.876
0	1	0	1	2	124	2	1.26e-06	5.9	0.554
0	1	0	1	2	124	3	1.00e-06	6	0.802
0	1	0	0	3	166	1	5.01e-07	6.3	1.741
0	1	0	0	3	166	2	1.26e-06	5.9	0.804
0	1	0	0	3	166	3	7.94e-07	6.1	nd
0	1	0	1	3	165	1	6.31e-07	6.2	1.168
0	1	0	1	3	165	2	1.00e-06	6	0.676
0	1	0	1	3	165	3	7.94e-07	6.1	0.891
0	1	0	0	4	224	1	6.31e-07	6.2	1.141
0	1	0	0	4	224	2	7.94e-07	6.1	0.691
0	1	0	0	4	224	3	7.94e-07	6.1	0.977
0	1	0	1	4	223	1	7.94e-07	6.1	1.080
0	1	0	1	4	223	2	5.01e-07	6.3	0.677
0	1	0	1	4	223	3	7.94e-07	6.1	1.068
0	1	1	0	1	75	1	5.01e-06	5.3	0.745
0	1	1	0	1	75	2	7.94e-07	6.1	0.647
0	1	1	0	1	75	3	7.94e-07	6.1	0.789
0	1	1	1	1	76	1	7.94e-07	6.1	0.814
0	1	1	1	1	76	2	6.31e-07	6.2	0.593
0	1	1	1	1	76	3	7.94e-07	6.1	0.812
0	1	1	0	2	121	1	1.26e-06	5.9	0.865
0	1	1	0	2	121	2	1.00e-06	6	0.734
0	1	1	0	2	121	3	1.00e-06	6	0.760
0	1	1	1	2	122	1	1.00e-06	6	0.954
0	1	1	1	2	122	2	3.16e-06	5.5	0.614
0	1	1	1	2	122	3	3.98e-07	6.4	0.860
0	1	1	0	3	168	1	6.31e-07	6.2	1.052
0	1	1	0	3	168	2	5.01e-07	6.3	0.842
0	1	1	0	3	168	3	6.31e-07	6.2	1.202
0	1	1	1	3	167	1	3.98e-07	6.4	1.047
0	1	1	1	3	167	2	5.01e-07	6.3	0.827
0	1	1	1	3	167	3	3.98e-07	6.4	0.993
0	1	1	0	4	221	1	2.00e-06	5.7	0.825
0	1	1	0	4	221	2	5.01e-07	6.3	0.746

Table A5 (cont). 1996 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
1	1	0	1	1	8	3	1.58e-06	5.8	1.035
1	1	0	0	2	81	1	6.31e-06	5.2	1.028
1	1	0	0	2	81	2	6.31e-06	5.2	0.554
1	1	0	0	2	81	3	7.94e-06	5.1	0.733
1	1	0	1	2	82	1	2.51e-06	5.6	1.259
1	1	0	1	2	82	2	3.98e-06	5.4	0.553
1	1	0	1	2	82	3	1.00e-06	6	1.194
1	1	0	0	3	202	1	1.00e-06	6	1.359
1	1	0	0	3	202	2	1.00e-06	6	0.782
1	1	0	0	3	202	3	1.26e-06	5.9	1.253
1	1	0	1	3	201	1	2.00e-06	5.7	1.140
1	1	0	1	3	201	2	1.00e-06	6	0.666
1	1	0	1	3	201	3	1.26e-06	5.9	0.951
1	1	0	0	4	251	1	1.58e-06	5.8	1.127
1	1	0	0	4	251	2	2.00e-06	5.7	0.742
1	1	0	0	4	251	3	2.00e-06	5.7	0.908
1	1	0	1	4	252	1	6.31e-07	6.2	1.498
1	1	0	1	4	252	2	1.00e-06	6	0.738
1	1	0	1	4	252	3	1.58e-06	5.8	1.223
1	1	1	0	1	6	1	5.01e-07	6.3	1.058
1	1	1	0	1	6	2	1.00e-06	6	nd
1	1	1	0	1	6	3	1.00e-06	6	nd
1	1	1	1	1	5	1	6.31e-07	6.2	0.926
1	1	1	1	1	5	2	1.00e-06	6	nd
1	1	1	1	1	5	3	1.00e-06	6	0.831
1	1	1	0	2	83	1	5.01e-07	6.3	0.806
1	1	1	0	2	83	2	1.00e-06	6	0.689
1	1	1	0	2	83	3	2.51e-06	5.6	nd
1	1	1	1	2	84	1	7.94e-07	6.1	0.854
1	1	1	1	2	84	2	3.98e-07	6.4	0.628
1	1	1	1	2	84	3	7.94e-07	6.1	0.776
1	1	1	0	3	203	1	2.51e-06	5.6	0.975
1	1	1	0	3	203	2	1.26e-06	5.9	0.878
1	1	1	0	3	203	3	1.00e-06	6	1.143
1	1	1	1	3	204	1	6.31e-07	6.2	1.017
1	1	1	1	3	204	2	3.98e-07	6.4	0.910
1	1	1	1	3	204	3	1.00e-06	6	0.915
1	1	1	0	4	250	1	7.94e-07	6.1	1.058
1	1	1	0	4	250	2	7.94e-07	6.1	0.796
1	1	1	0	4	250	3	6.31e-07	6.2	1.017

Table A5 (cont). 1996 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
2	1	0	0	2	31	1	6.31e-06	5.2	nd
2	1	0	0	2	31	2	1.58e-06	5.8	0.581
2	1	0	0	2	31	3	3.16e-06	5.5	0.776
2	1	0	1	2	32	1	6.31e-06	5.2	nd
2	1	0	1	2	32	2	2.00e-06	5.7	0.572
2	1	0	1	2	32	3	1.26e-06	5.9	nd
2	1	0	0	3	240	1	2.00e-06	5.7	1.037
2	1	0	0	3	240	2	1.26e-06	5.9	0.684
2	1	0	0	3	240	3	1.58e-06	5.8	1.058
2	1	0	1	3	239	1	7.94e-06	5.1	0.924
2	1	0	1	3	239	2	3.98e-06	5.4	0.628
2	1	0	1	3	239	3	5.01e-06	5.3	0.836
2	1	0	0	4	157	1	6.31e-06	5.2	nd
2	1	0	0	4	157	2	6.31e-06	5.2	0.742
2	1	0	0	4	157	3	5.01e-06	5.3	1.017
2	1	0	1	4	158	1	3.98e-06	5.4	1.051
2	1	0	1	4	158	2	1.58e-06	5.8	0.567
2	1	0	1	4	158	3	3.16e-06	5.5	1.122
2	1	1	0	1	104	1	1.00e-06	6	0.708
2	1	1	0	1	104	2	1.26e-06	5.9	nd
2	1	1	0	1	104	3	5.01e-07	6.3	nd
2	1	1	1	1	103	1	1.58e-06	5.8	1.019
2	1	1	1	1	103	2	2.00e-06	5.7	0.679
2	1	1	1	1	103	3	2.51e-06	5.6	nd
2	1	1	0	2	30	1	1.58e-06	5.8	1.058
2	1	1	0	2	30	2	1.26e-06	5.9	nd
2	1	1	0	2	30	3	1.00e-06	6	0.810
2	1	1	1	2	29	1	3.98e-07	6.4	1.167
2	1	1	1	2	29	2	7.94e-07	6.1	0.655
2	1	1	1	2	29	3	7.94e-07	6.1	0.785
2	1	1	0	3	237	1	3.16e-06	5.5	1.057
2	1	1	0	3	237	2	1.58e-06	5.8	0.735
2	1	1	0	3	237	3	2.00e-06	5.7	0.942
2	1	1	1	3	238	1	5.01e-07	6.3	0.979
2	1	1	1	3	238	2	1.58e-06	5.8	0.678
2	1	1	1	3	238	3	1.00e-06	6	nd
2	1	1	0	4	159	1	1.26e-06	5.9	1.041
2	1	1	0	4	159	2	1.26e-06	5.9	0.724
2	1	1	0	4	159	3	1.26e-06	5.9	0.807
2	1	1	1	4	160	1	1.00e-06	6	0.851

Table A5 (cont). 1996 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
3	1	0	0	2	50	2	1.26e-05	4.9	0.539
3	1	0	0	2	50	3	1.58e-05	4.8	0.869
3	1	0	1	2	49	1	1.58e-05	4.8	1.036
3	1	0	1	2	49	2	2.51e-05	4.6	0.588
3	1	0	1	2	49	3	1.58e-05	4.8	0.761
3	1	0	0	3	131	1	2.51e-06	5.6	1.419
3	1	0	0	3	131	2	5.01e-06	5.3	0.748
3	1	0	0	3	131	3	7.94e-06	5.1	1.098
3	1	0	1	3	132	1	1.00e-05	5	1.385
3	1	0	1	3	132	2	1.26e-05	4.9	0.797
3	1	0	1	3	132	3	6.31e-06	5.2	1.176
3	1	0	0	4	184	1	6.31e-06	5.2	1.356
3	1	0	0	4	184	2	3.98e-06	5.4	0.807
3	1	0	0	4	184	3	5.01e-06	5.3	0.989
3	1	0	1	4	183	1	1.58e-05	4.8	1.084
3	1	0	1	4	183	2	1.58e-05	4.8	0.631
3	1	0	1	4	183	3	1.00e-05	5	0.775
3	1	1	0	1	33	1	6.31e-06	5.2	0.771
3	1	1	0	1	33	2	1.00e-06	6	0.654
3	1	1	0	1	33	3	3.16e-06	5.5	0.936
3	1	1	1	1	34	1	2.00e-06	5.7	0.959
3	1	1	1	1	34	2	2.00e-06	5.7	0.637
3	1	1	1	1	34	3	1.58e-06	5.8	0.757
3	1	1	0	2	52	1	1.26e-05	4.9	0.903
3	1	1	0	2	52	2	3.98e-06	5.4	0.685
3	1	1	0	2	52	3	5.01e-06	5.3	0.826
3	1	1	1	2	51	1	7.94e-06	5.1	0.675
3	1	1	1	2	51	2	2.00e-06	5.7	0.732
3	1	1	1	2	51	3	3.16e-06	5.5	0.753
3	1	1	0	3	129	1	6.31e-06	5.2	0.841
3	1	1	0	3	129	2	2.00e-06	5.7	0.754
3	1	1	0	3	129	3	3.16e-06	5.5	0.843
3	1	1	1	3	130	1	1.58e-06	5.8	1.103
3	1	1	1	3	130	2	1.26e-06	5.9	0.871
3	1	1	1	3	130	3	1.00e-06	6	0.968
3	1	1	0	4	181	1	2.51e-06	5.6	1.014
3	1	1	0	4	181	2	1.00e-06	6	0.790
3	1	1	0	4	181	3	1.00e-06	6	0.858
3	1	1	1	4	182	1	2.00e-06	5.7	0.971
3	1	1	1	4	182	2	1.00e-06	6	0.825

Table A6. 1997 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
0	0	0	0	1	69	1	7.08e-07	6.15	0.595
0	0	0	0	1	69	2	7.41e-07	6.13	0.471
0	0	0	0	1	69	3	1.12e-06	5.95	0.472
0	0	0	1	1	70	1	2.29e-07	6.64	0.533
0	0	0	1	1	70	2	2.45e-07	6.61	0.462
0	0	0	1	1	70	3	3.89e-07	6.41	0.644
0	0	0	0	2	125	1	1.48e-07	6.83	0.804
0	0	0	0	2	125	2	1.07e-07	6.97	0.486
0	0	0	0	2	125	3	1.62e-07	6.79	0.726
0	0	0	1	2	126	1	2.40e-07	6.62	0.787
0	0	0	1	2	126	2	1.45e-07	6.84	0.489
0	0	0	1	2	126	3	2.14e-07	6.67	0.605
0	0	0	0	3	175	1	2.82e-07	6.55	0.858
0	0	0	0	3	175	2	1.07e-06	5.97	0.636
0	0	0	0	3	175	3	3.80e-07	6.42	0.992
0	0	0	1	3	176	1	1.51e-07	6.82	1.049
0	0	0	1	3	176	2	9.55e-07	6.02	0.669
0	0	0	1	3	176	3	3.55e-07	6.45	0.868
0	0	0	0	4	213	1	2.24e-07	6.65	0.905
0	0	0	0	4	213	2	1.32e-07	6.88	0.548
0	0	0	0	4	213	3	1.41e-07	6.85	0.728
0	0	0	1	4	214	1	2.75e-07	6.56	1.005
0	0	0	1	4	214	2	1.45e-07	6.84	0.564
0	0	0	1	4	214	3	1.70e-07	6.77	0.691
0	0	1	0	1	71	1	2.24e-07	6.65	0.674
0	0	1	0	1	71	2	2.34e-07	6.63	0.490
0	0	1	0	1	71	3	2.14e-07	6.67	0.587
0	0	1	1	1	72	1	2.88e-07	6.54	0.692
0	0	1	1	1	72	2	2.51e-07	6.60	0.529
0	0	1	1	1	72	3	3.47e-07	6.46	0.616
0	0	1	0	2	127	1	1.66e-07	6.78	0.793
0	0	1	0	2	127	2	1.29e-07	6.89	0.544
0	0	1	0	2	127	3	1.17e-07	6.93	0.674
0	0	1	1	2	128	1	1.78e-07	6.75	0.752
0	0	1	1	2	128	2	2.82e-07	6.55	0.525
0	0	1	1	2	128	3	2.14e-07	6.67	0.646
0	0	1	0	3	173	1	2.69e-07	6.57	1.001
0	0	1	0	3	173	2	3.47e-07	6.46	0.692
0	0	1	0	3	173	3	2.82e-07	6.55	1.031
0	0	1	1	3	174	1	4.37e-07	6.36	0.875

Table A6 (cont). 1997 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
1	0	0	0	1	2	2	nd	nd	nd
1	0	0	0	1	2	3	5.13e-07	6.29	0.985
1	0	0	1	1	1	1	3.72e-07	6.43	1.083
1	0	0	1	1	1	2	3.80e-07	6.42	0.607
1	0	0	1	1	1	3	2.63e-07	6.58	0.819
1	0	0	0	2	95	1	2.51e-07	6.60	1.018
1	0	0	0	2	95	2	1.07e-07	6.97	0.591
1	0	0	0	2	95	3	2.63e-07	6.58	0.763
1	0	0	1	2	96	1	3.55e-07	6.45	1.076
1	0	0	1	2	96	2	2.29e-07	6.64	0.591
1	0	0	1	2	96	3	3.02e-07	6.52	1.051
1	0	0	0	3	208	1	3.02e-07	6.52	1.057
1	0	0	0	3	208	2	5.75e-07	6.24	0.747
1	0	0	0	3	208	3	4.90e-07	6.31	0.942
1	0	0	1	3	207	1	1.91e-07	6.72	1.156
1	0	0	1	3	207	2	6.03e-07	6.22	0.748
1	0	0	1	3	207	3	5.25e-07	6.28	0.886
1	0	0	0	4	241	1	2.57e-07	6.59	0.992
1	0	0	0	4	241	2	1.45e-07	6.84	0.655
1	0	0	0	4	241	3	1.95e-07	6.71	0.845
1	0	0	1	4	242	1	4.27e-07	6.37	1.179
1	0	0	1	4	242	2	1.78e-07	6.75	0.632
1	0	0	1	4	242	3	3.31e-07	6.48	0.862
1	0	1	0	1	4	1	2.34e-07	6.63	1.049
1	0	1	0	1	4	2	1.95e-07	6.71	0.936
1	0	1	0	1	4	3	2.00e-07	6.7	0.938
1	0	1	1	1	3	1	1.15e-07	6.94	1.150
1	0	1	1	1	3	2	1.74e-07	6.76	0.601
1	0	1	1	1	3	3	1.41e-07	6.85	0.872
1	0	1	0	2	93	1	3.72e-07	6.43	1.149
1	0	1	0	2	93	2	2.57e-07	6.59	0.724
1	0	1	0	2	93	3	2.14e-07	6.67	0.791
1	0	1	1	2	94	1	2.09e-07	6.68	1.006
1	0	1	1	2	94	2	1.95e-07	6.71	0.660
1	0	1	1	2	94	3	2.45e-07	6.61	0.766
1	0	1	0	3	205	1	2.51e-07	6.60	0.934
1	0	1	0	3	205	2	2.88e-07	6.54	0.708
1	0	1	0	3	205	3	2.88e-07	6.54	0.927
1	0	1	1	3	206	1	6.92e-07	6.16	0.979
1	0	1	1	3	206	2	5.75e-07	6.24	0.685

Table A6 (cont). 1997 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
2	0	0	0	1	112	3	8.91e-07	6.05	0.909
2	0	0	1	1	111	1	3.24e-07	6.49	1.178
2	0	0	1	1	111	2	4.47e-07	6.35	0.600
2	0	0	1	1	111	3	4.57e-07	6.34	0.762
2	0	0	0	3	233	1	3.16e-07	6.50	1.486
2	0	0	0	3	233	2	3.24e-07	6.49	0.807
2	0	0	0	3	233	3	3.31e-07	6.48	1.039
2	0	0	1	3	234	1	2.04e-07	6.69	1.076
2	0	0	1	3	234	2	2.51e-07	6.60	0.728
2	0	0	1	3	234	3	2.19e-07	6.66	0.874
2	0	0	0	4	153	1	7.94e-07	6.10	1.005
2	0	0	0	4	153	2	3.89e-07	6.41	0.705
2	0	0	0	4	153	3	2.95e-07	6.53	0.898
2	0	0	1	4	154	1	2.88e-07	6.54	1.414
2	0	0	1	4	154	2	3.47e-07	6.46	0.661
2	0	0	1	4	154	3	3.16e-07	6.50	0.892
2	0	1	0	1	109	1	2.29e-07	6.64	0.937
2	0	1	0	1	109	2	2.88e-07	6.54	0.732
2	0	1	0	1	109	3	3.02e-07	6.52	0.811
2	0	1	1	1	110	1	1.12e-07	6.95	0.889
2	0	1	1	1	110	2	1.17e-07	6.93	0.643
2	0	1	1	1	110	3	1.05e-07	6.98	0.770
2	0	1	0	2	20	1	2.82e-07	6.55	1.032
2	0	1	0	2	20	2	2.75e-07	6.56	0.639
2	0	1	0	2	20	3	2.09e-07	6.68	0.741
2	0	1	1	2	19	1	1.26e-07	6.90	1.014
2	0	1	1	2	19	2	2.00e-07	6.70	0.714
2	0	1	1	2	19	3	1.23e-07	6.91	0.950
2	0	1	0	3	236	1	2.63e-07	6.58	1.228
2	0	1	0	3	236	2	3.16e-07	6.50	0.852
2	0	1	0	3	236	3	3.31e-07	6.48	0.881
2	0	1	1	3	235	1	1.20e-07	6.92	1.107
2	0	1	1	3	235	2	1.66e-07	6.78	0.869
2	0	1	1	3	235	3	1.20e-07	6.92	1.120
2	0	1	0	4	156	1	3.47e-07	6.46	0.901
2	0	1	0	4	156	2	3.24e-07	6.49	0.638
2	0	1	0	4	156	3	3.31e-07	6.48	0.815
2	0	1	1	4	155	1	1.51e-07	6.82	1.442
2	0	1	1	4	155	2	2.75e-07	6.56	0.741
2	0	1	1	4	155	3	1.48e-07	6.83	0.864

Table A6 (cont). 1997 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
3	0	0	1	2	58	1	1.02e-06	5.99	1.145
3	0	0	1	2	58	2	3.16e-07	6.50	0.521
3	0	0	1	2	58	3	6.17e-07	6.21	1.104
3	0	0	0	3	139	1	7.94e-07	6.10	1.073
3	0	0	0	3	139	2	7.94e-07	6.10	0.646
3	0	0	0	3	139	3	9.33e-07	6.03	0.875
3	0	0	1	3	140	1	4.37e-07	6.36	1.253
3	0	0	1	3	140	2	5.25e-07	6.28	0.700
3	0	0	1	3	140	3	5.37e-07	6.27	0.942
3	0	0	0	4	192	1	6.76e-07	6.17	0.880
3	0	0	0	4	192	2	2.63e-07	6.58	0.587
3	0	0	0	4	192	3	5.13e-07	6.29	0.770
3	0	0	1	4	191	1	3.89e-07	6.41	0.873
3	0	0	1	4	191	2	1.82e-07	6.74	0.628
3	0	0	1	4	191	3	3.09e-07	6.51	0.778
3	0	1	0	1	44	1	7.41e-07	6.13	0.816
3	0	1	0	1	44	2	6.17e-07	6.21	0.581
3	0	1	0	1	44	3	9.12e-07	6.04	0.793
3	0	1	1	1	43	1	3.31e-07	6.48	0.722
3	0	1	1	1	43	2	2.34e-07	6.63	0.591
3	0	1	1	1	43	3	3.16e-07	6.50	0.661
3	0	1	0	2	60	1	2.88e-07	6.54	0.736
3	0	1	0	2	60	2	3.89e-07	6.41	1.061
3	0	1	0	2	60	3	3.63e-07	6.44	0.572
3	0	1	1	2	59	1	9.12e-08	7.04	0.914
3	0	1	1	2	59	2	1.02e-07	6.99	0.609
3	0	1	1	2	59	3	9.77e-08	7.01	0.757
3	0	1	0	3	137	1	8.51e-07	6.07	0.965
3	0	1	0	3	137	2	6.61e-07	6.18	0.711
3	0	1	0	3	137	3	8.13e-07	6.09	0.916
3	0	1	1	3	138	1	2.14e-07	6.67	1.009
3	0	1	1	3	138	2	3.89e-07	6.41	0.636
3	0	1	1	3	138	3	2.69e-07	6.57	0.833
3	0	1	0	4	190	1	2.34e-07	6.63	0.982
3	0	1	0	4	190	2	3.80e-07	6.42	0.718
3	0	1	0	4	190	3	3.47e-07	6.46	0.810
3	0	1	1	4	189	1	2.34e-07	6.63	0.965
3	0	1	1	4	189	2	1.91e-07	6.72	0.709
3	0	1	1	4	189	3	1.35e-07	6.87	0.851
0	1	0	0	1	73	1	2.75e-07	6.56	0.844

Table A6 (cont). 1997 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
0	1	0	1	2	124	2	2.95e-07	6.53	0.547
0	1	0	1	2	124	3	1.29e-07	6.89	1.110
0	1	0	0	3	166	1	1.78e-07	6.75	1.185
0	1	0	0	3	166	2	4.27e-07	6.37	0.678
0	1	0	0	3	166	3	2.82e-07	6.55	0.925
0	1	0	1	3	165	1	1.51e-07	6.82	1.326
0	1	0	1	3	165	2	4.47e-07	6.35	0.700
0	1	0	1	3	165	3	2.14e-07	6.67	1.009
0	1	0	0	4	224	1	2.24e-07	6.65	1.313
0	1	0	0	4	224	2	3.72e-07	6.43	0.755
0	1	0	0	4	224	3	2.88e-07	6.54	0.894
0	1	0	1	4	223	1	1.58e-07	6.80	1.060
0	1	0	1	4	223	2	2.14e-07	6.67	0.750
0	1	0	1	4	223	3	1.58e-07	6.80	0.835
0	1	1	0	1	75	1	1.78e-07	6.75	0.904
0	1	1	0	1	75	2	2.51e-07	6.60	0.722
0	1	1	0	1	75	3	2.14e-07	6.67	0.775
0	1	1	1	1	76	1	1.32e-07	6.88	0.578
0	1	1	1	1	76	2	3.09e-07	6.51	0.581
0	1	1	1	1	76	3	3.39e-07	6.47	0.649
0	1	1	0	2	121	1	4.37e-07	6.36	0.907
0	1	1	0	2	121	2	3.98e-07	6.40	0.657
0	1	1	0	2	121	3	3.80e-07	6.42	0.767
0	1	1	1	2	122	1	3.47e-07	6.46	1.086
0	1	1	1	2	122	2	2.00e-07	6.70	0.708
0	1	1	1	2	122	3	2.63e-07	6.58	0.809
0	1	1	0	3	168	1	1.41e-07	6.85	0.987
0	1	1	0	3	168	2	1.62e-07	6.79	0.798
0	1	1	0	3	168	3	2.24e-07	6.65	1.314
0	1	1	1	3	167	1	8.32e-08	7.08	1.198
0	1	1	1	3	167	2	1.62e-07	6.79	0.759
0	1	1	1	3	167	3	8.51e-08	7.07	0.985
0	1	1	0	4	221	1	3.55e-07	6.45	1.145
0	1	1	0	4	221	2	2.63e-07	6.58	0.680
0	1	1	0	4	221	3	3.16e-07	6.50	0.915
0	1	1	1	4	222	1	2.82e-07	6.55	1.088
0	1	1	1	4	222	2	1.55e-07	6.81	0.656
0	1	1	1	4	222	3	2.51e-07	6.60	0.843
1	1	0	0	1	7	1	8.91e-07	6.05	1.262
1	1	0	0	1	7	2	3.39e-06	5.47	0.557

Table A6 (cont). 1997 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
1	1	0	1	2	82	3	5.50e-07	6.26	0.975
1	1	0	0	3	202	1	3.63e-07	6.44	1.252
1	1	0	0	3	202	2	3.98e-07	6.40	0.737
1	1	0	0	3	202	3	1.82e-07	6.74	1.082
1	1	0	1	3	201	1	1.78e-07	6.75	1.300
1	1	0	1	3	201	2	3.47e-07	6.46	0.704
1	1	0	1	3	201	3	1.82e-07	6.74	1.057
1	1	0	0	4	251	1	2.82e-07	6.55	1.432
1	1	0	0	4	251	2	7.41e-07	6.13	0.683
1	1	0	0	4	251	3	4.79e-07	6.32	1.008
1	1	0	1	4	252	1	2.45e-07	6.61	1.473
1	1	0	1	4	252	2	7.94e-07	6.10	0.735
1	1	0	1	4	252	3	4.07e-07	6.39	1.067
1	1	1	0	1	6	1	2.00e-07	6.70	0.983
1	1	1	0	1	6	2	3.47e-07	6.46	0.665
1	1	1	0	1	6	3	5.25e-07	6.28	0.858
1	1	1	1	1	5	1	1.26e-07	6.90	1.028
1	1	1	1	1	5	2	3.47e-07	6.46	0.664
1	1	1	1	1	5	3	4.07e-07	6.39	0.911
1	1	1	0	2	83	1	3.24e-07	6.49	0.914
1	1	1	0	2	83	2	7.94e-07	6.10	0.705
1	1	1	0	2	83	3	4.79e-07	6.32	0.933
1	1	1	1	2	84	1	1.32e-07	6.88	0.861
1	1	1	1	2	84	2	1.66e-07	6.78	0.645
1	1	1	1	2	84	3	1.55e-07	6.81	0.916
1	1	1	0	3	203	1	2.51e-07	6.60	0.980
1	1	1	0	3	203	2	3.47e-07	6.46	0.728
1	1	1	0	3	203	3	2.69e-07	6.57	0.897
1	1	1	1	3	204	1	1.12e-07	6.95	1.128
1	1	1	1	3	204	2	2.51e-07	6.60	0.842
1	1	1	1	3	204	3	1.45e-07	6.84	1.042
1	1	1	0	4	250	1	2.88e-07	6.54	1.138
1	1	1	0	4	250	2	1.26e-07	6.90	0.756
1	1	1	0	4	250	3	2.69e-07	6.57	1.084
1	1	1	1	4	249	1	1.10e-07	6.96	1.149
1	1	1	1	4	249	2	2.04e-07	6.69	0.726
1	1	1	1	4	249	3	1.35e-07	6.87	1.013
2	1	0	0	1	101	1	1.62e-06	5.79	1.122
2	1	0	0	1	101	2	2.29e-06	5.64	0.602
2	1	0	0	1	101	3	3.31e-06	5.48	0.755

Table A6 (cont). 1997 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
2	1	0	0	3	240	1	2.63e-07	6.58	1.200
2	1	0	0	3	240	2	2.95e-07	6.53	0.721
2	1	0	0	3	240	3	9.77e-07	6.01	0.873
2	1	0	1	3	239	1	2.51e-07	6.60	1.607
2	1	0	1	3	239	2	8.51e-07	6.07	0.705
2	1	0	1	3	239	3	9.77e-07	6.01	0.975
2	1	0	0	4	157	1	1.12e-06	5.95	1.353
2	1	0	0	4	157	2	1.62e-06	5.79	0.656
2	1	0	0	4	157	3	1.02e-06	5.99	1.061
2	1	0	1	4	158	1	6.61e-07	6.18	1.369
2	1	0	1	4	158	2	6.46e-07	6.19	0.611
2	1	0	1	4	158	3	6.17e-07	6.21	1.077
2	1	1	0	1	104	1	2.82e-07	6.55	0.843
2	1	1	0	1	104	2	3.63e-07	6.44	0.651
2	1	1	0	1	104	3	2.75e-07	6.56	0.766
2	1	1	1	1	103	1	1.82e-07	6.74	1.026
2	1	1	1	1	103	2	3.02e-07	6.52	0.671
2	1	1	1	1	103	3	2.51e-07	6.60	0.829
2	1	1	0	2	30	1	2.24e-07	6.65	1.076
2	1	1	0	2	30	2	4.79e-07	6.32	0.652
2	1	1	0	2	30	3	6.92e-07	6.16	0.938
2	1	1	1	2	29	1	1.17e-07	6.93	1.317
2	1	1	1	2	29	2	3.09e-07	6.51	0.644
2	1	1	1	2	29	3	1.58e-07	6.80	0.853
2	1	1	0	3	237	1	3.80e-07	6.42	1.066
2	1	1	0	3	237	2	5.50e-07	6.26	0.805
2	1	1	0	3	237	3	3.55e-07	6.45	0.973
2	1	1	1	3	238	1	1.10e-07	6.96	1.097
2	1	1	1	3	238	2	2.19e-07	6.66	0.887
2	1	1	1	3	238	3	1.29e-07	6.89	0.946
2	1	1	0	4	159	1	4.57e-07	6.34	1.336
2	1	1	0	4	159	2	5.37e-07	6.27	0.739
2	1	1	0	4	159	3	2.34e-07	6.63	0.917
2	1	1	1	4	160	1	1.02e-07	6.99	1.559
2	1	1	1	4	160	2	2.51e-07	6.60	0.872
2	1	1	1	4	160	3	1.29e-07	6.89	0.822
3	1	0	0	1	35	1	1.58e-06	5.80	1.352
3	1	0	0	1	35	2	3.31e-06	5.48	0.504
3	1	0	0	1	35	3	3.02e-06	5.52	0.935
3	1	0	1	1	36	1	5.25e-06	5.28	0.829

Table A6 (cont). 1997 pH, H ion, and total carbon

N rate	Cover	Tillage	Lime rate	Rep	Plot #	depth	H ion	pH	TC g/kg
3	1	0	0	3	131	2	4.57e-06	5.34	0.671
3	1	0	0	3	131	3	4.79e-06	5.32	0.874
3	1	0	1	3	132	1	1.12e-06	5.95	1.437
3	1	0	1	3	132	2	5.01e-06	5.30	0.667
3	1	0	1	3	132	3	1.58e-06	5.80	0.973
3	1	0	0	4	184	1	1.70e-06	5.77	1.165
3	1	0	0	4	184	2	1.10e-06	5.96	0.623
3	1	0	0	4	184	3	7.41e-07	6.13	0.832
3	1	0	1	4	183	1	1.26e-06	5.90	1.073
3	1	0	1	4	183	2	3.02e-06	5.52	0.616
3	1	0	1	4	183	3	2.14e-06	5.67	0.880
3	1	1	0	1	33	1	2.51e-07	6.60	0.974
3	1	1	0	1	33	2	3.89e-07	6.41	0.572
3	1	1	0	1	33	3	3.55e-07	6.45	0.770
3	1	1	1	1	34	1	5.13e-07	6.29	0.913
3	1	1	1	1	34	2	5.01e-07	6.30	0.558
3	1	1	1	1	34	3	4.17e-07	6.38	0.781
3	1	1	0	2	52	1	1.05e-06	5.98	0.823
3	1	1	0	2	52	2	1.95e-06	5.71	0.595
3	1	1	0	2	52	3	1.58e-06	5.80	0.835
3	1	1	1	2	51	1	1.20e-06	5.92	0.733
3	1	1	1	2	51	2	1.23e-06	5.91	0.622
3	1	1	1	2	51	3	7.08e-07	6.15	0.690
3	1	1	0	3	129	1	1.07e-06	5.97	1.019
3	1	1	0	3	129	2	5.75e-07	6.24	0.688
3	1	1	0	3	129	3	8.13e-07	6.09	0.782
3	1	1	1	3	130	1	3.80e-07	6.42	1.048
3	1	1	1	3	130	2	3.16e-07	6.50	0.726
3	1	1	1	3	130	3	2.88e-07	6.54	0.929
3	1	1	0	4	181	1	3.63e-07	6.44	1.057
3	1	1	0	4	181	2	3.98e-07	6.40	0.752
3	1	1	0	4	181	3	3.39e-07	6.47	0.911
3	1	1	1	4	182	1	1.74e-07	6.76	1.198
3	1	1	1	4	182	2	2.63e-07	6.58	0.704
3	1	1	1	4	182	3	1.62e-07	6.79	0.896

Table A7. 1995 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							-----cmol. kg ⁻¹ -----	
0	0	0	0	1	69	1	0.027	0.122
0	0	0	0	1	69	2	0.112	0.120
0	0	0	1	1	70	1	0.027	0.122
0	0	0	1	1	70	2	0.112	0.120
0	0	0	0	2	125	1	0.027	0.231
0	0	0	0	2	125	2	0.045	0.124
0	0	0	1	2	126	1	0.027	0.231
0	0	0	1	2	126	2	0.045	0.124
0	0	0	0	3	175	1	0.123	0.661
0	0	0	0	3	175	2	0.031	0.703
0	0	0	1	3	176	1	0.123	0.661
0	0	0	1	3	176	2	0.031	0.703
0	0	0	0	4	213	1	0.146	0.635
0	0	0	0	4	213	2	0.041	0.462
0	0	0	1	4	214	1	0.146	0.635
0	0	0	1	4	214	2	0.041	0.462
0	0	1	0	1	71	1	0.028	0.186
0	0	1	0	1	71	2	0.028	0.153
0	0	1	1	1	72	1	0.028	0.186
0	0	1	1	1	72	2	0.028	0.153
0	0	1	0	2	127	1	0.031	0.235
0	0	1	0	2	127	2	0.028	0.157
0	0	1	1	2	128	1	0.031	0.235
0	0	1	1	2	128	2	0.028	0.157
0	0	1	0	3	173	1	0.036	0.610
0	0	1	0	3	173	2	0.032	0.384
0	0	1	1	3	174	1	0.036	0.610
0	0	1	1	3	174	2	0.032	0.384
0	0	1	0	4	215	1	0.129	nd
0	0	1	0	4	215	2	0.068	nd
0	0	1	1	4	216	1	0.129	nd
0	0	1	1	4	216	2	0.068	nd
1	0	0	0	1	2	1	0.028	0.299
1	0	0	0	1	2	2	0.028	0.181
1	0	0	1	1	1	1	0.028	0.299
1	0	0	1	1	1	2	0.028	0.181
1	0	0	0	2	95	1	0.027	0.330
1	0	38	0	2	95	2	0.027	0.145
1	0	0	1	2	96	1	0.027	0.330

Table A7 (cont.) 1995 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol, kg ⁻¹ —	
1	0	0	1	2	96	2	0.027	0.145
1	0	0	0	3	208	1	0.129	0.447
1	0	0	0	3	208	2	0.322	0.493
1	0	0	1	3	207	1	0.129	0.447
1	0	0	1	3	207	2	0.322	0.493
1	0	0	0	4	241	1	0.138	0.252
1	0	0	0	4	241	2	0.228	0.154
1	0	0	1	4	242	1	0.138	0.252
1	0	0	1	4	242	2	0.228	0.154
1	0	1	0	1	4	1	0.028	0.390
1	0	1	0	1	4	2	0.028	0.299
1	0	1	1	1	3	1	0.028	0.390
1	0	1	1	1	3	2	0.028	0.299
1	0	1	0	2	93	1	0.027	0.344
1	0	1	0	2	93	2	0.027	0.182
1	0	1	1	2	94	1	0.027	0.344
1	0	1	1	2	94	2	0.027	0.182
1	0	1	0	3	205	1	0.131	0.601
1	0	1	0	3	205	2	0.096	0.280
1	0	1	1	3	206	1	0.131	0.601
1	0	1	1	3	206	2	0.096	0.280
1	0	1	0	4	243	1	0.054	0.281
1	0	1	0	4	243	2	0.159	0.202
1	0	1	1	4	244	1	0.054	0.281
1	0	1	1	4	244	2	0.159	0.202
2	0	0	0	1	112	1	0.044	0.594
2	0	0	0	1	112	2	0.044	0.369
2	0	0	1	1	111	1	0.044	0.594
2	0	0	1	1	111	2	0.044	0.369
2	0	0	0	2	17	1	0.034	0.459
2	0	0	0	2	17	2	0.028	0.442
2	0	0	1	2	18	1	0.034	0.459
2	0	0	1	2	18	2	0.028	0.442
2	0	0	0	3	233	1	0.166	nd
2	0	0	0	3	233	2	0.162	nd
2	0	0	1	3	234	1	0.166	nd
2	0	0	1	3	234	2	0.162	nd
2	0	0	0	4	153	1	0.048	0.629
2	0	0	0	4	153	2	0.030	0.225

Table A7 (cont.) 1995 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							-----cmol. kg ⁻¹ -----	
2	0	0	1	4	154	1	0.048	0.629
2	0	0	1	4	154	2	0.030	0.225
2	0	1	0	1	109	1	0.027	0.617
2	0	1	0	1	109	2	0.027	0.441
2	0	1	1	1	110	1	0.027	0.617
2	0	1	1	1	110	2	0.027	0.441
2	0	1	0	2	20	1	0.028	0.489
2	0	1	0	2	20	2	0.028	0.351
2	0	1	1	2	19	1	0.028	0.489
2	0	1	1	2	19	2	0.028	0.351
2	0	1	0	3	236	1	0.167	nd
2	0	1	0	3	236	2	0.628	nd
2	0	1	1	3	235	1	0.167	nd
2	0	1	1	3	235	2	0.628	nd
2	0	1	0	4	156	1	0.027	0.310
2	0	1	0	4	156	2	0.027	0.145
2	0	1	1	4	155	1	0.027	0.310
2	0	1	1	4	155	2	0.027	0.145
3	0	0	0	1	41	1	0.181	0.508
3	0	0	0	1	41	2	0.528	0.286
3	0	0	1	1	42	1	0.181	0.508
3	0	0	1	1	42	2	0.528	0.286
3	0	0	0	2	57	1	0.103	0.451
3	0	0	0	2	57	2	0.051	0.149
3	0	0	1	2	58	1	0.103	0.451
3	0	0	1	2	58	2	0.051	0.149
3	0	0	0	3	139	1	0.223	0.693
3	0	0	0	3	139	2	0.083	0.449
3	0	0	1	3	140	1	0.223	0.693
3	0	0	1	3	140	2	0.083	0.449
3	0	0	0	4	192	1	0.223	0.403
3	0	0	0	4	192	2	0.183	0.583
3	0	0	1	4	191	1	0.223	0.403
3	0	0	1	4	191	2	0.183	0.583
3	0	1	0	1	44	1	0.059	0.491
3	0	1	0	1	44	2	0.028	0.450
3	0	1	1	1	43	1	0.059	0.491

Table A7 (cont.) 1995 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol. kg ⁻¹ —	
3	0	1	0	2	60	2	0.027	0.296
3	0	1	1	2	59	1	0.247	0.493
3	0	1	1	2	59	2	0.027	0.296
3	0	1	0	3	137	1	0.061	0.646
3	0	1	0	3	137	2	0.030	0.466
3	0	1	1	3	138	1	0.061	0.646
3	0	1	1	3	138	2	0.030	0.466
3	0	1	0	4	190	1	0.085	0.287
3	0	1	0	4	190	2	0.204	0.470
3	0	1	1	4	189	1	0.085	0.287
3	0	1	1	4	189	2	0.204	0.470
0	1	0	0	1	73	1	0.027	0.291
0	1	0	0	1	73	2	0.027	0.269
0	1	0	1	1	74	1	0.027	0.291
0	1	0	1	1	74	2	0.027	0.269
0	1	0	0	2	123	1	0.027	0.285
0	1	0	0	2	123	2	0.029	0.355
0	1	0	1	2	124	1	0.027	0.285
0	1	0	1	2	124	2	0.027	0.355
0	1	0	0	3	166	1	0.069	0.558
0	1	0	0	3	166	2	0.028	0.418
0	1	0	1	3	165	1	0.069	0.558
0	1	0	1	3	165	2	0.028	0.418
0	1	0	0	4	224	1	0.091	nd
0	1	0	0	4	224	2	0.332	nd
0	1	0	1	4	223	1	0.091	nd
0	1	0	1	4	223	2	0.332	nd
0	1	1	0	1	75	1	0.027	0.251
0	1	1	0	1	75	2	0.027	0.286
0	1	1	1	1	76	1	0.027	0.251
0	1	1	1	1	76	2	0.027	0.286
0	1	1	0	2	121	1	0.034	0.372
0	1	1	0	2	121	2	0.035	0.309
0	1	1	1	2	122	1	0.034	0.372
0	1	1	1	2	122	2	0.035	0.309
0	1	1	0	3	168	1	0.033	0.518
0	1	1	0	3	168	2	0.040	0.404
0	1	1	1	3	167	1	0.033	0.518
0	1	1	1	3	167	2	0.040	0.404

Table A7 (cont.) 1995 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol, kg ⁻¹ —	
0	1	1	0	4	221	1	0.084	nd
0	1	1	0	4	221	2	0.382	nd
0	1	1	1	4	222	1	0.084	nd
0	1	1	1	4	222	2	0.382	nd
1	1	0	0	1	7	1	0.028	0.529
1	1	0	0	1	7	2	0.028	0.443
1	1	0	1	1	8	1	0.028	0.529
1	1	0	1	1	8	2	0.028	0.443
1	1	0	0	2	81	1	0.255	0.506
1	1	0	0	2	81	2	0.056	0.497
1	1	0	1	2	82	1	0.255	0.506
1	1	0	1	2	82	2	0.056	0.497
1	1	0	0	3	202	1	0.050	0.508
1	1	0	0	3	202	2	0.035	0.211
1	1	0	1	3	201	1	0.050	0.508
1	1	0	1	3	201	2	0.035	0.211
1	1	0	0	4	251	1	0.103	0.300
1	1	0	0	4	251	2	0.077	0.189
1	1	0	1	4	252	1	0.103	0.300
1	1	0	1	4	252	2	0.077	0.189
1	1	1	0	1	6	1	0.028	0.390
1	1	1	0	1	6	2	0.028	0.299
1	1	1	1	1	5	1	0.028	0.526
1	1	1	1	1	5	2	0.028	0.442
1	1	1	0	2	83	1	0.027	0.448
1	1	1	0	2	83	2	0.163	0.347
1	1	1	1	2	84	1	0.027	0.448
1	1	1	1	2	84	2	0.163	0.347
1	1	1	0	3	203	1	0.127	0.554
1	1	1	0	3	203	2	0.287	0.329
1	1	1	1	3	204	1	0.127	0.554
1	1	1	1	3	204	2	0.287	0.329
1	1	1	0	4	250	1	0.165	0.481
1	1	1	0	4	250	2	0.187	0.449
1	1	1	1	4	249	1	0.165	0.481
1	1	1	1	4	249	2	0.187	0.449
2	1	0	0	1	101	1	0.129	0.546
2	1	0	0	1	101	2	0.032	0.606
2	1	0	1	1	102	1	0.129	0.546

Table A7(cont.) 1995 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
-----cmol. kg ⁻¹ -----								
2	1	0	1	1	102	2	0.032	0.606
2	1	0	0	2	31	1	0.029	nd
2	1	0	0	2	31	2	0.054	0.522
2	1	0	1	2	32	1	0.029	nd
2	1	0	1	2	32	2	0.054	0.522
2	1	0	0	3	240	1	0.088	nd
2	1	0	0	3	240	2	0.103	nd
2	1	0	1	3	239	1	0.088	nd
2	1	0	1	3	239	2	0.103	nd
2	1	0	0	4	157	1	0.095	0.706
2	1	0	0	4	157	2	0.039	0.513
2	1	0	1	4	158	1	0.095	0.706
2	1	0	1	4	158	2	0.039	0.513
2	1	1	0	1	104	1	0.046	0.526
2	1	1	0	1	104	2	0.027	0.522
2	1	1	1	1	103	1	0.046	0.526
2	1	1	1	1	103	2	0.027	0.522
2	1	1	0	2	30	1	0.028	0.603
2	1	1	0	2	30	2	0.028	0.521
2	1	1	1	2	29	1	0.028	0.603
2	1	1	1	2	29	2	0.028	0.521
2	1	1	0	3	237	1	0.351	nd
2	1	1	0	3	237	2	0.114	nd
2	1	1	1	3	238	1	0.351	nd
2	1	1	1	3	238	2	0.114	nd
2	1	1	0	4	159	1	0.043	0.762
2	1	1	0	4	159	2	0.040	0.485
2	1	1	1	4	160	1	0.043	0.762
2	1	1	1	4	160	2	0.040	0.485
3	1	0	0	1	35	1	0.419	0.422
3	1	0	0	1	35	2	0.293	0.599
3	1	0	1	1	36	1	0.419	0.422
3	1	0	1	1	36	2	0.293	0.599
3	1	0	0	2	50	1	1.433	0.368
3	1	0	0	2	50	2	1.339	0.620
3	1	0	1	2	49	1	1.433	0.368
3	1	0	1	2	49	2	1.339	0.620
3	1	0	0	3	131	1	0.076	0.667
3	1	0	0	3	131	2	0.054	0.566

Table A7(cont.) 1995 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							-----cmol. kg ⁻¹ -----	
3	1	0	1	3	132	1	0.076	0.667
3	1	0	1	3	132	2	0.054	0.566
3	1	0	0	4	184	1	0.441	0.952
3	1	0	0	4	184	2	0.166	0.630
3	1	0	1	4	183	1	0.441	0.952
3	1	0	1	4	183	2	0.166	0.630
3	1	1	0	1	33	1	0.066	0.535
3	1	1	0	1	33	2	0.398	0.445
3	1	1	1	1	34	1	0.066	0.535
3	1	1	1	1	34	2	0.398	0.445
3	1	1	0	2	52	1	0.847	0.467
3	1	1	0	2	52	2	0.040	0.427
3	1	1	1	2	51	1	0.847	0.467
3	1	1	1	2	51	2	0.040	0.427
3	1	1	0	3	129	1	0.079	0.741
3	1	1	0	3	129	2	0.040	0.486
3	1	1	1	3	130	1	0.079	0.741
3	1	1	1	3	130	2	0.040	0.486
3	1	1	0	4	181	1	0.116	0.893
3	1	1	0	4	181	2	0.032	0.538
3	1	1	1	4	182	1	0.116	0.893
3	1	1	1	4	182	2	0.032	0.538

Table A8. 1996 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
-----cmol. kg ⁻¹ -----								
0	0	0	0	1	69	1	0.028	0.216
0	0	0	0	1	69	2	0.028	0.141
0	0	0	1	1	70	1	0.028	0.162
0	0	0	1	1	70	2	0.028	0.131
0	0	0	0	2	125	1	0.033	0.248
0	0	0	0	2	125	2	0.033	0.121
0	0	0	1	2	126	1	0.028	0.232
0	0	0	1	2	126	2	0.028	0.071
0	0	0	0	3	175	1	0.028	0.357
0	0	0	0	3	175	2	0.028	0.346
0	0	0	1	3	176	1	0.028	0.232
0	0	0	1	3	176	2	0.028	0.271
0	0	0	0	4	213	1	0.028	0.190
0	0	0	0	4	213	2	0.028	0.059
0	0	0	1	4	214	1	0.028	0.312
0	0	0	1	4	214	2	0.028	0.185
0	0	1	0	1	71	1	0.028	0.207
0	0	1	0	1	71	2	0.028	0.166
0	0	1	1	1	72	1	0.028	0.213
0	0	1	1	1	72	2	0.030	0.186
0	0	1	0	2	127	1	0.028	0.254
0	0	1	0	2	127	2	0.031	0.117
0	0	1	1	2	128	1	0.028	0.282
0	0	1	1	2	128	2	0.028	0.192
0	0	1	0	4	215	1	0.028	nd
0	0	1	0	4	215	2	0.028	nd
0	0	1	1	4	216	1	0.028	nd
0	0	1	1	4	216	2	0.028	nd
1	0	0	0	1	2	1	0.028	0.394
1	0	0	0	1	2	2	nd	0.231
1	0	0	1	1	1	1	0.028	0.417
1	0	0	1	1	1	2	0.028	0.390
1	0	0	0	2	95	1	0.028	0.264
1	0	0	0	2	95	2	0.028	nd
1	0	0	1	2	96	1	0.042	0.255
1	0	0	1	2	96	2	0.028	0.250
1	0	0	0	3	208	1	0.028	0.283
1	0	0	0	3	208	2	0.028	0.147
1	0	0	1	3	207	1	0.028	0.302

Table A8 (cont.) 1996 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							-----cmol, kg ⁻¹ -----	
1	0	0	1	3	207	2	0.028	0.120
1	0	0	0	4	241	1	0.028	0.309
1	0	0	0	4	241	2	0.035	0.347
1	0	0	1	4	242	1	0.028	0.376
1	0	0	1	4	242	2	0.028	0.356
1	0	1	0	1	4	1	0.028	0.239
1	0	1	0	1	4	2	0.028	0.066
1	0	1	1	1	3	1	0.028	0.298
1	0	1	1	1	3	2	nd	0.179
1	0	1	0	2	93	1	0.028	0.297
1	0	1	0	2	93	2	0.031	0.300
1	0	1	1	2	94	1	0.028	0.209
1	0	1	1	2	94	2	0.028	nd
1	0	1	0	3	205	1	0.028	0.370
1	0	1	0	3	205	2	0.028	0.274
1	0	1	1	3	206	1	0.028	0.355
1	0	1	1	3	206	2	0.028	0.257
1	0	1	0	4	243	1	0.028	0.347
1	0	1	0	4	243	2	0.028	0.300
1	0	1	1	4	244	1	0.028	0.477
1	0	1	1	4	244	2	0.028	0.415
2	0	0	0	1	112	1	0.028	0.286
2	0	0	0	1	112	2	0.028	nd
2	0	0	1	1	111	1	0.036	0.366
2	0	0	1	1	111	2	0.028	0.279
2	0	0	0	2	17	1	0.028	0.406
2	0	0	0	2	17	2	0.070	0.348
2	0	0	1	2	18	1	0.028	0.299
2	0	0	1	2	18	2	0.028	0.346
2	0	0	0	3	233	1	0.028	0.494
2	0	0	0	3	233	2	0.028	0.556
2	0	0	1	3	234	1	0.028	0.391
2	0	0	1	3	234	2	0.028	0.364
2	0	0	0	4	153	1	0.028	0.397
2	0	0	0	4	153	2	0.028	0.209
2	0	0	1	4	154	1	0.028	0.336
2	0	0	1	4	154	2	0.028	0.219
2	0	1	0	1	109	1	0.028	0.435

Table A8 (cont.) 1996 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							-----cmol. kg ⁻¹ -----	
2	0	1	1	1	110	1	0.028	0.319
2	0	1	1	1	110	2	0.028	0.251
2	0	1	0	2	20	1	0.028	0.366
2	0	1	0	2	20	2	0.042	0.273
2	0	1	1	2	19	1	0.028	0.214
2	0	1	1	2	19	2	0.028	0.212
2	0	1	0	3	236	1	0.028	0.333
2	0	1	0	3	236	2	0.035	0.241
2	0	1	1	3	235	1	0.028	0.331
2	0	1	1	3	235	2	0.028	0.235
2	0	1	0	4	156	1	0.028	0.495
2	0	1	0	4	156	2	0.028	0.387
2	0	1	1	4	155	1	0.028	0.398
2	0	1	1	4	155	2	nd	0.243
3	0	0	0	1	41	1	0.077	0.390
3	0	0	0	1	41	2	0.028	0.326
3	0	0	1	1	42	1	0.042	0.281
3	0	0	1	1	42	2	0.028	nd
3	0	0	0	2	57	1	0.028	0.461
3	0	0	0	2	57	2	0.028	0.191
3	0	0	1	2	58	1	0.028	0.415
3	0	0	1	2	58	2	0.028	0.191
3	0	0	0	3	139	1	0.028	0.353
3	0	0	0	3	139	2	0.072	0.250
3	0	0	1	3	140	1	0.028	0.355
3	0	0	1	3	140	2	0.028	0.201
3	0	0	0	4	192	1	0.034	0.511
3	0	0	0	4	192	2	0.028	0.265
3	0	0	1	4	191	1	0.028	0.417
3	0	0	1	4	191	2	0.028	0.326
3	0	1	0	1	44	1	0.028	0.625
3	0	1	0	1	44	2	0.028	0.422
3	0	1	1	1	43	1	0.033	0.441

Table A8 (cont.) 1996 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol. kg ⁻¹ —	
3	0	1	0	3	137	2	0.028	0.206
3	0	1	1	3	138	1	0.028	0.186
3	0	1	1	3	138	2	0.028	0.179
3	0	1	0	4	190	1	0.028	0.550
3	0	1	0	4	190	2	0.028	0.394
3	0	1	1	4	189	1	0.028	0.331
3	0	1	1	4	189	2	0.121	0.212
0	1	0	0	1	73	1	0.028	0.393
0	1	0	0	1	73	2	0.028	0.302
0	1	0	1	1	74	1	0.040	0.208
0	1	0	1	1	74	2	0.031	0.186
0	1	0	0	2	123	1	0.028	0.315
0	1	0	0	2	123	2	0.028	0.262
0	1	0	1	2	124	1	0.028	0.247
0	1	0	1	2	124	2	0.050	0.246
0	1	0	0	3	166	1	0.028	0.307
0	1	0	0	3	166	2	0.028	0.255
0	1	0	1	3	165	1	0.028	0.253
0	1	0	1	3	165	2	0.070	0.235
0	1	0	0	4	224	1	0.028	0.291
0	1	0	0	4	224	2	0.028	0.315
0	1	0	1	4	223	1	0.028	0.272
0	1	0	1	4	223	2	0.028	0.266
0	1	1	0	1	75	1	0.028	0.316
0	1	1	0	1	75	2	0.051	0.276
0	1	1	1	1	76	1	0.028	0.303
0	1	1	1	1	76	2	0.028	0.161
0	1	1	0	2	121	1	0.028	0.279
0	1	1	0	2	121	2	0.059	0.294
0	1	1	1	2	122	1	0.028	0.223
0	1	1	1	2	122	2	0.028	0.226
0	1	1	0	3	168	1	0.028	0.319
0	1	1	0	3	168	2	0.028	0.281

Table A8 (cont). 1996 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							——cmol, kg ⁻¹ ——	
1	1	0	0	1	7	1	0.028	0.484
1	1	0	0	1	7	2	0.071	0.345
1	1	0	1	1	8	1	0.028	0.492
1	1	0	1	1	8	2	0.028	0.309
1	1	0	0	2	81	1	0.028	0.413
1	1	0	0	2	81	2	0.161	0.442
1	1	0	1	2	82	1	0.028	0.386
1	1	0	1	2	82	2	0.080	0.341
1	1	0	0	3	202	1	0.035	0.421
1	1	0	0	3	202	2	0.028	0.421
1	1	0	1	3	201	1	0.028	0.315
1	1	0	1	3	201	2	0.028	0.359
1	1	0	0	4	251	1	0.028	0.402
1	1	0	0	4	251	2	0.038	0.340
1	1	0	1	4	252	1	0.028	0.414
1	1	0	1	4	252	2	0.028	0.311
1	1	1	0	1	6	1	0.028	0.397
1	1	1	0	1	6	2	nd	0.384
1	1	1	1	1	5	1	0.028	0.313
1	1	1	1	1	5	2	nd	0.364
1	1	1	0	2	83	1	0.045	0.281
1	1	1	0	2	83	2	0.033	nd
1	1	1	1	2	84	1	0.028	0.240
1	1	1	1	2	84	2	0.028	nd
1	1	1	0	3	203	1	0.028	0.293
1	1	1	0	3	203	2	0.028	0.279
1	1	1	1	3	204	1	0.048	0.225
1	1	1	1	3	204	2	0.028	0.267
1	1	1	0	4	250	1	0.028	0.463
1	1	1	0	4	250	2	0.028	0.399
1	1	1	1	4	249	1	0.028	0.314
1	1	1	1	4	249	2	0.028	0.261
2	1	0	0	1	101	1	0.084	0.408

Table A8 (cont.) 1996 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol, kg ⁻¹ —	
2	1	0	1	2	32	2	0.028	nd
2	1	0	0	3	240	1	0.028	0.471
2	1	0	0	3	240	2	0.028	nd
2	1	0	1	3	239	1	0.028	0.534
2	1	0	1	3	239	2	0.029	0.436
2	1	0	0	4	157	1	nd	0.315
2	1	0	0	4	157	2	0.089	0.477
2	1	0	1	4	158	1	0.028	0.492
2	1	0	1	4	158	2	0.028	nd
2	1	1	0	1	104	1	nd	0.585
2	1	1	0	1	104	2	0.028	0.536
2	1	1	1	1	103	1	0.028	0.369
2	1	1	1	1	103	2	0.028	nd
2	1	1	0	2	30	1	0.028	0.305
2	1	1	0	2	30	2	nd	0.348
2	1	1	1	2	29	1	0.028	0.396
2	1	1	1	2	29	2	0.028	0.487
2	1	1	0	3	237	1	0.028	nd
2	1	1	0	3	237	2	0.028	0.286
2	1	1	1	3	238	1	0.028	0.327
2	1	1	1	3	238	2	0.028	0.603
2	1	1	0	4	159	1	0.028	0.522
2	1	1	0	4	159	2	0.028	0.305
2	1	1	1	4	160	1	0.028	0.369
2	1	1	1	4	160	2	0.028	0.443
3	1	0	0	1	35	1	0.098	0.456
3	1	0	0	1	35	2	0.077	0.412
3	1	0	1	1	36	1	0.101	0.296
3	1	0	1	1	36	2	0.204	0.365
3	1	0	0	2	50	1	0.096	0.506
3	1	0	0	2	50	2	0.533	0.395
3	1	0	1	2	49	1	0.028	0.427
3	1	0	1	2	49	2	0.790	0.255

Table A8 (cont.) 1996 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							-----cmol, kg ⁻¹ -----	
3	1	0	1	4	183	1	0.041	0.720
3	1	0	1	4	183	2	0.028	0.643
3	1	1	0	1	33	1	0.047	0.521
3	1	1	0	1	33	2	0.028	0.476
3	1	1	1	1	34	1	0.028	0.729
3	1	1	1	1	34	2	0.028	0.407
3	1	1	0	2	52	1	0.110	0.259
3	1	1	0	2	52	2	0.028	0.316
3	1	1	1	2	51	1	0.122	0.262
3	1	1	1	2	51	2	0.085	0.439
3	1	1	0	3	129	1	0.028	0.439
3	1	1	0	3	129	2	0.028	0.371
3	1	1	1	3	130	1	0.028	0.327
3	1	1	1	3	130	2	0.067	0.478
3	1	1	0	4	181	1	0.028	0.394
3	1	1	0	4	181	2	0.028	0.329
3	1	1	1	4	182	1	0.028	0.243
3	1	1	1	4	182	2	0.028	0.419

Table A9. 1997 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
-----cmol, kg ⁻¹ -----								
0	0	0	0	1	69	1	0.028	0.175
0	0	0	0	1	69	2	0.028	0.169
0	0	0	1	1	70	1	0.055	0.135
0	0	0	1	1	70	2	0.028	0.108
0	0	0	0	2	125	1	0.028	0.359
0	0	0	0	2	125	2	0.036	0.219
0	0	0	1	2	126	1	0.028	0.226
0	0	0	1	2	126	2	0.028	0.214
0	0	0	0	3	175	1	0.028	0.219
0	0	0	0	3	175	2	0.028	0.270
0	0	0	1	3	176	1	0.028	0.155
0	0	0	1	3	176	2	0.028	0.303
0	0	0	0	4	213	1	0.028	0.259
0	0	0	0	4	213	2	0.035	0.096
0	0	0	1	4	214	1	0.028	0.264
0	0	0	1	4	214	2	0.028	0.118
0	0	1	0	1	71	1	0.028	0.176
0	0	1	0	1	71	2	0.028	0.098
0	0	1	1	1	72	1	0.028	0.184
0	0	1	1	1	72	2	0.028	0.121
0	0	1	0	2	127	1	0.028	0.209
0	0	1	0	2	127	2	0.028	0.199
0	0	1	1	2	128	1	0.028	0.150
0	0	1	1	2	128	2	0.028	0.095
0	0	1	0	3	173	1	0.028	0.282
0	0	1	0	3	173	2	0.028	0.197
0	0	1	1	3	174	1	0.028	0.385
0	0	1	1	3	174	2	0.028	0.321
0	0	1	0	4	215	1	0.028	0.302
0	0	1	0	4	215	2	0.028	0.215
0	0	1	1	4	216	1	0.028	0.367
0	0	1	1	4	216	2	0.028	0.261
1	0	0	0	1	2	1	0.028	0.175

Table A9 (cont.) 1997 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol, kg ⁻¹ —	
1	0	0	1	2	96	2	0.072	0.136
1	0	0	0	3	208	1	0.028	0.218
1	0	0	0	3	208	2	0.028	0.236
1	0	0	1	3	207	1	0.028	0.212
1	0	0	1	3	207	2	0.028	0.237
1	0	0	0	4	241	1	0.028	0.250
1	0	0	0	4	241	2	0.028	0.128
1	0	0	1	4	242	1	0.028	0.308
1	0	0	1	4	242	2	0.028	0.145
1	0	1	0	1	4	1	0.028	0.191
1	0	1	0	1	4	2	0.028	0.127
1	0	1	1	1	3	1	0.028	0.149
1	0	1	1	1	3	2	0.028	0.118
1	0	1	0	2	93	1	0.028	0.249
1	0	1	0	2	93	2	0.028	0.180
1	0	1	1	2	94	1	0.028	0.246
1	0	1	1	2	94	2	0.028	0.129
1	0	1	0	3	205	1	0.028	0.249
1	0	1	0	3	205	2	0.028	0.195
1	0	1	1	3	206	1	0.028	0.353
1	0	1	1	3	206	2	0.028	0.275
1	0	1	0	4	243	1	0.028	0.266
1	0	1	0	4	243	2	0.028	0.177
1	0	1	1	4	244	1	0.028	0.384
1	0	1	1	4	244	2	0.042	0.298
2	0	0	0	1	112	1	0.028	0.222
2	0	0	0	1	112	2	0.028	0.222
2	0	0	1	1	111	1	0.028	0.230
2	0	0	1	1	111	2	0.028	0.233
2	0	0	0	2	17	1	0.028	0.251
2	0	0	0	2	17	2	0.197	0.368
2	0	0	1	2	18	1	0.043	0.227
2	0	0	1	2	18	2	0.028	0.197

Table A9 (cont.) 1997 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol. kg ⁻¹ —	
2	0	0	1	4	154	1	0.028	0.202
2	0	0	1	4	154	2	0.028	0.189
2	0	1	0	1	109	1	0.028	0.301
2	0	1	0	1	109	2	0.028	0.223
2	0	1	1	1	110	1	0.028	0.356
2	0	1	1	1	110	2	0.028	0.178
2	0	1	0	2	20	1	nd	0.192
2	0	1	0	2	20	2	nd	0.156
2	0	1	1	2	19	1	0.028	0.136
2	0	1	1	2	19	2	0.028	0.124
2	0	1	0	3	236	1	0.028	0.364
2	0	1	0	3	236	2	0.028	0.247
2	0	1	1	3	235	1	0.028	0.245
2	0	1	1	3	235	2	0.028	0.177
2	0	1	0	4	156	1	0.028	0.217
2	0	1	0	4	156	2	0.034	0.173
2	0	1	1	4	155	1	0.028	0.175
2	0	1	1	4	155	2	0.028	0.125
3	0	0	0	1	41	1	0.031	0.223
3	0	0	0	1	41	2	0.028	0.229
3	0	0	1	1	42	1	0.028	0.190
3	0	0	1	1	42	2	0.028	0.190
3	0	0	0	2	57	1	0.028	0.236
3	0	0	0	2	57	2	0.028	0.151
3	0	0	1	2	58	1	0.050	0.230
3	0	0	1	2	58	2	0.028	0.144
3	0	0	0	3	139	1	0.028	0.388
3	0	0	0	3	139	2	0.041	0.290
3	0	0	1	3	140	1	0.028	0.347
3	0	0	1	3	140	2	0.028	0.268
3	0	0	0	4	192	1	0.028	0.332
3	0	0	0	4	192	2	0.033	0.151
3	0	0	1	4	191	1	0.028	0.316

Table A9 (cont.) 1997 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							-----cmol. kg ⁻¹ -----	
3	0	1	0	2	60	2	0.028	0.207
3	0	1	1	2	59	1	0.028	0.107
3	0	1	1	2	59	2	0.028	0.062
3	0	1	0	3	137	1	0.028	0.366
3	0	1	0	3	137	2	0.028	0.304
3	0	1	1	3	138	1	0.028	0.230
3	0	1	1	3	138	2	0.028	0.241
3	0	1	0	4	190	1	0.028	0.296
3	0	1	0	4	190	2	0.028	0.264
3	0	1	1	4	189	1	0.028	0.187
3	0	1	1	4	189	2	0.028	0.166
0	1	0	0	1	73	1	0.028	0.151
0	1	0	0	1	73	2	0.028	0.164
0	1	0	1	1	74	1	0.028	0.172
0	1	0	1	1	74	2	0.028	0.176
0	1	0	0	2	123	1	0.028	0.228
0	1	0	0	2	123	2	0.028	0.096
0	1	0	1	2	124	1	0.028	0.242
0	1	0	1	2	124	2	0.028	0.121
0	1	0	0	3	166	1	0.028	0.195
0	1	0	0	3	166	2	0.028	0.191
0	1	0	1	3	165	1	0.028	0.196
0	1	0	1	3	165	2	0.028	0.205
0	1	0	0	4	224	1	0.028	0.341
0	1	0	0	4	224	2	0.028	0.212
0	1	0	1	4	223	1	0.028	0.216
0	1	0	1	4	223	2	0.028	0.182
0	1	1	0	1	75	1	0.038	0.172
0	1	1	0	1	75	2	nd	0.170
0	1	1	1	1	76	1	0.028	0.158
0	1	1	1	1	76	2	0.028	nd
0	1	1	0	2	121	1	0.028	0.165
0	1	1	0	2	121	2	0.031	0.076

Table A9 (cont.) 1997 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol, kg ⁻¹ —	
0	1	1	0	4	221	1	0.028	0.432
0	1	1	0	4	221	2	0.028	0.223
0	1	1	1	4	222	1	0.028	0.365
0	1	1	1	4	222	2	0.037	0.168
1	1	0	0	1	7	1	0.028	0.269
1	1	0	0	1	7	2	0.085	0.309
1	1	0	1	1	8	1	0.028	0.177
1	1	0	1	1	8	2	0.028	0.230
1	1	0	0	2	81	1	0.028	0.241
1	1	0	0	2	81	2	0.090	0.277
1	1	0	1	2	82	1	0.028	0.145
1	1	0	1	2	82	2	0.028	0.202
1	1	0	0	3	202	1	0.028	0.310
1	1	0	0	3	202	2	0.028	0.221
1	1	0	1	3	201	1	0.028	0.210
1	1	0	1	3	201	2	0.028	0.189
1	1	0	0	4	251	1	0.028	0.341
1	1	0	0	4	251	2	0.028	0.378
1	1	0	1	4	252	1	0.028	0.293
1	1	0	1	4	252	2	0.028	0.385
1	1	1	0	1	6	1	0.028	0.200
1	1	1	0	1	6	2	0.028	0.149
1	1	1	1	1	5	1	0.039	0.148
1	1	1	1	1	5	2	0.028	0.141
1	1	1	0	2	83	1	0.028	0.202
1	1	1	0	2	83	2	0.028	0.219
1	1	1	1	2	84	1	0.028	0.106
1	1	1	1	2	84	2	0.028	0.104
1	1	1	0	3	203	1	0.028	0.203
1	1	1	0	3	203	2	0.028	0.210
1	1	1	1	3	204	1	0.028	0.232
1	1	1	1	3	204	2	0.045	0.189

Table A9 (cont.) 1997 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							-----cmol. kg ⁻¹ -----	
2	1	0	1	1	102	2	0.059	0.305
2	1	0	0	2	31	1	0.028	0.316
2	1	0	0	2	31	2	0.028	0.361
2	1	0	1	2	32	1	0.059	0.372
2	1	0	1	2	32	2	0.028	0.293
2	1	0	0	3	240	1	0.028	0.283
2	1	0	0	3	240	2	0.028	0.216
2	1	0	1	3	239	1	0.028	0.254
2	1	0	1	3	239	2	0.041	0.318
2	1	0	0	4	157	1	0.028	0.350
2	1	0	0	4	157	2	0.028	0.399
2	1	0	1	4	158	1	0.028	0.274
2	1	0	1	4	158	2	0.028	0.259
2	1	1	0	1	104	1	0.028	0.184
2	1	1	0	1	104	2	0.028	0.153
2	1	1	1	1	103	1	0.028	0.187
2	1	1	1	1	103	2	0.028	0.172
2	1	1	0	2	30	1	0.028	0.206
2	1	1	0	2	30	2	0.028	0.150
2	1	1	1	2	29	1	0.028	0.162
2	1	1	1	2	29	2	0.028	0.135
2	1	1	0	3	237	1	0.028	0.351
2	1	1	0	3	237	2	0.028	0.341
2	1	1	1	3	238	1	0.028	0.224
2	1	1	1	3	238	2	0.028	0.190
2	1	1	0	4	159	1	0.028	0.283
2	1	1	0	4	159	2	0.028	0.232
2	1	1	1	4	160	1	0.028	0.168
2	1	1	1	4	160	2	0.028	0.157
3	1	0	0	1	35	1	0.028	0.214
3	1	0	0	1	35	2	0.091	0.332
3	1	0	1	1	36	1	0.405	0.228

Table A9 (cont.) 1997 Exchangeable Al and Mn

N rate	Cover	Tillage	Lime rate	Rep	plot#	depth	Al	Mn
							—cmol. kg ⁻¹ —	
3	1	0	1	3	132	1	0.028	0.339
3	1	0	1	3	132	2	0.218	0.599
3	1	0	0	4	184	1	0.028	0.480
3	1	0	0	4	184	2	0.028	0.370
3	1	0	1	4	183	1	0.028	0.393
3	1	0	1	4	183	2	0.113	0.539
3	1	1	0	1	33	1	0.028	0.138
3	1	1	0	1	33	2	0.028	0.115
3	1	1	1	1	34	1	0.028	0.221
3	1	1	1	1	34	2	0.028	0.174
3	1	1	0	2	52	1	0.028	0.190
3	1	1	0	2	52	2	0.028	0.255
3	1	1	1	2	51	1	0.035	0.172
3	1	1	1	2	51	2	0.028	0.175
3	1	1	0	3	129	1	0.028	0.182
3	1	1	0	3	129	2	0.028	0.209
3	1	1	1	3	130	1	0.028	0.256
3	1	1	1	3	130	2	0.028	0.181
3	1	1	0	4	181	1	0.028	0.279
3	1	1	0	4	181	2	0.028	0.199
3	1	1	1	4	182	1	0.028	0.265
3	1	1	1	4	182	2	0.028	0.178

Vita

Edwin Ritchey was born in the Panama Canal Zone on February 12, 1973. The son of a military officer, he moved extensively until 1984, when his father moved to Clarksville, TN. He graduated in May of 1991 from Northwest High School in Clarksville, TN. He graduated from The University of Tennessee at Martin in Fall of 1995, with a Bachelor of Sciences degree in Natural Resources Management. Upon completion of his B.S. degree, he started a Master's program at The University of Tennessee at Knoxville in Plant and Soil Science, with a concentration in Soil Management. After a three year stay at The University of Tennessee at Knoxville, he graduated in August of 1999.

At the completion of his M. S. degree, he is planning to work at the University of Kentucky as a Research Specialist working with tobacco production. He also plans to peruse a doctoral degree in Agriculture.

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