

Continuous No-till Management: Implications for Soil Quality, Carbon Sequestration, and Nitrogen Conservation

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Dissertation submitted to the faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in
Crop and Soil Environmental Sciences

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1 February 2008

Blacksburg, VA

Keywords: Nitrogen use efficiency, carbon trading, nutrient trading, soil organic matter

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Dissertation Abstract

No-till management for agronomic crop production is recognized as an effective practice to regain a portion of soil organic matter lost following decades of cultivation. Increasing soil organic matter sequesters C, conserves organic N and concomitantly improves soil quality. Objectives of this research were to: i) quantify C sequestration rate and N conservation with duration of continuous no-till; ii) measure C stratification with continuous no-till as an indicator of soil quality; and iii) evaluate the Illinois soil N test (ISNT) for its value to predict fertilizer N needs of corn in Virginia.

Objectives i and ii were achieved by collecting soil samples from 63 production fields in the Virginia Coastal Plain that were managed using continuous no-till from 0 to 14 yrs. No-till management resulted in sequestration of $0.308 \pm 0.280 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ and conservation of $22.2 \pm 21.2 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ (0-15 cm). The C stratification ratio (0-2.5 cm: 7.5-15 cm) increased with increasing duration of continuous no-till ($0.133 \pm 0.056 \text{ yr}^{-1}$) due to the accumulation of organic matter at the soil surface indicating improved soil quality with continuous no-till management.

Objective iii was addressed by conducting 29 on-farm fertilizer N response trials in major corn producing areas of Virginia with the duration of continuous no-till management ranging from 0 to 25 yrs. The ISNT values were significantly related to yield without fertilizer N ($r^2 = 0.57$; $p < 0.001$) and relative yield ($r^2 = 0.64$; $p < 0.0001$). We

also found that the ISNT extracted a relatively consistent percentage of total soil N (16.3 ± 0.73 %) suggesting it is a poor indicator of labile N. Total soil N values did almost as well as the ISNT in predicting yield without fertilizer N ($r^2 = 0.53$; $p = 0.0002$), and equally well predicting relative yield ($r^2 = 0.64$; $p < 0.0001$). Results do not suggest the ISNT is useful for measuring mineralizable N or improving fertilizer N recommendations in Virginia cropping systems.

For Roan

Authors Acknowledgements

A number of people have assisted me along the way to my PhD degree, and all deserve recognition. I would like to begin by expressing gratitude to my advisor, Dr. Mark Alley. He has been an extraordinary teacher, mentor and a great friend. His guidance and insightful evaluation of my work has been fundamental to my development as a scientist. I am grateful to my committee members Dr. Greg Evanylo, Dr. Ron Follett, Dr. Steve Phillips, and Dr. Lucian Zelazny for their expert guidance and support. In addition to his role on my doctoral committee, Dr. Greg Evanylo served as my M.S. advisor; he has been an exceptional mentor and terrific friend during my graduate studies. I owe a great deal of thanks to Dr. Follett for initialing much of the research contained in this dissertation. He served an invaluable role on my committee by providing expertise on C and N cycling in agroecosystems. I am grateful to Dr. Phillips for his contribution to my education. Not only was he instrumental in securing funding for this research, but on numerous occasions he challenged me intellectually and inspired a great deal of personal reflection and professional growth. I would also like to thank Dr. Lucian Zelazny for providing me with an excellent education in the intricacies of soil chemistry. Dr. Zelazny is by far the greatest classroom instructor I have ever had.

I would like to extend my gratitude to the following individuals, whose assistance in the execution of my research made my work possible: Steve Nagle for all of his help in the field, the lab, and hours of conversation during long drives to and from the Virginia Coastal Plain and Shenandoah Valley; Mike Brosius, W.T. Price, Julie Burger, Harry Behl, Liz Rucker, Catherine Byers, Shelly Shultz, Jon Dickerson, and Laura St. Jean for their help collecting, processing and analyzing countless soil, water, and plant samples; Jim Wallace for identifying field locations for the C sequestration and N conservation

work, and his help collecting samples; Brian Noyse for his insight into this work, it's implications, and his help securing funding; Paul Davis for allowing us to conduct research on his farm, for hours of help in the field, and for locating a number of sites to conduct fertilizer N response trials; Keith Balderson, David Moore, Brian Jones, and Bobby Clark for identifying fields to conduct fertilizer N response trials, and for their help in the field laying out plots, applying treatments, and collecting samples; and Todd Luxton for his receptive ear and thoughtful perspective on all matters scientific and otherwise.

I would like to express my sincere appreciation of the producers whose farms this research was conducted on. Without their cooperation, none of this work would have been possible.

Of course, I would like to thank all the faculty, staff and graduate students of the Crop and Soil Environmental Science Department for their friendship, encouragement and dedication to the science.

I am especially grateful to my family. I am indebted to my mother for instilling in me a healthy work ethic and my father for making me believe that there is nothing I cannot do. I would like to extend a very special thanks to my daughter Roan and her mother Amy for their patience and inspiration. I would also like to give a warm thanks to my fiancé, Erica Husser for her enduring love and support.

Partial funding of this research was provided by the USDA-NRCS through a Conservation Innovation Grant, the Virginia Agricultural Council, and Phillip Morris USA.

Attributions

Several colleagues made significant scholarly contributions to several chapters of this dissertation. The following is a brief description of their background and contributions made.

Marcus M. Alley- (Crop and Soil Environmental Sciences Department

Virginia Tech) is major Advisor and Committee Chair. Dr. Alley provided expert advice and guidance for the design and implementation of the research and preparation of the dissertation.

Chapter 2: Soil Carbon Sequestration with Continuous No-Till Management of Grain

Cropping Systems in the Virginia Coastal Plain

and,

Chapter 3: Soil Nitrogen Status in Continuous No-Till Grain Cropping Systems of the

Virginia Coastal Plain

Ronald F. Follett- (United States Department of Agriculture – Agriculture Research

Services) served as Committee Member. Dr. Follett aided in the development and

implementation of this research and was extremely helpful in preparation of

manuscripts.

James V. Wallace- (Virginia Colonial Soil and Water Conservation District) is a

colleague who has collaborated with much of our research in the region. Mr. Wallace

identified potential research locations, determined farm management history, and

aided in collection of soil samples.

Chapter 4: Illinois Soil Nitrogen Test for Prediction of Fertilizer Nitrogen Needs of
Corn in Virginia

Steven M. Nagle- (Crop and Soil Environmental Sciences Department
Virginia Tech) Senior Research Specialist, was a member of the authors research
group. Mr. Nagle provided a great deal of support for the design and execution of
fertilizer N trials for this study. Mr. Nagle also provided assistance in the preparation
of the manuscript.

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1 Introduction

No-till crop production is a decades old practice for improving soil and water quality, and reducing crop production costs. It is recognized as one of the most important options for sustainable economic crop production (Martens, 2001). Adoption of no-tillage cultivation has steadily increased over the last 20 years (Fig 1-1; CTIC, 2004). Currently, about 23% of U.S. cropland is managed no-till. In Virginia, approximately 35% of the annual cropland is no-till. Economic benefits of no-till crop production include reduced machinery, labor and fuel compared to intensive tillage systems, and such benefits are a major force behind increased no-till crop production. Improved moisture retention and higher yields in many instances are also reasons for increased adoption of no-till management. No-till crop production will continue increasing, as economic forces are dramatic for reducing crop production costs and the need to maintain and improve soil quality while reducing water quality impairments associated with soil loss is greater than ever.

Tillage management has a dramatic influence on a number of soil processes, especially soil organic matter (SOM) cycling. The elimination of tillage reduces SOM decomposition. No-till cultivation is an effective management practice to regain a portion of the SOM lost following decades of intensive cultivation and erosion (Follett, 2001; Franzluebbbers, 2005). For this reason, no-till management has recently been identified as an effective strategy to partially offset the anthropogenic carbon dioxide emissions that are associated with climate change (Uri, 2001; West and Marland, 2002).

Soils managed using no-till have improved soil structure (Franzluebbbers, 2002a; Franzluebbbers, 2002b; Grandy et al., 2006), and reduced runoff and erosion (Laflen and

Tabatabai, 1984; Pesant et al., 1987; Ghidey and Alberts, 1998; Rhoton et al., 2002).

These improvements come about, in large part, as a result of the accumulation of organic matter at the soil surface (Franzluebbers, 2002a). Franzluebbers (2002b) has suggested that the degree of C stratification may be used as an indicator of soil quality because of the positive impacts of increased surface soil organic matter.

Increased SOM in no-till soils may also have a significant effect on N cycling (i.e., retention and release) because SOM contains approximately 5% N (Stevenson, 1994). Thus, increasing SOM conserves N. For example, consider an increase in soil organic matter of 1% in the surface 15 cm of a no-till field. This is approximately 22 Mg SOM ha⁻¹. Since SOM averages 5% N, the 1% increase in SOM results in an additional 1.1 Mg of N ha⁻¹ retained in the soil.

A portion of the additional N conserved with no-till is potentially available for crops. Mineralization rates of N from SOM during a single growing season may range from 1 to 4%, depending on a number of factors, particularly soil temperature and moisture conditions (Jansson and Persson, 1982). Thus, increasing SOM of the surface 15 cm by 1% has the potential to provide between 9 and 45 kg N ha⁻¹ for crop growth throughout a single growing season. While crop response to an additional 9 kg N ha⁻¹ may be difficult to measure, the availability of 45 kg N ha⁻¹ from SOM would significantly change the required amount and timing of fertilizer N applications for most crops.

1.1 Statement of Problem, Significance and Rationale

Agriculture in the Virginia coastal plain can be highly productive due to a warm, moist climate. These conditions are conducive for high annual photosynthetic CO₂

fixation as well as rapid SOM decomposition (Franzluebbers, 2005). A common crop rotation in the Virginia Coastal Plain is corn (*Zea mays* L.) – wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.) – double crop soybean (*Glycine max* L.). There is potential to conserve a substantial amount of SOM with no-till management in this intensive cropping system. There has been little research conducted to quantify the affect of this management system on C and N cycling in Virginia. In addition, there is a paucity of on-farm C and N measurements with duration of no-till management. Most research concerning the implications of no-till management has been conducted using small plot research with little field scale validation.

The implementation of a trading system that offers economic incentives for C sequestration practices will encourage producers to adapt management practices that increase C sequestration (Marland et al., 2001; Esuola and Weersink, 2006). The Chicago Climate Exchange (CCX) has initiated a voluntary, legally binding trading system to reduce emissions of greenhouse gasses (CCX, 2007). The CCX issues tradable contracts to owners or aggregators of eligible projects. Similarly, in an attempt to mitigate pollution of the Chesapeake Bay, Virginia House Bill 2862 was promulgated in April 2005 to institute a nutrient (e.g., N) credit exchange program among point source polluters (e.g., water treatment facilities) or between point sources and non-point sources, such as agricultural land (Chesapeake Bay Watershed Nutrient Credit Exchange Program, 2005). If no-till cultivation in Virginia is to be recognized for its true capacity to sequester C and reduce nutrient loads to the Chesapeake Bay (and credits traded), these benefits must be quantified.

1.2 Research Objectives

The overall objective of this research was to evaluate the impact of continuous no-till management in Virginia on SOM using on-farm observations. The specific objectives of the research were to: i) determine C sequestration rate with duration of continuous no-till; ii) measure C stratification with continuous no-till as an indicator of soil quality; iii) quantify the amount of total and labile soil N retained with duration of continuous no-till; and iv) evaluate the Illinois soil N test for its value as a tool for prediction of fertilizer N needs of grain cropping systems in Virginia using continuous no-till management.

1.3 Historical and Background Data

1.3.1 Carbon Sequestration, Stratification, and Soil Quality

Nearly all modern amenities of industrialized societies derive directly, or indirectly, from fossil fuel energy. In fact, our contemporary period has been termed the “Carbon Civilization” or “Carbon Era”(Lal, 2007). The availability of low-cost fossil fuel energy has resulted in significant improvements in quality of life; however, it has had significant environmental costs. The concentration of atmospheric CO₂ increased from a pre-industrial (1750) value of about 280 μL L⁻¹ to 380 μL L⁻¹ in 2006 (WMO, 2006). Most of this increase in CO₂ has resulted from combustion of fossil fuel for transportation and energy. Other significant sources of CO₂ during this period include expansion of cultivated agriculture, destruction of wetlands and forest clearing (IPCC, 2007). The dramatic increase in atmospheric CO₂ has been associated with increased average global temperature, reduction in Arctic ice, and rise of global sea level (WMO, 2006; IPCC, 2007). The greatest reduction of atmospheric CO₂ concentrations could be achieved with

a significant reduction in fossil fuels combustion; however, at this time, the economic cost of this strategy is considered excessive. A more favorable strategy under development is to alter the global C cycle by implementing practices that sequester C; thus, allowing sufficient time for the development of alternative, non-fossil fuel, energy sources. This has led to significant interest in sequestration of atmospheric CO₂ in terrestrial ecosystems.

Soil C is the largest global pool of terrestrial C. Globally, SOM contains 1550 Pg C (Pg = petagram = 1×10^{15} g), or twice as much as the atmosphere and three times that held in terrestrial vegetation (Post et al., 1990). Agricultural cropland, rangeland, and forest have potential to offset significant amounts of CO₂ through improved land management. Changes in agronomic practices in the United States are thought to have the potential to offset nearly 10% of its total carbon emissions by sequestering C in SOM (FAO, 2001). The net gain or loss of soil C depends on the relative rates of C additions as plant biomass and/or organic residuals (i.e., manure or biosolids) versus that lost through crop removal, microbial respiration and/or erosion. Sequestration of C in agricultural soils may be accomplished by producing more biomass in a given time period, adding an external source of C to soil, and the elimination of tillage (Havlin et al., 1990; Follett, 1993; Paustian et al., 1997; Lal et al., 1999; Follett, 2001; Uri, 2001; West and Marland, 2002).

A number of tillage-dependent factors influence the rate of residue decomposition in agronomic cropping systems. Incorporation of residue into the soil makes it more available to microorganisms. Removal of residues from the surface exposes more soil to solar radiation, decreasing the soil albedo, resulting in higher soil temperatures. Tillage

also aerates soil, creating a more oxidative environment. The higher moisture content in soil than on the surface is probably the biggest factor leading to organic matter decomposition in tilled soils (Franzluebbbers and Arshad, 1996). Surface placed residues experience frequent drying and rewetting, depending on rainfall frequency, and thus do not decompose as rapidly as incorporated residues.

A number of plot scale studies have been conducted to estimate the C sequestration rate with continuous no-till management thus allowing researchers to estimate average C sequestration rate. West and Post (2002) used meta-analysis of 93 observations from around the world to calculate a C sequestration rate of $0.48 \pm 0.13 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ with conversion of conventional- to no-tillage management. Using 96 observations in the southeastern United States, Franzluebbbers (2005) estimated that a switch from conventional- to no-tillage resulted in sequestration of $0.42 \pm 0.46 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$. There has been little research conducted at the field scale to validate these rates under field conditions.

Additional benefits of continuous no-till management have also been recognized. Soils managed no-till have improved soil structure (Franzluebbbers, 2002b), water availability (Peterson and Westfall, 1997), and reduced runoff and erosion (Rhoton et al., 2002). These improvements come about, in large part, as a result of the accumulation of organic matter at the soil surface (Franzluebbbers, 2002a). The soil surface is the vital interface that buffers precipitation impact, wind ablation, solar radiation and gas exchange and receives most production inputs, such as fertilizer nutrients and pesticides.

Soil quality improvements are generally associated with increasing soil organic matter. Franzluebbbers (2002a) has suggested the degree of organic matter stratification

as an index of soil quality because soil organic matter in surface layers has the greatest influence on water infiltration, reduced erosion, and reductions in surface crusting. He illustrated that the degree of soil organic C stratification may be used as an indicator of ecosystem functioning because of the positive impacts of increased surface soil organic matter (Franzluebbbers, 2002b). A number of other researchers have recently used the degree of stratification of SOM as an index of soil quality and found it to be sensitive to management changes (Kay and VandenBygaart, 2002; Mrabet, 2002; Jarecki and Lal, 2005; Leifeld and Kogel-Knabner, 2005; Moreno et al., 2006; Murillo et al., 2006).

1.3.2 Conservation of Soil Nitrogen

Nitrogen is among the most important nutrients required for production of the world's food supply. Currently, as much as 40% of the world's protein supply is estimated to be derived from fertilizer N; by 2050 it is expected to be about 60% (Smil, 2001). Nitrogen use efficiency is paramount to both agronomic viability and environmental health. Continuous no-till management can have a significant influence on soil organic N cycling (Franzluebbbers et al., 1994a; Kristensen et al., 2000) and fertilizer N use efficiency (Meisinger et al., 1985; Martens and Dick, 2003).

Fertilizer N use efficiency (NUE) has been defined using a number of factors of input and recovery within a given system (e.g., Moll et al., 1982; Raun and Johnson, 1999; Cassman et al., 2002; Semenov et al., 2007). The scope and nature of the system under study depends on the observer's interest. Any discussion of NUE must begin by providing a concise definition of the term. Here, we have adapted our definition of NUE from that presented by Cassman et al. (2002). The NUE of a cropping system is determined as the proportion of applied N recovered in the harvested crop, contained in recycled crop residues, and incorporated into soil organic matter (SOM). The N not

recovered in these pools is lost from the system and contributes to the reactive N load in the environment external to the cropping system. Thus, NUE of a cropping system increases through greater crop uptake recovery of applied N, by conserving N as SOM, or both.

No-till management has been recognized as an effective strategy to sequester C and partially offset anthropogenic CO₂ emissions (Paustian et al., 1997; Follett, 2001; Uri, 2001; West and Marland, 2002; West and Post, 2002; Franzluebbers, 2005). Any management practice that changes soil organic C will also influence soil organic N since the C/N ratio of stable SOM has a relatively narrow range ($\approx 10:1$ to $12:1$). There is potential to conserve a substantial amount of soil organic N with no-till management. Franzluebbers (2004) used meta-analysis to estimate the rate of total soil N sequestration with no-till management compared to shallow tillage and found that total soil N was increased by an average rate of $28 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ ($n = 26$) under no-till. This is slightly greater than the estimated rate of N sequestration rate of $22 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ in the central U.S. Corn Belt with conservation tillage (Fixen and West, 2002).

A portion of the additional N retained as SOM in no-till soils may potentially become available for crops (Franzluebbers et al., 1994a; Wienhold and Halvorson, 1999). For example, Franzluebbers et al. (1994a) found that mineralizable N was an average of 45% greater in soils treated no-till for 9 years in Texas compared to those that were disk tilled. In a spring wheat-winter wheat-sunflower crop rotation Wienhold and Halvorson (1999) observed that N mineralization in the surface 5 cm of soil treated no-till was 112 and 143% greater than those cultivated using minimal (sweep plow) or conventional tillage (chisel plow and a double disk), respectively.

Little research has been conducted to investigate N conservation and turnover in long-term no-till soils, particularly in the Mid-Atlantic Coastal Plain. Quantification of organic N cycling in no-till soils may improve the precision of fertilizer N recommendations, as well as provide a basis for developing nutrient trading programs in the region.

1.3.3 Illinois Soil N Test for Prediction of Fertilizer N Needs

The primary objective of N applications to cropland by the agricultural producer is to increase yield with a subsequent economic return from the capital invested. In order to maximize profit, N needs must be accurately determined so that producers are able to meet yield goals with minimal capital investment. Excessive N applications are not only undesirable from an economic standpoint. The negative environmental ramifications of unnecessary N applications are also widely recognized (Follett and Hatfield, 2001).

Current N rate recommendations in Virginia are based on expected yield (Simpson et al., 1993). Quantification of organic N turnover in no-till soils should improve the precision of fertilizer N recommendations and increase N use efficiency. A number of chemical methods have been proposed for estimating soil N availability (Stevenson and Cole, 1999). Chemical methods designed to estimate potentially mineralizable N have been based on an empirical approach, and their use has been limited due to low correlations with mineral N and crop N uptake (Khan et al., 2001a). Soil NO₃-N testing is currently the best method for identifying soils where yield response to fertilizer N may be limited. The pre-sidedress soil NO₃-N test (PSNT) has shown some potential for use in Virginia for corn grown on land receiving manures or where legumes have been grown in the rotation (Evanylo and Alley, 1997). However, usage has been limited by the need to collect samples during the growing season and the delay in N

fertilization until soil samples are analyzed. In addition to the logistical problems, the PSNT is also limited by the temporal and spatial variability of soil $\text{NO}_3\text{-N}$ and its dependence on unpredictable N-cycle processes.

Ideally, a soil N test would estimate a labile organic fraction that supplies plant available N through mineralization. Such an approach would depend on fewer N-cycle processes and therefore, should be less variable. The ISNT was developed by Khan et al. (2001) as a simple soil assay to estimate mineralizable soil N and predict reduced response to N-fertilization. The ISNT uses direct alkaline hydrolysis to estimate hydrolysable amino sugar-N, a labile fraction of total soil N. Khan et al (2001) found that ISNT values were well correlated with hydrolysable amino sugar-N ($r=0.91$) and used the assay to successfully identify soils in Illinois that were non-responsive to fertilizer-N. They found a wide range of N-test values for both responsive and non-responsive sites and suggested the possibility of using the soil test to quantitatively determine fertilizer N rates in conjunction with expected yield goals. The ISNT has also been found to provide useful data in other regions of the U.S. Klapwyk and Ketterings (2006) were able to identifying non-responsive corn silage fields on dairy farms in New York using the ISNT. Williams et al.(2007b) successfully predicted the economic optimum N rate (EONR) for corn grown on well- ($r^2 = 0.87$) or poorly- ($r^2 = 0.78$) drained soils in North Carolina. Sharifi et al. (2007) found that the ISNT was highly correlated ($r=0.72$) with N mineralization during a 24 week aerobic incubation period of 153 soils that were collected from existing field experiments extending across 4 Canadian provinces and into Maine, USA.

The ISNT has not proven useful in all regions or cropping systems. For example, working in Iowa Barker et al. (2006) found no relationship between the ISNT and relative corn grain yield, corn response to fertilizer N, or EONR. The soils used in their study had relatively high levels of hydrolysable $\text{NH}_4\text{-N}$ relative to amino sugar-N, and the authors suggested that this partially explained the poor performance of the ISNT. Marriott and Wander (2006) used the assay to compare labile soil N in conventional and organic cropping systems and found that the ISNT was not a sensitive index of labile N. The ISNT fraction was not preferentially enriched by organic management and its response was similar to that of total soil C and N. For these reasons, it is not likely that the assay will be adopted as a universal soil N test. Rather, its use will be limited to regions and applications where the assay has proven useful.

The ISNT is a simple, convenient assay that warrants evaluation on Virginia no-till soils to determine if the test is applicable to regional soil and climatic conditions. To our knowledge, the assay has not been tested for detecting changes in soil N with long-term continuous no-till management. If the assay does prove useful for quantification of potentially mineralizable N in these cropping systems, it could significantly improve fertilizer N recommendations.

1.4 Summary

Climatic conditions of the Virginia Coastal Plain are conducive for high annual photosynthetic CO_2 fixation as well as rapid decomposition. No-till management of these intensive cropping systems has potential to conserve a substantial amount of SOM. There has been little research conducted to quantify the effect of this management system

on C and N cycling in Virginia. In addition, there are few on-farm C and N measurements related to duration of no-till management.

Characterization of SOM contents in these systems will improve our understanding of soil C and N cycling with continuous no-till management. Knowledge gained by this research will i) quantify potential sequestration of C and conservation of N with duration of no-till management in the region; ii) establish base level values for C and N “trading programs” associated with reducing greenhouse gas emissions and water quality; and, iii) improve N use efficiency by crops grown in soils managed long-term no-till.

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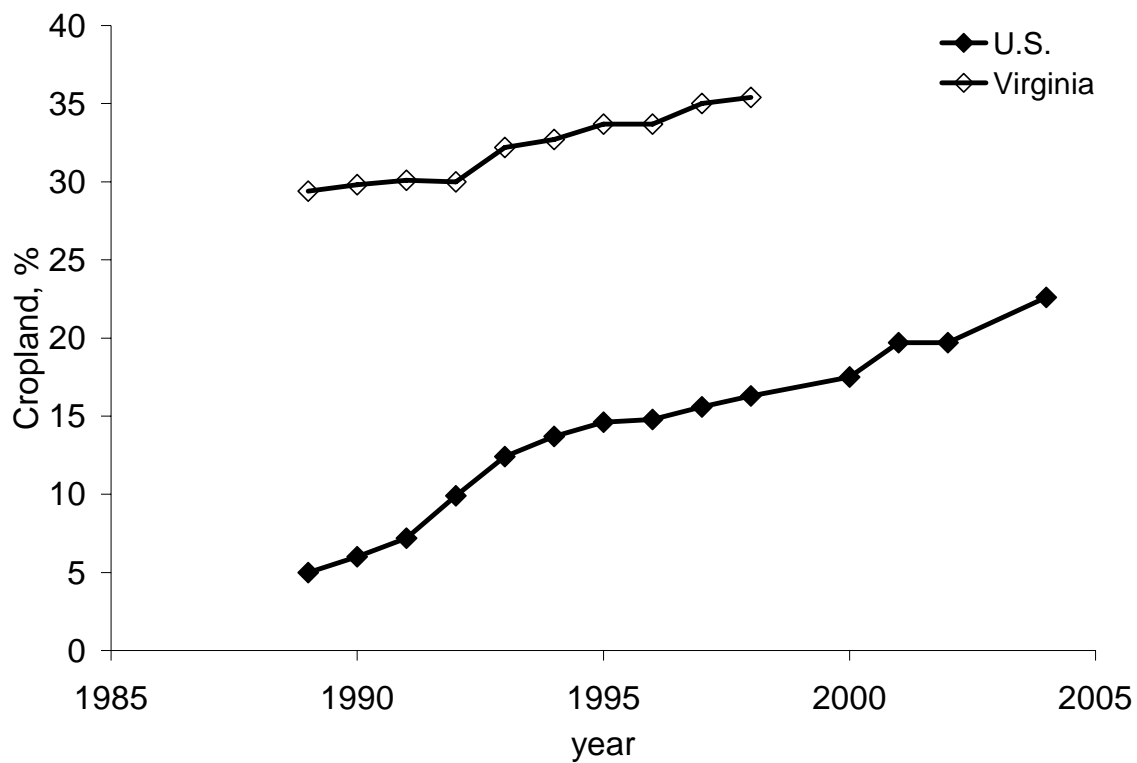


Figure 1-1. Percentage of U.S. and Virginia annual cropland managed no-till from 1989 to 2004 (CTIC, 2004). Virginia data from 1999-2004 unavailable.

2 Soil Carbon Sequestration with Continuous No-Till Management of Grain Cropping Systems in the Virginia Coastal Plain.

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2.1 Abstract

Carbon sequestration in agroecosystems represents a significant opportunity to offset a portion of anthropogenic CO₂ emissions. Climatic conditions in the Virginia Coastal Plain and modern production practices make it possible for high annual photosynthetic CO₂ fixation. There is potential to sequester a substantial amount of C, and concomitantly improve soil quality, where no-till management is practiced. The objectives of our research were to measure C sequestration rate with continuous no-till management of grain cropping systems and to evaluate its impact on the C stratification ratio, an indicator of soil quality. Samples were collected from 63 sites in production fields using a rotation of corn (*Zea mays* L.) - wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.) / double-crop soybean (*Glycine max* L.) across three soil series [Bojac (Coarse-loamy, mixed, semiactive, thermic Typic Hapludults), Altavista (Fine-loamy, mixed semiactive, thermic Aquic Hapludults), and Kempsville (Fine-loamy, siliceous, subactive, thermic Typic Hapludults)] with a history of continuous no-till that ranged from 0 to 14 yrs. Forty-one of the sites had a history of biosolids application. Five soil cores were collected at each site from 0 - 2.5, 2.5 - 7.5 and 7.5 - 15 cm and analyzed for bulk density and soil C. Bulk density in the 0 - 2.5 cm layer decreased and C stratification ratio (0 - 2.5 cm: 7.5 - 15 cm) increased with increasing duration of continuous no-till due to the accumulation of organic matter at the soil surface. A history of biosolids application resulted in an increase of $4.19 \pm 1.93 \text{ Mg C ha}^{-1}$ (0 - 15 cm). Continuous no-till resulted in the sequestration of $0.308 \pm 0.280 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ (0 - 15 cm). Our results provide quantitative validation of the C sequestration rate and improved soil quality with continuous no-till management in the region using on-farm observations.

2.2 Introduction

Concerns about global warming have led to significant interest in sequestration of atmospheric CO₂ in terrestrial ecosystems. Changes in agronomic practices in the United States are thought to have the potential to offset nearly 10% of its total carbon emissions (FAO, 2001). Several management practices have proven effective. For example, sequestration of C in agricultural soils may be accomplished by producing more biomass in a given time period, adding an external source of C to soil (e.g., manure, or biosolids) and the elimination of tillage (Havlin et al., 1990; Follett, 1993; Paustian et al., 1997; Lal et al., 1999; Follett, 2001; Uri, 2001; West and Marland, 2002).

Agriculture in the Virginia Coastal Plain can be highly productive due to a warm, moist climate. These conditions are conducive for high annual photosynthetic CO₂ fixation as well as rapid decomposition (Franzluebbers, 2005). Thus, management practices that maximize biomass inputs and minimize losses can have a large impact on C sequestration. The net gain or loss of soil organic C (SOC) depends on the relative rates of C additions as plant biomass and/or organic residuals (i.e., manure or biosolids) versus that lost through crop removal, microbial respiration and/or erosion.

The elimination of tillage generally results in slower residue decomposition and a net increase in SOC. In contrast, a number of tillage – dependent factors generally increase the rate of residue decomposition. Incorporation of residues into the soil increases their availability for loss through microbial decomposition. Removal of residues from the surface exposes more soil to solar radiation, decreases the soil's albedo, and results in higher soil temperatures, thus also increasing the decomposition of any

remaining residues. Tillage aerates the soil, thereby creating a more oxidative environment which also enhances residue decomposition. The higher moisture content in soil than on the surface is probably the greatest factor leading to organic matter decomposition in tilled soils (Franzluebbbers and Arshad, 1996).

Using 96 observations in the southeastern United States, Franzluebbbers (2005) estimated that a switch from conventional- to no-tillage resulted in sequestration of $0.42 \pm 0.46 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$. West and Post (2002) estimated that conversion of conventional- to no-tillage management sequestered $0.48 \pm 0.13 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ from 93 observations from around the world. Continuous no-till cultivation is reported by Uri (2001) and West and Marland (2002) to be a superior type of conservation tillage to bring about C sequestration benefits. Periodic cultivation of no-till land undermines biotic and abiotic processes. Grandy et al. (2006) indicated that with even a single tillage event, sequestered soil C and years of soil restoration may be lost.

Additional benefits of continuous no-till management have been recognized including its positive impact on various soil quality parameters. Soils managed using no-till have improved soil structure (Franzluebbbers, 2002a; Franzluebbbers, 2002b; Grandy et al., 2006), increased infiltration and reduced runoff and erosion (Laflen and Tabatabai, 1984; Pesant et al., 1987; Ghidey and Alberts, 1998; Rhoton et al., 2002). These improvements come about, in large part, as a result of the accumulation of organic matter at the soil surface (Franzluebbbers, 2002a). The soil surface is the vital interface that buffers precipitation impact, wind ablation, solar radiation and gas exchange and receives most production inputs such as fertilizer nutrients and pesticides.

Soil quality improvements are generally associated with increasing soil organic matter and Franzluebbbers (2002a) has suggested the degree of organic matter stratification as an index of soil quality because soil organic matter in surface layers has the greatest influence on water infiltration, reduced erosion, and reductions in surface crusting. Franzluebbbers (2002b) suggested that the degree of soil organic C stratification may be used as an indicator of ecosystem functioning because of the positive impacts of increased surface soil organic matter. A number of other researchers have recently used the degree of stratification of organic matter as an index of soil quality and found it to be sensitive to management changes (Kay and VandenBygaart, 2002; Mrabet, 2002; Jarecki and Lal, 2005; Leifeld and Kogel-Knabner, 2005; Moreno et al., 2006; Murillo et al., 2006).

No-till management has been implemented on a significant portion of U.S. cropland due to increased fuel costs, conservation awareness and improved technology. In 2004, about 23% of U.S cropland was managed no-till (CTIC., 2004). In Virginia, approximately 35% of the annual crop production was managed using no-till (CTIC, 2004). The implementation of a trading system that offers economic incentives for C sequestration practices will encourage producers to adapt management practices that increase C sequestration (Marland et al., 2001; Esuola and Weersink, 2006). The Chicago Climate Exchange (CCX) has initiated a voluntary, legally binding trading system to reduce emissions of greenhouse gasses (CCX, 2007). The CCX issues tradable contracts to owners or aggregators of eligible projects. They have recently implemented a soil carbon management offset project for no-till management. The current offset issuance

rates offered by CCX for continuous no-till range from 0.13 to 0.40 Mg C ha⁻¹ yr⁻¹ depending on the region in which the practice is initiated.

A common crop rotation in the coastal plain of Virginia is corn (*Zea mays* L.) – wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.) / double-crop soybean (*Glycine max* L.). With three crops grown in two years there is potential to sequester a substantial amount of C where no-till management is practiced. Corn and soybean have been planted no-till on most farms since at least the early to mid 1980's; however, on many farms some tillage is conducted prior to planting small grain (i.e., wheat or barley). In addition, many no-till fields are periodically tilled to alleviate soil compaction, incorporate organic amendments (i.e., biosolids) or remove tire ruts left by harvesting equipment. If continuous no-till cultivation in Virginia grain cropping systems is to be recognized for its capacity to sequester C (and credits traded) and improve soil quality, effects must be quantified. Since on-farm measurements of C sequestration are limited, we were interested in determining if C sequestration could be measured in production fields under “real-world” conditions where growers have managed continuous no-till systems for varying duration. Our specific objectives were: 1) measure C sequestration rate with continuous no-till management of grain cropping systems of the Virginia middle Coastal Plain; 2) determine the influence of biosolids application history on C content and its interaction with tillage management; and 3) evaluate the impact of continuous no-till on bulk density and C stratification as an indicator of soil quality.

2.3 Materials and Methods

2.3.1 Sampling Locations

Sixty-three grain crop production fields were selected across three soil series in the Virginia Coastal Plain with a history of continuous no-till management ranging from 0 to 14 years (Table 2-1). Fields were located within the geographic region 37°41 N to 37°17 N and 77°40 W to 77°12 W. Average annual temperature of the region is 14°C and precipitation is 112 cm yr⁻¹. The three soils series, Bojac (Coarse-loamy, mixed, semiactive, thermic Typic Hapludults), Altavista (Fine-loamy, mixed semiactive, thermic Aquic Hapludults), and Kempsville (Fine-loamy, siliceous, subactive, thermic Typic Hapludults), represent a significant portion of the land area used for crop production in the region. All but eight sites were in a corn – wheat or barley / double-crop soybean rotation. The eight sites that did not have a small grain (wheat or barley) in rotation grew full season soybean. Forty one of the sites had a history of biosolids application. All fields with a history of biosolids received the most recent application 4 or 5 years prior to the sampling date.

2.3.2 Sampling and Analysis

Fields were sampled in 2005 or 2006 shortly following corn harvest except locations 10, 30, and 49 which were tilled following corn harvest in preparation for small grain planting. These locations were not sampled until 3 months following tillage to allow soil conditions to stabilize. Five soil samples were collected from each location along a 100 m transect using 5 cm dia. soil cores split into 0 - 2.5 cm, 2.5 - 7.5 cm and 7.5 to 15 cm depth increments. The shallow sampling depth was chosen since the predominant form of tillage in the region is shallow double-disking and typically does not incorporate residues deeper than 10 cm. This was confirmed at multiple locations by

excavating miniature soil pits following tillage operations. Intact soil cores were sealed in plastic wrap and stored on ice immediately following collection. On returning to the lab the cores were separated by layer, the soil removed and air-dried. Bulk density was determined on each core at each depth increment by obtaining an air-dry weight for each core and oven drying (105°C) a subsample to determine moisture content. Following bulk density measurements, air-dried soil samples were ground and sieved (2 mm). For C analysis, composite samples were made for each sampling layer by thoroughly mixing equal volume subsamples from each core. Total soil C levels were determined in duplicate by dry combustion using a VarioMax CNS macro elemental analyzer (Elementar, New Jersey).

2.3.3 Data Analysis

Bulk density and total soil C were calculated for 0 – 7.5 cm and 0 – 15 cm depths using depth weighted summation. Stratification ratio of soil C was calculated by dividing measurements at 0 – 2.5 cm by those at 7.5 – 15 cm. Bulk density values were used to calculate the mass of C on an areal basis, i.e. Mg C ha⁻¹.

Analysis of variance was performed using PROC GLM of SAS with duration of continuous no-till (dNT) treated as a continuous quantitative variable, biosolids as a dummy variable and soil series as a class variable (SAS Institute, 2002). Sites with a history of biosolids application were assigned a value of 1 for the biosolids effect and sites with no history of biosolids application a value of 0. For model building, marginal sum of squares (type III) were used to test significance of main effects and interactions. Effects not significant at the $p < 0.05$ level were dropped from the model. When soil series was significant, t-tests were used to determine which of the soil series contributed

($p < 0.05$) to the model. Parameter estimates and confidence intervals were calculated using the SOLUTION and CLPARM commands in SAS, respectively.

2.4 Results and Discussion

2.4.1 Soil Carbon Concentration

Tillage accelerates microbial oxidation of organic matter (Al-Kaisi and Yin, 2005) and thus continuous no-till management is expected to conserve soil C. Analysis of variance and parameter estimates for the effects of dNT, biosolids and soil series on the concentration of soil C are summarized in Table 2-2. Soil C concentration increased significantly with increasing dNT at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depths, and alone explained 38%, 40%, and 10% of the variation, respectively (as indicated by the GLM type 1 sum of squares). Continuous no-till management increased the concentration of soil C by 0.678, 0.415, and 0.207 g C kg⁻¹ yr⁻¹ at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depths, respectively. The higher rate of increase in the surface 2.5 cm is indicative of the stratification of soil C with the elimination of tillage.

Biosolids led to an increase of C in the surface 0 – 2.5 cm when applied to land managed using continuous no-till. Incorporation of the biosolids negated this increase. At the 0 – 2.5 cm depth there was a significant interaction between dNT and biosolids. The concentration of soil C increased faster where biosolids have been applied with dNT (1.29 g C kg⁻¹ yr⁻¹) since C added with biosolids, and not incorporated by tillage, accumulated at the soil surface. The interaction between dNT and biosolids was not significant at 0 – 7.5 or 0 – 15 cm. The additive effect of biosolids was significant at 0 – 7.5 and 0 – 15 cm but not at 0 – 2.5 cm. Biosolids increased the concentration of C by 2.89 and 2.03 g kg⁻¹ at 0 – 7.5 and 0 – 15 cm, respectively. We expected to find an

interaction between biosolids application and dNT in the 0 – 7.5 cm and 0 – 15 cm depth. This would have indicated that biosolids derived soil organic matter mineralized at a slower rate under continuous no-till management. Interpretation of these results are complicated by the fact that all fields with a history of biosolids received an application 4 to 5 years prior to the sampling and several of these locations were tilled following application (i.e., sites 10 – 15, 30 – 34, and 51 – 54) while others were not.

Soil series had a significant effect on soil C concentration at the 0 – 7.5 and 0 – 15 cm but not at 0 – 2.5 cm depth. The Bojac soil series had 2.48 and 2.09 g C kg⁻¹ less than the other two soil series at the 0 – 7.5 and 0 – 15 cm depths, respectively. The Bojac has a much coarser texture than either the Altavista or Emporia soils. Soils with higher clay content typically have higher soil organic C (Nichols, 1984). This is due, in part, to the formation of soil organic matter – clay mineral complexes and aggregates that protect organic matter from microbial oxidation (Wiseman and Puttmann, 2006). In addition, the coarse textured Bojac soil series has a much lower water holding capacity and, with more rapid depletion of available soil water, it has a lower capacity for plant biomass production than do either the Altavista or Emporia soils. Since crop yields are typically lower on the Bojac soil, the amount of crop residues returned each season is reduced, resulting in lower soil C contents (Lal et al., 1999; Follett, 2001).

2.4.2 Bulk Density

Bulk density is inversely related to soil porosity and is an indicator of the capacity for air and water transports in the soil. Excessive bulk density increases penetration resistance, reduces aeration and may limit root growth (Pabin et al., 1998). One of the goals of tillage is to alleviate soil compaction by reducing bulk density; however, the effect of tillage potentially has undesirable effects as well. Tillage destroys soil structure

and hastens oxidation of soil organic matter; shortly following tillage, soil settles, recovering its former bulk density (Franzluebbers et al., 1995). We expected a decrease in bulk density, due to the increase of soil organic matter, with the implementation of continuous no-till management, particularly at the soil surface. We found that bulk density at 0 – 2.5 cm decreased with dNT management and was not significantly affected by biosolids or soil series (Fig. 2-1). Bulk density was unaffected by dNT, biosolids or soil series at 0 – 7.5 cm or 0 – 15 cm depths. The negative relationship between dNT and bulk density in the 0 – 2.5 cm depth was a result of the concentration of C near the surface with continuous no-till management (Heuscher et al., 2005). Bulk density decreased with increasing concentration of soil C in the 0 – 2.5 cm depth ($r^2=0.21$; $p<0.0001$) and the 0 – 7.5 cm ($r^2=0.084$; $p=0.022$) but the relationship was not significant at 0 – 15 cm ($r^2=0.022$; $p=0.24$) (Fig. 2-2). In order to obtain an accurate estimate of C sequestration, measured bulk density values were used to calculate the mass of C on an areal basis, i.e. Mg C ha⁻¹.

2.4.3 Carbon Sequestration Rate

Analysis of variance and parameter estimates for the effects of dNT, biosolids and soil series on the areal content of soil C are summarized in Table 2-3. The overall trends for changes in mass of soil C with depth were similar to changes in C concentration; however, the variance was slightly increased by inclusion of measured bulk density in the calculation. For example, 60% of the variation of C concentration at 0 – 15 cm depth was unexplained by the model while 63% of the variance in the mass of C was unexplained (as indicated by the GLM type 1 sum of squares sum for the error term for each of the respective models; Table 2-2 and 2-3). The mass of soil C was significantly increased by dNT at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depths, explaining 27%, 26%, and 5% of the

variation, respectively. The significant interaction between dNT and biosolids on mass of soil C at the 0 – 2.5 cm persisted following adjustment for bulk density. Biosolids and the Bojac soil series had an additive effect on the mass of soil C observed at the 0 – 7.5, and 0 – 15 cm depth. Sites with a history of biosolids application had 4.19 ± 1.93 Mg C ha^{-1} (0 – 15 cm) more than those that did not. While this may not be considered net C sequestered (lest the alternative disposal method was incineration) biosolids use does provide a substantial portion of fertilizer requirements; thus, offsetting the quantity of commercial fertilizer applied and the C releases associated with energy expenditures for their production (Pendell et al., 2006). Further research to quantify this offset is needed but is beyond the scope of this study.

West and Post (2002) found that approximately 86% of soil C sequestered with the adoption of no-till occurs in the surface 7 cm. The rate of C sequestration with continuous no-till management in our study was 0.308 ± 0.280 Mg C $\text{ha}^{-1} \text{yr}^{-1}$ (0 – 15 cm) with all of it occurring in the surface 7.5 cm of the profile (0.314 ± 0.155 Mg C $\text{ha}^{-1} \text{yr}^{-1}$). Our observed rate of C sequestration with continuous no-till is comparable to other estimates made for this region of the U.S. for conversion of conventional tillage to continuous no-till (0.42 ± 0.46 Mg C $\text{ha}^{-1} \text{yr}^{-1}$; Franzluebbers, 2005; 0.33 Mg C $\text{ha}^{-1} \text{yr}^{-1}$; Eve et al., 2002). The baseline (i.e. duration of continuous no-till = 0) used in this research was the last season the site was tilled. Prior to adoption of continuous no-till the farms in our study used intermittent or rotational conservation tillage (i.e., disk or chisel) at 2 to 4 year intervals. The agreement between our estimates in this system with those comparing no-till to conventional tillage supports the supposition that periodic cultivation of no-till land may undermine the processes leading to C sequestration (Grandy et al.,

2006) and that continuous no-till may be a more effective practice for C sequestration than other conservation tillage practices (Uri, 2001; West and Marland, 2002).

2.4.4 Carbon Stratification

In addition to preserving soil organic matter, continuous no-till management results in the development of a mulch layer which enriches the soil surface in organic matter. Organic matter accumulation at the soil surface increases water infiltration, provides erosion control, and conserves moisture and nutrients. For these reasons, Franzluebbbers (2002a) suggested organic matter stratification as an index of soil quality. Analysis of variance and parameter estimates for the effect of dNT, biosolids and soil series on the stratification of C between the 0 – 2.5 cm depth and the 0 – 15 cm depth are shown in Table 2-4. In the absence of biosolids, dNT increased C stratification ratio by 0.133 yr^{-1} . Where biosolids have been applied, dNT increased C stratification ratio by 0.195 yr^{-1} .

Surprisingly, soil series had a significant effect on the stratification of soil C. The concentration of soil C was greater at 0 – 2.5 cm than at 7.5 – 15 cm in the Bojac soil series than was observed for either the Emporia or the Altavista series. This is likely a reflection of the difference in soil texture between the soil series and may have occurred due to a difference in response of the coarser textured Bojac to tillage compared to the other two soil series. With chisel or disk tillage there is often very little soil inversion. This may be especially true in very coarse soils with little structure. This may undermine the usefulness of soil C stratification ratio as a universal index to assess the impact of tillage practices on soil quality when comparing soils with drastically different soil textures. Franzluebbbers (2002a) suggested a stratification ratio >2 as an indicator that soil quality may be improving. Our findings suggest that following 10 years of continuous no-

till the stratification ratio of soil C would be 3.2 in the Emporia and Altavista soil series with a history of biosolids application and 2.6 where no biosolids have been applied. Following 10 years of no-till management, a stratification ratio of 3.8 would be predicted in the Bojac soil series where biosolids have been applied and 3.2 with no history of biosolids application.

2.5 Conclusions

Continuous no-till is an effective management practice to sequester C and increase surface (0-2.5 cm) soil C content, an indicator of improved soil quality. We found that the implementation of continuous no-till on farms previously using rotational or intermittent tillage resulted in the sequestration of $0.308 \pm 0.280 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ (0 – 15 cm). These data provide a quantitative estimate of the sequestration rate within the top 15 cm for the region that is based upon on-farm observations. The observed rate is similar to the offset issuance rate of 0.4 Mg C ha^{-1} used by CCX for the region for conversion of conventionally tilled land to continuous no-till.

The use of continuous no-till for producing corn, wheat/barley and soybeans resulted in soil C stratification ratios that ranged from 2.6 to 3.8 following 10 years of continuous no-till management. The higher levels of soil C in the surface layer will potentially increase capture and retention of rain, reduce erosion, and increase nutrient retention. Continuous no-till is a sustainable management practice within this region of Virginia, has a number of agronomic and environmental benefits, and based upon the data presented here its implementation should be encouraged on all crop production fields where the elimination of tillage is practical.

2.6 References

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2.7 Tables

Table 2-1. Sampling location site descriptions, depth weighted concentration of soil C and bulk density, and stratification ratio of soil C.

| Site | Soil Series† | Crop Rotation‡ | History of biosolids application | Duration continuous no-till | Tillage type last applied§ | Soil C -----g kg ⁻¹ ----- | | | Bulk density -----Mg m ⁻³ ----- | | | Stratification ratio of soil C¶ |
|------|--------------|----------------|----------------------------------|-----------------------------|----------------------------|---|----------|---------|---|----------|---------|---------------------------------|
| | | | | | | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm | |
| 1 | Altavista | C-SG/DCB | No | 1 | DD | 9.78 | 8.45 | 7.33 | 1.12 | 1.20 | 1.37 | 1.6 |
| 2 | Altavista | C-SG/DCB | No | 3 | DD | 9.42 | 7.24 | 6.58 | 1.01 | 1.31 | 1.48 | 1.6 |
| 3 | Altavista | C-FSB | No | 5 | DD | 11.8 | 10.2 | 9.45 | 1.38 | 1.44 | 1.53 | 1.3 |
| 4 | Altavista | C-SG/DCB | No | 6 | DD | 11.5 | 8.42 | 7.07 | 1.44 | 1.49 | 1.58 | 2.2 |
| 5 | Altavista | C-SG/DCB | No | 6 | DD | 14.6 | 12.0 | 10.1 | 1.24 | 1.35 | 1.49 | 2.0 |
| 6 | Altavista | C-FSB | No | 6 | DD | 12.5 | 8.75 | 6.71 | 1.39 | 1.46 | 1.53 | 3.1 |
| 7 | Altavista | C-SG/DCB | No | 7 | DD | 12.3 | 8.47 | 6.45 | 1.11 | 1.38 | 1.48 | 2.8 |
| 8 | Altavista | C-SG/DCB | No | 7 | DD | 20.0 | 14.5 | 11.5 | 0.92 | 1.26 | 1.45 | 2.4 |
| 9 | Altavista | C-SG/DCB | No | 8 | DD | 14.6 | 10.3 | 8.15 | 1.29 | 1.46 | 1.57 | 2.3 |
| 10 | Altavista | C-SG/DCB | No | 8 | DD | 15.3 | 11.6 | 9.67 | 0.98 | 1.26 | 1.38 | 2.0 |
| 11 | Altavista | C-SG/DCB | No | 13 | DD | 20.3 | 14.6 | 11.8 | 1.04 | 1.33 | 1.44 | 2.3 |
| 12 | Altavista | C-SG/DCB | No | 14 | DD | 15.1 | 9.26 | 7.00 | 1.15 | 1.42 | 1.51 | 3.2 |
| 13 | Altavista | C-SG/DCB | No | 14 | DD | 19.3 | 13.0 | 10.6 | 0.97 | 1.31 | 1.43 | 2.4 |
| 14 | Altavista | C-SG/DCB | Yes | 0 | DD | 11.3 | 11.2 | 10.0 | 1.33 | 1.37 | 1.48 | 1.3 |
| 15 | Altavista | C-SG/DCB | Yes | 2 | DD | 13.7 | 12.8 | 10.7 | 1.21 | 1.36 | 1.48 | 1.5 |
| 16 | Altavista | C-SG/DCB | Yes | 2 | DD | 13.2 | 11.8 | 10.1 | 1.27 | 1.35 | 1.46 | 1.3 |
| 17 | Altavista | C-SG/DCB | Yes | 4 | DD | 13.9 | 9.80 | 7.78 | 1.03 | 1.28 | 1.38 | 2.4 |
| 18 | Altavista | C-SG/DCB | Yes | 4 | DD | 14.6 | 10.6 | 8.64 | 1.06 | 1.28 | 1.42 | 2.2 |
| 19 | Altavista | C-SG/DCB | Yes | 5 | DD | 13.6 | 9.74 | 8.34 | 1.12 | 1.34 | 1.40 | 2.0 |
| 20 | Altavista | C-SG/DCB | Yes | 8 | DD | 27.2 | 16.2 | 11.7 | 1.10 | 1.32 | 1.45 | 5.1 |
| 21 | Altavista | C-SG/DCB | Yes | 8 | DD | 28.6 | 17.2 | 13.0 | 1.08 | 1.28 | 1.41 | 3.2 |
| 22 | Altavista | C-SG/DCB | Yes | 8 | DD | 19.8 | 13.5 | 10.2 | 1.18 | 1.35 | 1.51 | 2.4 |
| 23 | Altavista | C-SG/DCB | Yes | 8 | DD | 16.2 | 12.0 | 9.56 | 1.17 | 1.32 | 1.43 | 1.8 |

Table 2-1. Continued.

| Site | Soil Series† | Crop Rotation‡ | History of biosolids application | Duration continuous no-till | Tillage type last applied§ | Soil C -----g kg ⁻¹ ----- | | | Bulk density -----Mg m ⁻³ ----- | | | Stratification ratio of soil C¶ |
|------|--------------|----------------|----------------------------------|-----------------------------|----------------------------|---|----------|---------|---|----------|---------|---------------------------------|
| | | | | | | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm | |
| 24 | Altavista | C-SG/DCB | Yes | 9 | DD | 18.3 | 12.8 | 9.65 | 1.12 | 1.41 | 1.55 | 3.1 |
| 25 | Bojac | C-FSB | No | 5 | DD | 10.6 | 7.31 | 5.89 | 1.28 | 1.43 | 1.52 | 2.7 |
| 26 | Bojac | C-FSB | No | 5 | DD | 12.6 | 8.53 | 6.43 | 1.31 | 1.46 | 1.54 | 3.7 |
| 27 | Bojac | C-SG/DCB | No | 8 | DD | 13.3 | 8.30 | 6.28 | 1.31 | 1.48 | 1.58 | 3.5 |
| 28 | Bojac | C-SG/DCB | No | 8 | DD | 14.3 | 8.57 | 6.39 | 0.98 | 1.25 | 1.37 | 3.4 |
| 29 | Bojac | C-SG/DCB | No | 8 | DD | 12.8 | 7.66 | 5.62 | 1.07 | 1.28 | 1.40 | 3.6 |
| 30 | Bojac | C-SG/DCB | Yes | 0 | DD | 7.5 | 7.55 | 6.44 | 1.35 | 1.39 | 1.49 | 1.3 |
| 31 | Bojac | C-SG/DCB | Yes | 2 | MB/DD | 11.7 | 8.29 | 6.88 | 1.25 | 1.37 | 1.46 | 2.9 |
| 32 | Bojac | C-SG/DCB | Yes | 2 | DD | 11.8 | 10.1 | 8.66 | 1.30 | 1.40 | 1.51 | 1.9 |
| 33 | Bojac | C-SG/DCB | Yes | 2 | DD | 11.7 | 9.78 | 8.12 | 1.33 | 1.43 | 1.52 | 2.2 |
| 34 | Bojac | C-SG/DCB | Yes | 3 | DD | 12.0 | 9.89 | 9.00 | 1.33 | 1.42 | 1.49 | 1.6 |
| 35 | Bojac | C-SG/DCB | Yes | 6 | DD | 13.3 | 9.83 | 8.10 | 1.18 | 1.33 | 1.42 | 2.1 |
| 36 | Bojac | C-SG/DCB | Yes | 8 | DD | 16.3 | 10.7 | 7.56 | 1.06 | 1.27 | 1.41 | 3.9 |
| 37 | Bojac | C-SG/DCB | Yes | 8 | DD | 14.8 | 9.07 | 6.59 | 1.10 | 1.34 | 1.45 | 4.3 |
| 38 | Bojac | C-SG/DCB | Yes | 8 | DD | 16.3 | 11.8 | 9.42 | 1.29 | 1.39 | 1.48 | 2.4 |
| 39 | Bojac | C-SG/DCB | Yes | 8 | DD | 21.2 | 13.7 | 10.1 | 1.12 | 1.28 | 1.41 | 2.2 |
| 40 | Bojac | C-SG/DCB | Yes | 9 | DD | 18.8 | 13.2 | 9.33 | 1.14 | 1.35 | 1.50 | 3.4 |
| 41 | Emporia | C-SG/DCB | No | 0 | DD | 8.7 | 8.47 | 7.53 | 1.15 | 1.24 | 1.37 | 1.3 |
| 42 | Emporia | C-SG/DCB | No | 2 | MB/DD | 11.4 | 9.68 | 7.59 | 1.22 | 1.43 | 1.52 | 2.1 |
| 43 | Emporia | C-FSB | No | 4 | DD | 11.1 | 9.04 | 7.11 | 1.42 | 1.50 | 1.61 | 2.0 |
| 44 | Emporia | C-FSB | No | 4 | DD | 13.5 | 10.6 | 8.71 | 1.46 | 1.54 | 1.61 | 2.2 |
| 45 | Emporia | C-FSB | No | 4 | DD | 11.6 | 9.67 | 8.18 | 1.51 | 1.49 | 1.57 | 1.8 |
| 46 | Emporia | C-FSB | No | 4 | DD | 9.2 | 7.16 | 5.96 | 1.50 | 1.55 | 1.59 | 1.8 |
| 47 | Emporia | C-SG/DCB | No | 5 | DD | 12.5 | 9.59 | 8.21 | 1.21 | 1.39 | 1.45 | 1.8 |
| 48 | Emporia | C-SG/DCB | No | 6 | DD | 14.2 | 12.3 | 9.87 | 1.17 | 1.38 | 1.52 | 1.8 |
| 49 | Emporia | C-SG/DCB | No | 8 | DD | 16.0 | 12.3 | 9.86 | 1.01 | 1.31 | 1.41 | 2.2 |

Table 2–1. Continued.

| Site | Soil Series† | Crop Rotation‡ | History of biosolids application | Duration continuous no-till | Tillage type last applied§ | Soil C -----g kg ⁻¹ ----- | | | Bulk density -----Mg m ⁻³ ----- | | | Stratification ratio of soil C¶ |
|------|--------------|----------------|----------------------------------|-----------------------------|----------------------------|---|----------|---------|---|----------|---------|---------------------------------|
| | | | | | | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm | |
| 50 | Emporia | C-SG/DCB | No | 8 | DD | 16.5 | 11.8 | 8.93 | 1.02 | 1.26 | 1.40 | 2.7 |
| 51 | Emporia | C-SG/DCB | No | 11 | DD | 14.8 | 11.6 | 8.98 | 1.01 | 1.21 | 1.38 | 2.3 |
| 52 | Emporia | C-SG/DCB | No | 11 | DD | 16.6 | 12.6 | 9.57 | 1.03 | 1.21 | 1.37 | 2.5 |
| 53 | Emporia | C-SG/DCB | No | 11 | DD | 13.5 | 9.72 | 7.63 | 1.06 | 1.27 | 1.43 | 2.4 |
| 54 | Emporia | C-SG/DCB | Yes | 3 | Ch | 12.6 | 11.0 | 9.57 | 1.32 | 1.44 | 1.55 | 1.4 |
| 55 | Emporia | C-SG/DCB | Yes | 3 | Ch | 16.3 | 13.3 | 10.6 | 1.16 | 1.33 | 1.53 | 2.1 |
| 56 | Emporia | C-SG/DCB | Yes | 4 | Ch | 14.5 | 11.5 | 9.05 | 1.15 | 1.43 | 1.58 | 2.2 |
| 57 | Emporia | C-SG/DCB | Yes | 5 | Ch | 14.9 | 11.8 | 9.20 | 0.89 | 1.15 | 1.38 | 2.2 |
| 58 | Emporia | C-SG/DCB | Yes | 9 | DD | 11.7 | 9.33 | 7.53 | 1.12 | 1.33 | 1.43 | 2.0 |
| 59 | Emporia | C-SG/DCB | Yes | 9 | DD | 16.6 | 12.8 | 9.40 | 1.24 | 1.49 | 1.60 | 2.8 |
| 60 | Emporia | C-SG/DCB | Yes | 9 | DD | 24.2 | 21.4 | 18.2 | 1.06 | 1.32 | 1.43 | 1.6 |
| 61 | Emporia | C-SG/DCB | Yes | 9 | DD | 14.2 | 11.0 | 8.37 | 1.24 | 1.46 | 1.56 | 2.5 |
| 62 | Emporia | C-SG/DCB | Yes | 9 | DD | 16.7 | 11.6 | 8.65 | 1.24 | 1.52 | 1.61 | 2.9 |
| 63 | Emporia | C-SG/DCB | Yes | 14 | DD | 39.1 | 23.3 | 15.8 | 0.93 | 1.28 | 1.49 | 6.5 |

† Bojac (Coarse-loamy, mixed, semiactive, thermic Typic Hapludults), Altavista (Fine-loamy, mixed semiactive, thermic Aquic Hapludults), and Kempsville (Fine-loamy, siliceous, subactive, thermic Typic Hapludults)

‡ Corn (*Zea mays* L.), C; small grain [wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.)], SG; double-crop soybean (*Glycine max* L.), DCB; and full season soybean, FSB

§ Double disk, DD; mould-board plow, MB; chisel plow, Ch

¶ Stratification ratio of soil C calculated by dividing measurements at 0 – 2.5 cm by those at 7.5 – 15 cm

Table 2-2. Analysis of variance and parameter estimates for the effects of duration of continuous no-till management, biosolids application and soil series on the concentration of soil C at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depth.

| <u>0 – 2.5 cm Depth</u> | | | | |
|-------------------------|----|-----------------|---------|---------|
| Source | df | Sum of Squares† | F Value | Pr > F |
| Model | 2 | 900.3 | 40.3 | <0.0001 |
| dNT | 1 | 598.5 | 26.9 | <0.0001 |
| dNT x Biosolids | 1 | 301.8 | 27.0 | <0.0001 |
| Error | 60 | 670.0 | | |
| Total | 62 | 1570 | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-----------------|----------|-------------------------------|----------|
| | | -----g kg ⁻¹ ----- | |
| Intercept | 8.90 | 0.88 | 1.78 |
| dNT | 0.678 | 0.131 | 0.261 |
| dNT x Biosolids | 0.615 | 0.118 | 0.236 |

| <u>0 – 7.5 cm Depth</u> | | | | |
|-------------------------|----|----------------|---------|---------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 4 | 270.5 | 14.0 | <0.0001 |
| dNT | 1 | 114.0 | 23.5 | <0.0001 |
| Biosolids | 1 | 95.9 | 19.8 | <0.0001 |
| Soil Series | 2 | 60.6 | 6.26 | 0.0035 |
| Error | 58 | 280.9 | | |
| Total | 62 | 551.4 | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|--------------|----------|-------------------------------|----------|
| | | -----g kg ⁻¹ ----- | |
| Intercept | 10.7 | 0.75 | 1.51 |
| dNT | 0.415 | 0.082 | 0.165 |
| Biosolids | 2.89 | 0.57 | 1.14 |
| Soil series‡ | | | |
| Bojac | -2.48 | 0.734 | 1.47 |

Table 2-2. Continued.

| <u>0 – 15 cm Depth</u> | | | | |
|------------------------|----|----------------|---------|--------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 4 | 119.8 | 9.54 | <0.001 |
| dNT | 1 | 29.1 | 9.27 | 0.0035 |
| Biosolids | 1 | 43.7 | 13.9 | 0.0004 |
| Soil Series | 2 | 47.0 | 7.48 | 0.0013 |
| Error | 58 | 182.1 | | |
| Total | 62 | 301.9 | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-------------|----------|-------------------------------|----------|
| | | -----g kg ⁻¹ ----- | |
| Intercept | 7.07 | 0.62 | 1.24 |
| dNT | 0.207 | 0.066 | 0.133 |
| Biosolids | 2.03 | 0.46 | 0.920 |
| Soil series | | | |
| Bojac | -2.09 | 0.59 | 1.18 |

† Main effect sum of squares are Type I.

‡ Individual soil series were evaluated using t-test to determine significance (not shown).

Table 2-3. Analysis of variance and parameter estimates for the effects of duration of continuous no-till management, biosolids application and soil series on the mass of soil C (Mg ha⁻¹) at the 0 – 2.5, 0 – 7.5, and 0 - 15 cm depth.

| <u>0 – 2.5 cm Depth</u> | | | | |
|-------------------------|----|-----------------|---------|--------|
| Source | df | Sum of Squares† | F Value | Pr > F |
| Model | 2 | 47.3 | 31.2 | <0.001 |
| dNT | 1 | 25.1 | 33.1 | <0.001 |
| dNT x Biosolids | 1 | 22.2 | 29.3 | <0.001 |
| Error | 60 | 45.5 | | |
| Total | 62 | 92.8 | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-----------------|----------|---------------------------------|----------|
| | | ----- Mg ha ⁻¹ ----- | |
| Intercept | 3.13 | 0.23 | 0.464 |
| dNT | 0.124 | 0.034 | 0.0684 |
| dNT x Biosolids | 0.167 | 0.031 | 0.0615 |

| <u>0 – 7.5 cm Depth</u> | | | | |
|-------------------------|----|----------------|---------|--------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 4 | 210.8 | 12.3 | <0.001 |
| dNT | 1 | 64.52 | 15.1 | 0.0003 |
| Biosolids | 1 | 83.5 | 19.5 | <0.001 |
| Soil Series | 2 | 62.7 | 7.32 | 0.0015 |
| Error | 58 | 248.4 | | |
| Total | 62 | 459.2 | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|--------------|----------|---------------------------------|----------|
| | | ----- Mg ha ⁻¹ ----- | |
| Intercept | 11.4 | 0.711 | 1.41 |
| dNT | 0.314 | 0.0774 | 0.155 |
| Biosolids | 2.72 | 0.537 | 1.08 |
| Soil series‡ | | | |
| Bojac | -2.59 | 0.690 | 1.38 |

Table 2-3. Continued.

| <u>0 – 15 cm Depth</u> | | | | |
|------------------------|----|----------------|---------|---------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 4 | 481.5 | 8.62 | <0.0001 |
| dNT | 1 | 64.62 | 4.63 | 0.036 |
| Biosolids | 1 | 178.3 | 12.8 | 0.0007 |
| Soil Series | 2 | 238.6 | 8.55 | 0.0006 |
| Error | 58 | 809.8 | | |
| Total | 62 | 1291 | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-------------|----------|--------------------------------|----------|
| | | -----Mg ha ⁻¹ ----- | |
| Intercept | 16.5 | 1.31 | 2.63 |
| dNT | 0.308 | 0.140 | 0.280 |
| Biosolids | 4.19 | 0.969 | 1.93 |
| Soil series | | | |
| Bojac | -4.85 | 1.25 | 2.49 |

†Main effect sum of squares are Type I.

‡Individual soil series were evaluated using t-test to determine significance (not shown).

Table 2-4. Analysis of variance and parameter estimates for the effects of duration of continuous no-till management, dNT, biosolids application and soil series on the stratification ratio of C at the 0 – 2.5 cm depth to C at the 7.5 – 15 cm depth.

| Source | df | Sum of Squares† | F Value | Pr > F |
|-----------------|----|-----------------|---------|---------|
| Model | 5 | 23.6 | 11.1 | <0.0001 |
| dNT | 1 | 15.8 | 4.66 | <0.0001 |
| dNT x Biosolids | 1 | 3.96 | 10.3 | 0.007 |
| Soil Series | 2 | 3.88 | 5.40 | 0.027 |
| Error | 57 | 29.3 | | |
| Total | 62 | 53.0 | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-----------------|-------------------------------|----------------|----------|
| | ----- g g ⁻¹ ----- | | |
| Intercept | 1.24 | 0.281 | 0.460 |
| dNT | 0.133 | 0.0361 | 0.0564 |
| dNT x Biosolids | 0.0621 | 0.0255 | 0.0511 |
| Soil Series‡ | | | |
| Bojac | 0.599 | 0.234 | 0.467 |

†Main effect sum of squares are Type I.

‡Individual soil series were evaluated using t-test to determine significance (not shown).

2.8 Figures

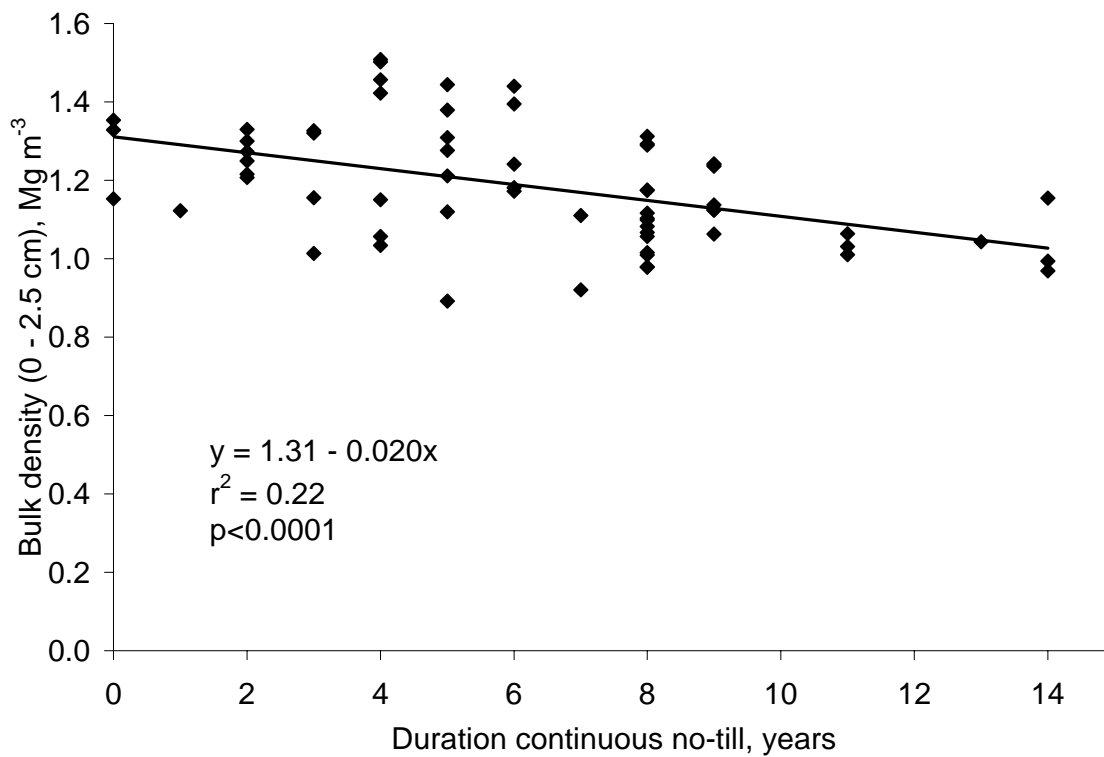


Figure 2-1. Relationship between bulk density at 0 – 2.5 cm and duration of continuous no-till management.

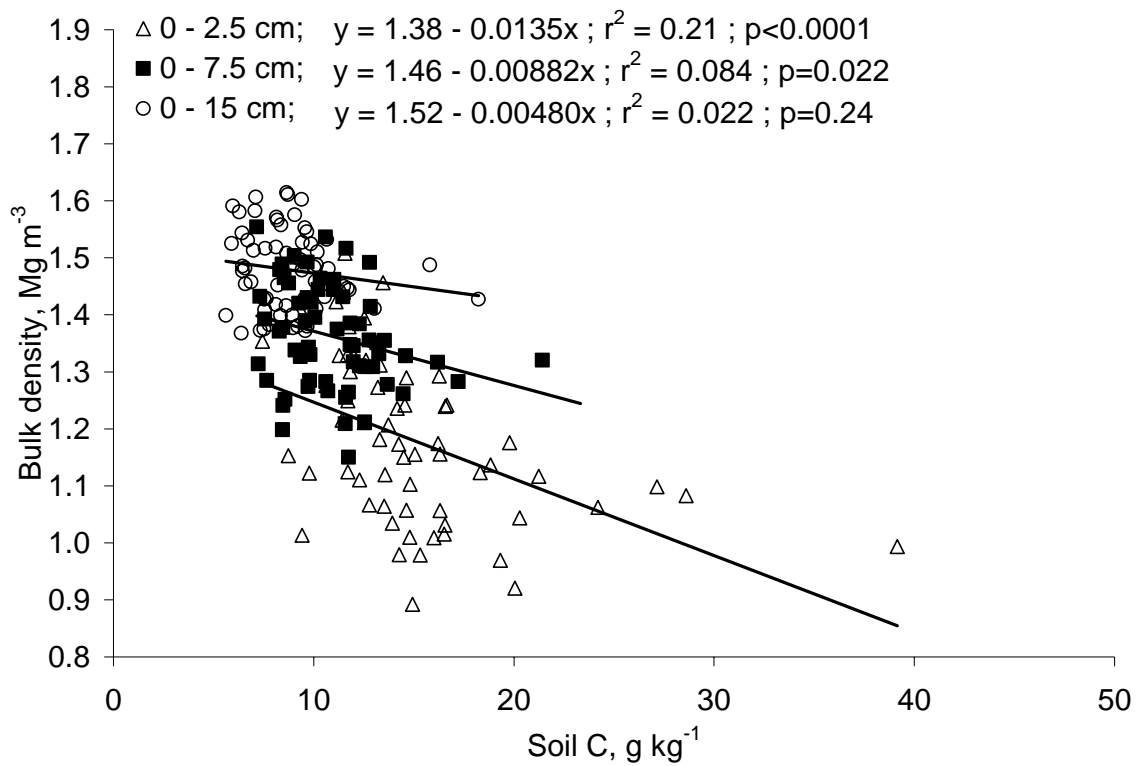


Figure 2-2. Relationship between bulk density and the concentration of soil C at 0 – 2.5, 0 – 7.5 and 0 – 15 cm.

3 Soil Nitrogen Status in Continuous No-Till Grain Cropping Systems of the Virginia Coastal Plain.

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3.1 Abstract

Tillage management is an important regulator of organic matter decomposition and N mineralization in agroecosystems. Tillage has resulted in the loss of considerable organic N from surface soils. There is potential to rebuild and conserve substantial amounts of soil N where no-till management is implemented in crop production systems. The objectives of our research were to measure N sequestration rate with continuous no-till management of grain cropping systems and evaluate its impact on mineralizable and inorganic soil N. Samples were collected from 63 sites in production fields using a rotation of corn (*Zea mays* L.) - wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.) – double-crop soybean (*Glycine max* L.) across three soil series [Bojac (Coarse-loamy, mixed, semiactive, thermic Typic Hapludults), Altavista (Fine-loamy, mixed semiactive, thermic Aquic Hapludults), and Kempsville (Fine-loamy, siliceous, subactive, thermic Typic Hapludults)] with a history of continuous no-till that ranged from 0 to 14 yrs. Forty-one of the sites had a history of biosolids application. Soil cores were collected at each site from 0 – 2.5, 2.5 – 7.5 and 7.5 – 15 cm and analyzed for total N, Illinois soil N test-N (ISNT-N), and $[\text{NH}_4+\text{NO}_3]\text{-N}$. A history of biosolids application increased the concentration of total soil N by $154 \pm 66.8 \text{ mg N kg}^{-1}$ ($310 \pm 140 \text{ kg N ha}^{-1}$) but surprisingly did not increase ISNT-N in the surface 0 – 15 cm. Continuous no-till increased the concentration of total soil N by $9.98 \text{ mg N kg}^{-1} \text{ yr}^{-1}$ ($22.2 \pm 21.2 \text{ kg N ha}^{-1} \text{ yr}^{-1}$) and ISNT-N by $1.68 \text{ mg N kg}^{-1} \text{ yr}^{-1}$ in the surface 0 – 15 cm. The implementation of continuous no-till management in this cropping system has resulted in conservation of soil N.

3.2 Introduction

Due to conservation awareness, improved technology, and increased fuel costs no-till management has been implemented on a significant portion of U.S. cropland. In 2004, about 23% of U.S cropland was managed no-till (CTIC., 2004). In Virginia, approximately 35% of annual crop production land was managed using no-till (CTIC, 2004). Continuous no-till management can have a significant influence on soil organic N cycling (Franzluebbers et al., 1994a; Kristensen et al., 2000) and fertilizer N use efficiency (Meisinger et al., 1985; Martens and Dick, 2003).

Nitrogen is among the most important nutrients required for the production of world food supplies. Currently, as much as 40% of the world's protein supply is estimated to be derived from fertilizer N; by 2050 it is expected to be about 60% (Smil, 2001). Nitrogen use efficiency is paramount to both agronomic viability and environmental health. The primary objective of N applications to cropland by the agricultural producer is to increase yield with a subsequent economic return from the capital invested. In order to maximize profit, N needs must be accurately determined to allow producers to meet yield goals with economically acceptable capital investments. Excessive N applications are undesirable from an economic standpoint. The negative environmental ramifications of unnecessary N applications, such as the potential for contamination of ground water and hypoxia in surface waters, are also widely recognized (Follett and Hatfield, 2001).

Nitrogen use efficiency has been defined using a number of factors of input and recovery (e.g., Moll et al., 1982; Raun and Johnson, 1999; Semenov et al., 2007). Here, we have adapted our definition of N use efficiency of a cropping system from Cassman et

al. (2002) as the proportion of applied N recovered in the harvested crop, contained in recycled crop residues, and incorporated into soil organic matter (SOM). The N not recovered in these pools is lost from the system and contributes to the reactive N load in the environment external to the cropping system. Thus, N use efficiency of a cropping system may be increased through greater crop uptake recovery of applied N, by decreasing N lost from SOM, or both.

Soil tillage is one of the oldest known management tools for mining soil organic nutrient reserves to enhance crop growth (Martens, 2001). A number of tillage dependent factors influence the rate of SOM decomposition in agronomic cropping systems. With tillage, soil organic matter becomes more evenly distributed within the plow layer. Residues left on the soil surface with no-till management experiences frequent wetting and drying while residues that are incorporated with tillage are buffered against extremes in moisture conditions thus favoring microbial activity. This may be the greatest factor leading to SOM decomposition in tilled soils (Franzluebbers, 2004). Tillage also aerates soil, creating a more oxidative environment. Removal of residues from the surface exposes more soil to solar radiation, decreases soil albedo, and results in higher soil temperatures.

No-till management has received a great deal of attention for its potential to sequester C and offset anthropogenic CO₂ emissions (Paustian et al., 1997; Follett, 2001; Uri, 2001; West and Marland, 2002; West and Post, 2002; Franzluebbers, 2005). Any management practice that changes soil organic C will also influence soil organic N since the C/N ratio of stable SOM has a relatively narrow range (~10:1 to 12:1). There is potential to conserve a substantial amount of soil organic N with no-till management.

Franzluebbers (2004) used meta-analysis to estimate the rate of total soil N sequestration with no-till management compared to shallow tillage and found that total soil N was increased by an average rate of $28 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ ($n = 26$) under no-till.

Increased tillage intensity decreases the soils capacity to immobilize and conserve mineral N (Carter and Rennie, 1984; Follett and Schimel, 1989). Follett and Schimel (1989) observed that after 16 years of cultivation, total N in the surface 10 cm of soil had decreased by 27, 32, and 50% of native sod in no-till, stubble-mulch, and plow treatments, respectively. Pierce and Fortin (1997) found similar results in Michigan comparing no-till to conventional till treatments that had been in place for 11 years. Carter and Rennie (1984) found immobilization of fertilizer N in no-till soils into microbial biomass mainly in the surface 5 cm and less from 5 to 10 cm. By immobilizing N at the soil surface, soil N cycling with no-till management is slower but may be more efficient (House et al., 1984).

A portion of the additional N retained as SOM in no-till soils may potentially become available for crops (Franzluebbers et al., 1994a; Wienhold and Halvorson, 1999). Franzluebbers et al. (1994a) found that mineralizable N was an average of 45% greater in soils treated no-till for 9 years in Texas compared to those that were disk tilled. In a spring wheat-winter wheat-sunflower crop rotation Wienhold and Halvorson (1999) observed that N mineralization in the surface 5 cm of soil treated no-till was 112 and 143% greater than those cultivated using minimal (sweep plow) or conventional tillage (chisel plow and a double disk), respectively.

A soil based approach that attempts to quantify organic N turnover could improve the precision of fertilizer N recommendations and increase N use efficiency (Mulvaney et

al., 2005). A number of chemical methods have been proposed for estimating soil N availability (Bundy and Meisinger, 1994; Stevenson and Cole, 1999). Soil test methods designed to estimate potentially mineralizable N have been based on an empirical approach, and their use has been limited due to poor correlations with seasonal N mineralization and crop N uptake (Stevenson and Cole, 1999; Khan et al., 2001a). The ISNT was developed by Khan et al. (2001b) as a simple soil assay to estimate mineralizable soil N and predict reduced response to N-fertilization. The ISNT uses direct alkaline hydrolysis to estimate hydrolysable amino sugar-N, a labile fraction of total soil N. Khan et al (2001a) found that ISNT values were well correlated with hydrolysable amino sugar-N ($r=0.91$) and used the assay to successfully identify soils in Illinois that were non-responsive to fertilizer-N. They found a wide range of N-test values for both responsive and non-responsive sites and suggested the possibility of using the soil test to quantitatively determine fertilizer N rates in conjunction with expected yield goals. The ISNT has also been found to provide useful data in other regions of the U.S. Klapwyk and Ketterings (2006) were able to identifying non-responsive corn silage fields on dairy farms in New York using the ISNT. Williams et al.(2007b) successfully predicted the economic optimum N rate (EONR) for corn grown on well- ($r^2 = 0.87$) or poorly- ($r^2 = 0.78$) drained soils in North Carolina. Sharifi et al. (2007) found that the ISNT was highly correlated ($r=0.72$) with N mineralization during a 24 week aerobic incubation period of 153 soils that were collected from existing field experiments extending across 4 Canadian provinces and into Maine, USA.

The ISNT has not proven useful in all regions or cropping systems. For example, working in Iowa Barker et al. (2006) found no relationship between the ISNT and relative

corn grain yield, corn response to fertilizer N, or EONR. The soils used in their study had relatively high levels of hydrolysable $\text{NH}_4\text{-N}$ relative to amino sugar-N and the authors suggested that this may partially explain the poor performance of the ISNT. Marriott and Wander (2006) used the assay to compare labile soil N in conventional and organic cropping systems and found that the ISNT was not a sensitive index of labile N. The ISNT fraction was not preferentially enriched by organic management and its response was similar to that of total soil C and N. For these reasons it is not likely that the assay will be adopted as a universal soil N test. Rather, its use will be limited to regions and applications where the assay has proven useful. To our knowledge, the assay has not been tested for its ability to detect changes in soil N with no-till management.

Little research has been conducted to investigate N sequestration in long-term no-till soils, particularly in the Mid-Atlantic Coastal Plain. Quantification of organic N cycling in no-till soils may improve the precision of fertilizer N recommendations and increase N use efficiency. The most common crop rotations in the middle coastal plain of Virginia is corn (*Zea mays* L.) – wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.) – double-crop soybean (*Glycine max* L.). Corn and soybean have been planted no-till on most farms since at least the early to mid 1980's; however, on many farms some tillage is conducted prior to planting small grain (i.e., wheat or barley). Many no-till fields are also periodically tilled to alleviate soil compaction, control difficult weeds, incorporate organic amendments (i.e., biosolids) or remove tire ruts left by harvesting equipment. The objectives of this research were to measure N sequestration rate with continuous no-till management of grain cropping systems and evaluate its impact on ISNT- and inorganic- N content.

3.3 Materials and Methods

3.3.1 Sampling Locations

Sixty-three grain crop production fields were selected across three soil series in the Virginia Coastal Plain with a history of continuous no-till management ranging from 0 to 14 years (Table 3-1). Fields were located within the geographic region 37°41 N to 37°17 N and 77°40 W to 77°12 W. Average annual temperature of the region is 14°C and precipitation is 112 cm yr⁻¹. The three soils series, Bojac (Coarse-loamy, mixed, semiactive, thermic Typic Hapludults), Altavista (Fine-loamy, mixed semiactive, thermic Aquic Hapludults), and Kempsville (Fine-loamy, siliceous, subactive, thermic Typic Hapludults), represent a significant portion of the land area used for crop production in the region. All but eight sites were in a corn – wheat or barley – double-crop soybean rotation. The eight sites that did not have a small grain (wheat or barley) in rotation grew full season soybeans. Forty one of the sites had a history of biosolids application. All fields with a history of biosolids received the most recent application 4 or 5 years prior to the sampling date.

3.3.2 Sampling and Analysis

Fields were sampled in 2005 or 2006 shortly following corn harvest except locations 10, 30, and 49 which were tilled following corn harvest in preparation for small grain planting. These locations were not sampled until 3 months following tillage to allow for soil conditions to stabilize. Five soil samples were collected from each location along a 100 m transect using 5 cm diam. soil cores split into 0 - 2.5 cm, 2.5 - 7.5 cm and 7.5 to 15 cm depth increments. The shallow sampling depth was chosen since the predominant form of tillage in the region is shallow double-disking and typically does not incorporate residues deeper than 10 cm. This was confirmed at multiple locations by

excavating miniature soil pits following tillage operations. Intact soil cores were sealed in plastic wrap and stored on ice immediately following collection. On returning to the lab the cores were separated by layer, the soil removed and rapidly air-dried. Bulk density was determined on each core at each depth increment by obtaining an air-dry weight for each core and oven drying (105°C) an aliquot to determine moisture content. Following bulk density measurements, air-dried soil samples were ground and sieved (2 mm). For chemical analysis, composite samples were made for each sampling layer by thoroughly mixing equal volume sub samples from each core.

Total soil C and N levels were determined in duplicate by dry combustion using a VarioMax CNS macro elemental analyzer (Elementar, New Jersey). The concentration of ISNT-N was determined using the procedures described in Technical Note 02-01 (University of Illinois at Urbana Champaign [UIUC], 2004) and Khan et al. (1997). Briefly, 1 g of soil was treated with 10 mL of 2 M NaOH in a 473-mL wide-mouth Ball[®] jar, and heated for 5 hrs at 50° C on a hotplate to liberate [NH₄⁺+amino sugar] – N as gaseous NH₃ which was collected in a 4% w/v H₃BO₃ solution. The [NH₄⁺+amino sugar] – N was subsequently determined by acidimetric titration with standardized 0.01 M H₂SO₄ using a Radiometer TIM 900 Titration Manager and ABU901 autoburette (Radiometer Analytical S.A., Lyon France). Soil NH₄-N and NO₃-N were extracted with 2 M KCl for one hour on a reciprocating shaker and determined colorimetrically using a QuickChem Automated Ion Analyzer (Lachat Instruments, Milwaukee, WI).

3.3.3 Data Analysis

Total soil C and N, ISNT-N, NO₃-N, NH₄-N and bulk density were calculated for 0 – 7.5 cm and 0 – 15 cm depths using depth weighted summation. The depth weighted concentration of total soil N, ISNT-N and [NO₃+NH₄]-N for 0-2.5, 0-7.5 and 0-15 cm at

each of the 63 locations sampled are listed in Table 3-2. Bulk density and total soil C data are reported elsewhere (Spargo et al., In review-b). Analysis of variance was performed using PROC GLM of SAS with duration of continuous no-till (dNT) treated as a continuous quantitative variable, biosolids as a dummy variable, and soil series as a class variable (SAS Institute, 2002). Sites with a history of biosolids application were assigned a value of 1 for the biosolids effect and sites with no history of biosolids application a value of 0. For model building, marginal sums of squares (type III) were used to test significance of main effects and interactions. When biosolids and soil series were not significant at the $p < 0.05$ level they were dropped from the model. When soil series was significant, t-tests were used to determine which of the soil series contributed ($p < 0.05$) to the model. Parameter estimates and confidence intervals were calculated using the SOLUTION and CLPARM commands in SAS, respectively.

3.4 Results and Discussion

3.4.1 Total Soil N

Soil C may become limiting in tilled systems, increasing N mineralization and limiting N immobilization (Follett and Schimel, 1989). The elimination of tillage generally results in slower residue decomposition and a net increase in SOM thus, continuous no-till management is expected to conserve soil N (Martens, 2001). Analysis of variance and parameter estimates for the effects of dNT, biosolids and soil series on the concentration of total soil N are summarized in Table 3-3. Concentration of total soil N increased significantly with dNT at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depths. Continuous no-till management increased the concentration of soil N by 50, 28, and 10 $\text{mg N kg}^{-1} \text{ yr}^{-1}$ at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depths, respectively. The higher rate

of increase near the surface is indicative of the stratification of SOM with the elimination of tillage (Franzluebbers, 2002a; Spargo et al., In review-b). Tillage practices affect N immobilization processes in soil due to residue placement. The stratification of SOM near the soil surface is more similar to natural systems rather than the complete mixing that results from tillage (Follett and Peterson, 1988; Franzluebbers, 2002a). The accumulation of crop residues near the soil surface stratifies microbial activity and conserves more soil N (Schomberg and Jones, 1999).

Biosolids also had a significant effect on the concentration of total soil N. There was an interaction between dNT and biosolids at the 0 – 2.5 cm depth. The concentration of soil N increased faster where biosolids were applied with dNT ($51 \text{ mg N kg}^{-1} \text{ yr}^{-1}$) since organic N added with biosolids not incorporated by tillage accumulated at the soil surface. The interaction between dNT and biosolids was not significant at 0 – 7.5 or 0 – 15 cm but biosolids did have a significant effect on the concentration of total soil N. Biosolids increased the concentration of total N by 232 and 154 mg N kg^{-1} at 0 – 7.5 and 0 – 15 cm, respectively. We expected to find an interaction between biosolids application and dNT in the 0 – 7.5 cm and 0 – 15 cm depth. This would have suggested that biosolids derived soil organic N mineralized at a slower rate under continuous no-till management. Interpretation of these results are complicated by the fact that all fields with a history of biosolids received an application 4 to 5 years prior to the sampling and several of these locations were tilled following application (i.e., 10 – 15, 30 – 34, and 51 – 54) while others were not.

Soil series had a significant effect on total soil N concentration at 0 – 7.5 and 0 – 15 cm but not at 0 – 2.5 cm. The Bojac soil series had 168 and 142 $\text{mg total soil N kg}^{-1}$

less than the other two soil series at the 0 – 7.5 and 0 – 15 cm depths, respectively. The Bojac has a much coarser texture than either the Altavista or Emporia soils. Soils with higher clay content typically have higher SOM (Nichols, 1984). This is due, in part, to the formation of SOM – clay mineral complexes and aggregates that protect SOM from microbial oxidation (Wiseman and Puttmann, 2006). In addition, the coarse textured Bojac soil series has much lower water holding capacity and, with more rapid depletion of available soil water, it has a lower biomass productive capacity than the Altavista or Emporia soils. Since crop yields are typically lower, the amount of crop residues returned to the soil each season is reduced, resulting in lower SOM contents (Lal et al., 1999; Follett, 2001).

In order to estimate the mass of total N sequestered we used bulk density to calculate N on an areal basis (kg N ha^{-1}). Analysis of variance and parameter estimates for the effects of dNT, biosolids and soil series on the mass of total soil N at the 0 – 2.5, 0 – 7.5 and 7.5 – 15 cm depths are summarized in Table 3-4. The overall trends for changes in the mass of total N with depth were similar to changes in the concentration of total N; however, dNT had no significant effect on the mass of total N at the 0 – 15 cm depth. This is surprising considering dNT did significantly increase the concentration of total N at the 0 – 15 cm depth. The only way this would be possible is if bulk density increased with dNT. Our previous analysis of the data indicated that bulk density was decreased with dNT at 0 – 2.5 cm and unaffected at both 0 – 7.5 cm and 0 – 15 cm (Spargo et al., In review-b). The lack of a significant relationship between dNT and the mass of soil N in the 0-15 cm may simply be due to variance introduced by including bulk density in the calculation. An alternative method to estimate the sequestration rate of total soil N on an

areal basis with continuous no-till is to use the average bulk density for all locations at the 0 – 15 cm depth which we determined to be 1.48 Mg m^{-3} . Using this value and the sequestration rate of $9.98 \pm 9.56 \text{ mg N kg}^{-1} \text{ yr}^{-1}$ for the 0 – 15 cm depth from Table 3-3 we estimate a sequestration rate on an areal basis of $22.2 \pm 21.2 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ with continuous no-till management. This is similar to the average N sequestration rate of $28 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ with no-till reported by Franzluebbers (2004).

We also examined the effect of dNT, biosolids, and soil series on the soil C:N ratio. The C:N ratio was unaffected at the 0 – 2.5 cm depth and increased at the 2.5 – 7.5 and 7.5 – 15 cm depths by continuous no-till management (Fig. 3-1). We expected the C:N ratio to increase with continuous no-till management due to the accumulation of high C:N ratio particulate organic matter with the elimination of tillage (Wander and Bidart, 2000; Diekow et al., 2005; Pikul et al., 2007). It is interesting that the accumulation of crop residues at the soil surface with continuous no-till management did not increase the C:N ratio at the 0 – 2.5 cm depth but increased it at depth. Crozier and King (1993) found that the C:N ratio of above ground corn shoot residue (42:1) and fine roots (33:1) were lower than below ground shoot residue (118:1) and coarse roots (78:1). Without tillage to evenly distribute corn residues through the plow layer, this would be expected to lead to stratification with lower C:N residues near the surface. In addition, Franzluebbers (1994b) suggested that repeated wetting and drying, such as occurs at the soil surface, leads to an accumulation of organic N which may be due to the accumulation of microbial resistant N compounds in crop residues. This would also lead to accumulation of lower C:N residues at the soil surface than at depth. Neither biosolids nor soil series had a significant influence on the C:N ratio at any depth.

3.4.2 Illinois Soil N Test and Inorganic N

The concentration of ISNT – N followed a similar trend as total soil N. Analysis of variance and parameter estimates for the effects of dNT, biosolids and soil series on the concentration of ISNT – N are summarized in Table 3-5. The concentration of ISNT – N increased significantly with dNT at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depths.

Continuous no-till management increased the concentration of ISNT – N by 6.63, 4.12, and 1.68 mg ISNT – N kg⁻¹ yr⁻¹ at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depths, respectively.

There was a significant interaction between dNT and biosolids at the 0 – 2.5 cm depth but not at the 0 – 7.5 or 0 – 15 cm depths. The concentration of ISNT – N increased faster with dNT where biosolids were applied. The interaction between dNT and biosolids was not significant at 0 – 7.5 or 0 – 15 cm and the additive effect of biosolids was only significant at 0 – 7.5 cm. Biosolids increased the concentration of ISNT – N by 20 mg N kg⁻¹ at 0 – 7.5 cm. It is interesting that sites with a history of biosolids did not have a significantly higher concentration of ISNT-N at 0 – 15 cm but did have great total N.

Soil series also had a significant effect on ISNT – N concentration at 0 – 2.5, 0 – 7.5 and 0 – 15 cm. The Bojac soil series had 29.0, 38.0 and 29.2 mg N kg⁻¹ less than the other two soil series at the 0 – 2.5, 0 – 7.5 and 0 – 15 cm depths, respectively. The reasons that the coarse-textured Bojac soil has lower concentrations of ISNT – N are likely similar to those previously discussed for total N.

We also considered the effect of dNT, biosolids, and soil series on ratio of ISNT-N to total N (data not shown). The only factor that had a significant influence was biosolids (p=0.004). The ratio of INST-N to total N was 0.15 where biosolids had been

applied compared to 0.17 where it had not. This may indicate that the application of biosolids increases the concentration of recalcitrant organic soil N.

It appears that ISNT – N was no more sensitive to management than total N. For example, at 0 – 15 cm both models explained 37% of the variability in total N and ISNT-N (as indicated by GLM Type I sum of squares). In a comparison of labile SOM between organic and conventional farming systems Marriott and Wander found ISNT – N to be highly correlated ($r = 0.98$) with total soil N and suggested this indicated that ISNT – N may extract some recalcitrant forms of soil N. We also found significant correlation between ISNT-N and total soil N at the 0 – 2.5, 2.5 – 7.5, and 7.5 – 15 cm depths but the relationship was not as strong ($r = 0.83, 0.62, \text{ and } 0.53$, respectively; Fig. 3-2) as that found by Marriott and Wander (2006). Further, the fraction of total N extracted by the ISNT was significantly different ($p < 0.05$) at each of the sampling depths. The percentage of total N extracted by the ISNT was 13.6, 15.6, 17.0 % at the 0 – 2.5, 2.5 – 7.5, and 7.5 – 15 cm depths, respectively. The frequent drying and rewetting of surface-placed residues reduces N mineralization from plant residues (Varco et al., 1993) and may increase the resistance of certain N compounds to microbial decomposition (Franzluebbers et al., 1994b). Future work involving more detailed soil N fractionation will need to be done on these soils in order to elucidate this trend and determine potential agronomic and environmental implications.

Concentrations of NO_3^- and $\text{NH}_4\text{-N}$ were unaffected by tillage or biosolids history. The concentration of inorganic soil N is dependent on numerous N-cycle processes (Stevenson and Cole, 1999) and the sensitivity of inorganic soil N to management practices may be limited by its temporal and spatial variability. The

concentration of $\text{NO}_3\text{-N}$ was significantly greater ($p < 0.05$) at the surface 0-2.5 cm (16.8 mg N kg^{-1}) than 2.5-7.5 cm (9.5 mg N kg^{-1}) and 7.5-15 cm (7.2 mg N kg^{-1}). The concentration of $\text{NH}_4\text{-N}$ was also significantly greater ($p < 0.05$) at the surface 0-2.5 cm (5.9 mg N kg^{-1}) than 2.5-7.5 cm (4.5 mg N kg^{-1}) and 7.5-15 cm (3.9 mg N kg^{-1}). Soil series had a significant affect on the concentration of soil $\text{NO}_3\text{-N}$ but not $\text{NH}_4\text{-N}$. The Bojac soil series had 12.6 ($p = 0.0008$), 6.01 ($p = 0.003$) and 3.91 ($p = 0.01$) $\text{mg NO}_3\text{-N kg}^{-1}$ more than the Altavista and Emporia soils at 0 – 2.5, 0 – 7.5 and 0 – 15 cm depths, respectively (data not shown). The higher concentration of $\text{NO}_3\text{-N}$ in the coarse-textured Bojac soils is of particular concern since leaching losses are more likely to occur from these excessively well drained soils.

3.5 Conclusions

Continuous no-till is an effective management practice in the Virginia middle coastal plain to conserve soil N. We found that the implementation of continuous no-till on farms previously using rotational or intermittent tillage resulted in the sequestration of $22.2 \pm 21.2 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ (0 – 15 cm). These data provide a quantitative estimate of the N sequestration rate within the surface 15 cm for the region based upon on-farm observations. Our observed rate is similar to the average N sequestration rate of $28 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ ($n = 26$) with no-till reported by Franzluebbbers (2004). The conservation of soil N with continuous no-till management indicates improved N use efficiency of the cropping system.

It is important to recognize that a substantial portion of the soil N conserved with continuous no-till management can become rapidly available and potentially lost from the system when intermittent tillage is used as a modifier to address perceived soil

compaction, remove ruts, control weeds or incorporate residues (Pierce and Fortin, 1997). Therefore, the use of periodic or intermittent tillage of no-till cropping systems should only be practiced when absolutely necessary. When intermittent tillage is used, it should be synchronized with cropping to maximize the capture of mineralized soil N by growing vegetation.

A portion of the additional N retained as SOM in no-till soils may potentially become available for crops (Franzluebbers et al., 1994a; Wienhold and Halvorson, 1999). A soil based approach that quantifies organic N turnover may be necessary to improve the precision of fertilizer N recommendations in these systems. The ISNT has shown promise in some regions in certain cropping systems to predict N-mineralization (Sharifi et al., 2007) and a concomitant reduction in fertilizer N needs (Khan et al., 2001b; Mulvaney et al., 2005; Klapwyk and Ketterings, 2006; Williams et al., 2007b) but has failed in others (Barker et al., 2006). Future work will need to determine if the ISNT is an effective assay for the prediction of soil N availability in the corn-wheat-double crop soybean cropping system of the middle coastal plain of Virginia.

3.6 Referances

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3.7 Tables

Table 3-1. Sampling location site descriptions.

| Site | Soil Series† | Crop Rotation‡ | History of biosolids application | Duration continuous no-till | Tillage type last applied§ |
|------|--------------|----------------|----------------------------------|-----------------------------|----------------------------|
| 1 | Altavista | C-SG/DCB | No | 1 | DD |
| 2 | Altavista | C-SG/DCB | No | 3 | DD |
| 3 | Altavista | C-FSB | No | 5 | DD |
| 4 | Altavista | C-SG/DCB | No | 6 | DD |
| 5 | Altavista | C-SG/DCB | No | 6 | DD |
| 6 | Altavista | C-FSB | No | 6 | DD |
| 7 | Altavista | C-SG/DCB | No | 7 | DD |
| 8 | Altavista | C-SG/DCB | No | 7 | DD |
| 9 | Altavista | C-SG/DCB | No | 8 | DD |
| 10 | Altavista | C-SG/DCB | No | 8 | DD |
| 11 | Altavista | C-SG/DCB | No | 13 | DD |
| 12 | Altavista | C-SG/DCB | No | 14 | DD |
| 13 | Altavista | C-SG/DCB | No | 14 | DD |
| 14 | Altavista | C-SG/DCB | Yes | 0 | DD |
| 15 | Altavista | C-SG/DCB | Yes | 2 | DD |
| 16 | Altavista | C-SG/DCB | Yes | 2 | DD |
| 17 | Altavista | C-SG/DCB | Yes | 4 | DD |
| 18 | Altavista | C-SG/DCB | Yes | 4 | DD |
| 19 | Altavista | C-SG/DCB | Yes | 5 | DD |
| 20 | Altavista | C-SG/DCB | Yes | 8 | DD |
| 21 | Altavista | C-SG/DCB | Yes | 8 | DD |
| 22 | Altavista | C-SG/DCB | Yes | 8 | DD |
| 23 | Altavista | C-SG/DCB | Yes | 8 | DD |
| 24 | Altavista | C-SG/DCB | Yes | 9 | DD |
| 25 | Bojac | C-FSB | No | 5 | DD |
| 26 | Bojac | C-FSB | No | 5 | DD |
| 27 | Bojac | C-SG/DCB | No | 8 | DD |
| 28 | Bojac | C-SG/DCB | No | 8 | DD |
| 29 | Bojac | C-SG/DCB | No | 8 | DD |
| 30 | Bojac | C-SG/DCB | Yes | 0 | DD |
| 31 | Bojac | C-SG/DCB | Yes | 2 | MB/DD |
| 32 | Bojac | C-SG/DCB | Yes | 2 | DD |
| 33 | Bojac | C-SG/DCB | Yes | 2 | DD |
| 34 | Bojac | C-SG/DCB | Yes | 3 | DD |
| 35 | Bojac | C-SG/DCB | Yes | 6 | DD |
| 36 | Bojac | C-SG/DCB | Yes | 8 | DD |
| 37 | Bojac | C-SG/DCB | Yes | 8 | DD |

Table 3-1. Continued.

| Site | Soil Series† | Crop Rotation‡ | History of biosolids application | Duration continuous no-till | Tillage type last applied§ |
|------|--------------|----------------|----------------------------------|-----------------------------|----------------------------|
| 39 | Bojac | C-SG/DCB | Yes | 8 | DD |
| 40 | Bojac | C-SG/DCB | Yes | 9 | DD |
| 41 | Emporia | C-SG/DCB | No | 0 | DD |
| 42 | Emporia | C-SG/DCB | No | 2 | MB/DD |
| 43 | Emporia | C-FSB | No | 4 | DD |
| 44 | Emporia | C-FSB | No | 4 | DD |
| 45 | Emporia | C-FSB | No | 4 | DD |
| 46 | Emporia | C-FSB | No | 4 | DD |
| 47 | Emporia | C-SG/DCB | No | 5 | DD |
| 48 | Emporia | C-SG/DCB | No | 6 | DD |
| 49 | Emporia | C-SG/DCB | No | 8 | DD |
| 50 | Emporia | C-SG/DCB | No | 8 | DD |
| 51 | Emporia | C-SG/DCB | No | 11 | DD |
| 52 | Emporia | C-SG/DCB | No | 11 | DD |
| 53 | Emporia | C-SG/DCB | No | 11 | DD |
| 54 | Emporia | C-SG/DCB | Yes | 3 | Ch |
| 55 | Emporia | C-SG/DCB | Yes | 3 | Ch |
| 56 | Emporia | C-SG/DCB | Yes | 4 | Ch |
| 57 | Emporia | C-SG/DCB | Yes | 5 | Ch |
| 58 | Emporia | C-SG/DCB | Yes | 9 | DD |
| 59 | Emporia | C-SG/DCB | Yes | 9 | DD |
| 60 | Emporia | C-SG/DCB | Yes | 9 | DD |
| 61 | Emporia | C-SG/DCB | Yes | 9 | DD |
| 62 | Emporia | C-SG/DCB | Yes | 9 | DD |
| 63 | Emporia | C-SG/DCB | Yes | 14 | DD |

† Bojac (Coarse-loamy, mixed, semiactive, thermic Typic Hapludults), Altavista (Fine-loamy, mixed semiactive, thermic Aquic Hapludults), and Kempsville (Fine-loamy, siliceous, subactive, thermic Typic Hapludults)

‡ Corn (*Zea mays* L.), C; small grain [wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.)], SG; double-crop soybean (*Glycine max* L.), DCB; and full season soybean, FSB

§ Double disk, DD; mould-board plow, MB; chisel plow, Ch

Table 3-2. Depth weighted concentration of total soil N, Illinois soil N test – N (ISNT-N), and KCl extractable [NO₃+NH₄]-N from each of the sampling sites.

| Site | Total N, g kg ⁻¹ † | | | ISNT-N, mg kg ⁻¹ ‡ | | | [NO ₃ +NH ₄]-N, mg kg ⁻¹ § | | |
|------|-------------------------------|----------|---------|-------------------------------|----------|---------|--|----------|---------|
| | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm |
| 1 | 0.725 | 0.652 | 0.585 | 141 | 132 | 121 | 10.2 | 8.29 | 6.75 |
| 2 | 0.797 | 0.603 | 0.553 | 149 | 126 | 117 | 14.7 | 10.1 | 7.47 |
| 3 | 0.960 | 0.833 | 0.810 | 130 | 120 | 114 | 16.5 | 16.2 | 16.3 |
| 4 | 0.892 | 0.663 | 0.541 | 140 | 104 | 90.7 | 45.4 | 31.2 | 27.4 |
| 5 | 1.17 | 0.956 | 0.802 | 158 | 145 | 127 | 26.0 | 20.1 | 18.2 |
| 6 | 1.04 | 0.712 | 0.543 | 126 | 96.0 | 77.1 | 19.8 | 20.4 | 17.8 |
| 7 | 0.939 | 0.644 | 0.483 | 163 | 123 | 103 | 8.25 | 6.02 | 5.04 |
| 8 | 1.51 | 1.09 | 0.850 | 209 | 167 | 140 | 8.69 | 6.98 | 6.36 |
| 9 | 1.16 | 0.811 | 0.634 | 154 | 117 | 97.8 | 22.4 | 18.5 | 15.5 |
| 10 | 1.16 | 0.837 | 0.676 | 178 | 139 | 119 | 12.8 | 8.6 | 6.6 |
| 11 | 1.53 | 1.05 | 0.810 | 247 | 174 | 139 | 21.6 | 15.3 | 12.1 |
| 12 | 1.16 | 0.695 | 0.520 | 169 | 118 | 94.0 | 19.1 | 13.3 | 10.2 |
| 13 | 1.57 | 1.03 | 0.818 | 209 | 157 | 135 | 21.3 | 14.7 | 11.6 |
| 14 | 0.928 | 0.939 | 0.838 | 135 | 133 | 121 | 12.2 | 9.83 | 7.96 |
| 15 | 1.09 | 1.03 | 0.871 | 141 | 138 | 118 | 24.9 | 23.5 | 23.7 |
| 16 | 1.08 | 0.957 | 0.803 | 132 | 122 | 107 | 31.3 | 24.6 | 19.5 |
| 17 | 1.12 | 0.796 | 0.633 | 185 | 147 | 127 | 17.7 | 13.7 | 10.9 |
| 18 | 1.12 | 0.827 | 0.676 | 181 | 148 | 129 | 7.57 | 6.40 | 5.36 |
| 19 | 1.07 | 0.789 | 0.676 | 189 | 146 | 138 | 14.3 | 10.5 | 9.37 |
| 20 | 2.31 | 1.37 | 0.963 | 271 | 177 | 128 | 31.9 | 23.4 | 18.7 |
| 21 | 2.40 | 1.44 | 1.08 | 288 | 201 | 160 | 25.5 | 19.2 | 17.3 |
| 22 | 1.71 | 1.18 | 0.880 | 209 | 165 | 131 | 22.2 | 18.8 | 17.2 |
| 23 | 1.47 | 1.06 | 0.817 | 187 | 148 | 122 | 40.3 | 26.7 | 20.7 |

Table 3-2. Continued.

| Site | Total N, g kg ⁻¹ † | | | ISNT-N, mg kg ⁻¹ ‡ | | | [NO ₃ +NH ₄]-N, mg kg ⁻¹ § | | |
|------|-------------------------------|----------|---------|-------------------------------|----------|---------|--|----------|---------|
| | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm |
| 24 | 1.41 | 1.03 | 0.774 | 199 | 149 | 115 | 15.7 | 14.4 | 9.73 |
| 25 | 0.922 | 0.637 | 0.513 | 119 | 84.8 | 69.0 | 50.1 | 30.9 | 24.8 |
| 26 | 1.09 | 0.735 | 0.545 | 129 | 97.3 | 76.0 | 48.9 | 33.9 | 25.5 |
| 27 | 1.06 | 0.639 | 0.467 | 131 | 90.0 | 71.1 | 36.5 | 20.6 | 18.2 |
| 28 | 1.17 | 0.698 | 0.502 | 168 | 122 | 102 | 14.6 | 9.56 | 7.25 |
| 29 | 0.980 | 0.591 | 0.425 | 128 | 102 | 89.0 | 15.1 | 13.4 | 9.22 |
| 30 | 0.638 | 0.643 | 0.557 | 89.9 | 88.7 | 78.6 | 8.12 | 8.02 | 6.40 |
| 31 | 0.876 | 0.623 | 0.522 | 89.8 | 62.7 | 56.9 | 18.7 | 16.4 | 15.6 |
| 32 | 0.996 | 0.840 | 0.726 | 140 | 125 | 109 | 54.9 | 39.8 | 31.9 |
| 33 | 0.942 | 0.795 | 0.660 | 129 | 118 | 97.6 | 25.8 | 20.1 | 16.9 |
| 34 | 0.988 | 0.821 | 0.733 | 104 | 90.2 | 84.6 | 23.5 | 19.5 | 17.7 |
| 35 | 1.02 | 0.763 | 0.623 | 194 | 144 | 127 | 18.1 | 14.2 | 9.83 |
| 36 | 1.50 | 0.944 | 0.628 | 188 | 113 | 77.5 | 91.6 | 44.6 | 29.6 |
| 37 | 1.21 | 0.745 | 0.538 | 143 | 103 | 72.6 | 38.0 | 25.3 | 20.8 |
| 38 | 1.41 | 0.977 | 0.737 | 150 | 105 | 86.5 | 43.7 | 27.7 | 22.2 |
| 39 | 1.83 | 1.24 | 0.889 | 191 | 136 | 102 | 26.9 | 19.5 | 16.0 |
| 40 | 1.58 | 1.12 | 0.779 | 197 | 149 | 110 | 10.4 | 7.24 | 5.35 |
| 41 | 0.699 | 0.689 | 0.611 | 112 | 119 | 110 | 8.21 | 6.95 | 6.94 |
| 42 | 0.940 | 0.802 | 0.628 | 166 | 150 | 124 | 9.80 | 7.09 | 6.06 |
| 43 | 0.920 | 0.765 | 0.595 | 115 | 101 | 82.8 | 17.3 | 17.0 | 15.5 |
| 44 | 1.14 | 0.923 | 0.758 | 165 | 139 | 123 | 25.9 | 19.8 | 17.7 |
| 45 | 0.962 | 0.803 | 0.683 | 139 | 121 | 105 | 15.4 | 15.3 | 14.7 |
| 46 | 0.742 | 0.606 | 0.499 | 111 | 89.3 | 75.1 | 17.0 | 13.1 | 12.5 |
| 47 | 0.957 | 0.742 | 0.621 | 176 | 145 | 127 | 13.8 | 12.1 | 10.2 |
| 48 | 1.18 | 1.02 | 0.822 | 159 | 136 | 111 | 27.7 | 23.1 | 20.2 |
| 49 | 1.21 | 0.954 | 0.749 | 197 | 159 | 137 | 10.8 | 8.72 | 8.32 |

Table 3-2. Continued.

| Site | Total N, g kg ⁻¹ † | | | ISNT-N, mg kg ⁻¹ ‡ | | | [NO ₃ +NH ₄]-N, mg kg ⁻¹ § | | |
|------|-------------------------------|----------|---------|-------------------------------|----------|---------|--|----------|---------|
| | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm | 0-2.5 cm | 0-7.5 cm | 0-15 cm |
| 50 | 1.28 | 0.933 | 0.706 | 206 | 165 | 131 | 9.73 | 7.05 | 5.45 |
| 51 | 1.20 | 0.950 | 0.726 | 180 | 152 | 127 | 17.7 | 12.4 | 8.93 |
| 52 | 1.44 | 1.09 | 0.820 | 224 | 189 | 156 | 17.2 | 12.7 | 10.9 |
| 53 | 1.10 | 0.796 | 0.608 | 157 | 132 | 110 | 11.7 | 6.76 | 4.78 |
| 54 | 1.06 | 0.920 | 0.795 | 126 | 112 | 101 | 23.3 | 20.2 | 17.9 |
| 55 | 1.35 | 1.09 | 0.843 | 135 | 113 | 87.7 | 20.7 | 16.7 | 15.4 |
| 56 | 1.27 | 1.00 | 0.790 | 158 | 121 | 96.7 | 31.5 | 23.9 | 20.0 |
| 57 | 1.25 | 1.00 | 0.780 | 224 | 182 | 149 | 16.3 | 12.9 | 9.67 |
| 58 | 0.882 | 0.725 | 0.581 | 154 | 133 | 111 | 21.4 | 16.9 | 12.2 |
| 59 | 1.21 | 0.933 | 0.669 | 214 | 171 | 131 | 15.7 | 14.9 | 12.0 |
| 60 | 1.54 | 1.34 | 1.08 | 225 | 203 | 174 | 18.4 | 15.2 | 12.2 |
| 61 | 1.06 | 0.828 | 0.595 | 157 | 138 | 110 | 18.5 | 16.0 | 11.4 |
| 62 | 1.27 | 0.860 | 0.613 | 192 | 142 | 111 | 16.3 | 12.9 | 9.49 |
| 63 | 3.09 | 1.81 | 1.18 | 383 | 226 | 147 | 30.7 | 20.3 | 18.7 |
| Mean | 1.21 | 0.895 | 0.702 | 169 | 134 | 111 | 22.7 | 16.9 | 14.0 |

† Total soil N was determined by dry combustion using a VarioMax CNS macro elemental analyzer (Elementar, New Jersey).

‡ ISNT-N was determined using the procedures described in Technical Note 02-01 (University of Illinois at Urbana Champaign [UIUC], 2004) and Khan et al. (1997)

§ Soil [NH₄ + NO₃]-N were extracted with 2 M KCl and determined colorimetrically using a QuickChem Automated Ion Analyzer (Lachat Instruments, Milwaukee, WI).

Table 3-3. Analysis of variance and parameter estimates for the effects of duration of continuous no-till management (dNT), biosolids application and soil series on the depth weighted concentration of total soil N at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depth.

| <u>0 – 2.5 cm Depth</u> | | | | |
|-------------------------|----|------------------------|---------|---------|
| Source | df | Sum of Squares† | F Value | Pr > F |
| Model | 2 | 5.53 x 10 ⁶ | 34.9 | <0.0001 |
| dNT | 1 | 3.48 x 10 ⁶ | 43.9 | <0.0001 |
| dNT x Biosolids | 1 | 2.06 x 10 ⁶ | 26.0 | <0.0001 |
| Error | 60 | 4.75 x 10 ⁶ | | |
| Total | 62 | 10.3 x 10 ⁶ | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-----------------|----------|--------------------------------|----------|
| | | -----mg kg ⁻¹ ----- | |
| Intercept | 741 | 74.9 | 150 |
| dNT | 50.3 | 11.0 | 39.3 |
| dNT x Biosolids | 50.8 | 9.97 | 20.0 |

| <u>0 – 7.5 cm Depth</u> | | | | |
|-------------------------|----|------------------------|---------|---------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 4 | 1.44 x 10 ⁶ | 12.1 | <0.0001 |
| dNT | 1 | 5.08 x 10 ⁵ | 17.1 | 0.0001 |
| Biosolids | 1 | 6.48 x 10 ⁵ | 21.8 | <0.0001 |
| Soil Series | 2 | 2.81 x 10 ⁵ | 4.72 | 0.013 |
| Error | 58 | 1.73 x 10 ⁶ | | |
| Total | 62 | 3.17 x 10 ⁶ | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|--------------|----------|--------------------------------|----------|
| | | -----mg kg ⁻¹ ----- | |
| Intercept | 882. | 59.3 | 119. |
| dNT | 28.4 | 6.46 | 12.9 |
| Biosolids | 232 | 44.8 | 89.8 |
| Soil series‡ | | | |
| Bojac | -168 | 57.5 | 115 |

Table 3-3. Continued.

| <u>0 – 15 cm Depth</u> | | | | |
|------------------------|----|------------------------|---------|---------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 4 | 5.54 x 10 ⁵ | 8.47 | <0.0001 |
| dNT | 1 | 6.19 x 10 ⁴ | 3.79 | 0.041 |
| Biosolids | 1 | 2.57 x 10 ⁵ | 15.7 | 0.0002 |
| Soil Series | 2 | 2.35 x 10 ⁵ | 7.20 | 0.0016 |
| Error | 58 | 9.49 x 10 ⁵ | | |
| Total | 62 | 1.50 x 10 ⁶ | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-------------|----------|--------------------------------|----------|
| | | -----mg kg ⁻¹ ----- | |
| Intercept | 596 | 44.9 | 90.4 |
| dNT | 9.98 | 4.79 | 9.56 |
| Biosolids | 154 | 33.2 | 66.8 |
| Soil series | | | |
| Bojac | -142 | 42.6 | 85.3 |

† Main effect sum of squares are Type I.

‡ Individual soil series were evaluated using t-test to determine significance (not shown).

Table 3-4. Analysis of variance and parameter estimates for the effects of duration of continuous no-till management (dNT), biosolids application and soil series on the depth weighted mass of total soil N at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depth.

| <u>0 – 2.5 cm Depth</u> | | | | |
|-------------------------|----------|--------------------------------|----------|---------|
| Source | df | Sum of Squares† | F Value | Pr > F |
| Model | 2 | 2.89 x 10 ⁵ | 24.9 | <0.0001 |
| dNT | 1 | 1.38 x 10 ⁵ | 23.9 | <0.0001 |
| dNT x Biosolids | 1 | 1.51 x 10 ⁵ | 26.0 | <0.0001 |
| Error | 60 | 3.47 x 10 ⁵ | | |
| Total | 62 | 6.36 x 10 ⁵ | | |
| Parameter | Estimate | Standard Error | ± 95% CI | |
| | | -----kg ha ⁻¹ ----- | | |
| Intercept | 260 | 20.3 | 40.2 | |
| dNT | 8.70 | 2.98 | 5.96 | |
| dNT x Biosolids | 13.7 | 2.70 | 5.37 | |
| <u>0 – 7.5 cm Depth</u> | | | | |
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 4 | 1.08 x 10 ⁶ | 10.5 | <0.0001 |
| dNT | 1 | 2.37 x 10 ⁵ | 9.15 | 0.0037 |
| Biosolids | 1 | 5.52 x 10 ⁵ | 21.4 | <0.0001 |
| Soil Series | 2 | 2.95 x 10 ⁵ | 5.70 | 0.0055 |
| Error | 58 | 1.50 x 10 ⁶ | | |
| Total | 62 | 2.58 x 10 ⁶ | | |
| Parameter | Estimate | Standard Error | ± 95% CI | |
| | | -----kg ha ⁻¹ ----- | | |
| Intercept | 943 | 55.3 | 111 | |
| dNT | 19.7 | 6.01 | 12.0 | |
| Biosolids | 216 | 41.7 | 83.8 | |
| Soil series‡ | | | | |
| Bojac | -178 | 53.6 | 107 | |

Table 3-4. Continued.

| <u>0 – 15 cm Depth</u> | | | | |
|------------------------|----|------------------------|---------|---------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 4 | 2.24 x 10 ⁶ | 7.74 | <0.0001 |
| dNT | 1 | 4.45 x 10 ⁴ | 0.63 | 0.43 |
| Biosolids | 1 | 9.94 x 10 ⁵ | 13.74 | 0.0007 |
| Soil Series | 2 | 1.20 x 10 ⁶ | 8.29 | 0.0005 |
| Error | 58 | 4.19 x 10 ⁶ | | |
| Total | 62 | 6.43 x 10 ⁶ | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-------------|----------|--------------------------------|----------|
| | | -----kg ha ⁻¹ ----- | |
| Intercept | 1396 | 94.5 | 189 |
| dNT | 8.90 | 10.1 | 20.1 |
| Biosolids | 310 | 69.7 | 140 |
| Soil series | | | |
| Bojac | -334 | 89.6 | 180 |

† Main effect sum of squares are Type I.

‡ Individual soil series were evaluated using t-test to determine significance (not shown).

Table 3-5. Analysis of variance and parameter estimates for the effects of duration of continuous no-till management (dNT), biosolids application and soil series on the depth weighted concentration of Illinois soil N test - N at the 0 – 2.5, 0 – 7.5, and 0 – 15 cm depth.

| <u>0 – 2.5 cm Depth</u> | | | | |
|-------------------------|----|------------------------|---------|---------|
| Source | df | Sum of Squares† | F Value | Pr > F |
| Model | 1 | 9.19 x 10 ⁴ | 22.9 | <0.0001 |
| dNT | 1 | 6.06 x 10 ⁴ | 60.2 | <0.0001 |
| dNT x Biosolids | 1 | 1.87 x 10 ⁴ | 18.6 | <0.0001 |
| Soil Series | 2 | 1.26 x 10 ⁴ | 6.28 | <0.0034 |
| Error | 58 | 5.84 x 10 ⁴ | | |
| Total | 62 | 1.50 x 10 ⁵ | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-----------------|----------|---------------------------------|----------|
| | | ----- mg kg ⁻¹ ----- | |
| Intercept | 116. | 10.3 | 20.5 |
| dNT | 6.63 | 1.26 | 2.52 |
| dNT x Biosolids | 5.43 | 1.14 | 2.28 |
| Soil Series | | | |
| Bojac | -29.0 | 10.4 | 20.8 |

| <u>0 – 7.5 cm Depth</u> | | | | |
|-------------------------|----|------------------------|---------|---------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 3 | 3.12 x 10 ⁴ | 15.3 | <0.0001 |
| dNT | 1 | 3.32 x 10 ³ | 26.3 | <0.0001 |
| Biosolids | 1 | 2.93 x 10 ³ | 5.73 | 0.02 |
| Soil Series | 2 | 1.48 x 10 ⁴ | 14.5 | <0.0001 |
| Error | 58 | 2.97 x 10 ⁴ | | |
| Total | 62 | 6.09 x 10 ⁴ | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|--------------|----------|---------------------------------|----------|
| | | ----- mg kg ⁻¹ ----- | |
| Intercept | 129 | 7.77 | 15.3 |
| dNT | 4.12 | 0.846 | 1.70 |
| Biosolids | 20.0 | 5.87 | 11.7 |
| Soil series‡ | | | |
| Bojac | -38.0 | 7.54 | 15.1 |

Table 3-5. Continued.

| <u>0 – 15 cm Depth</u> | | | | |
|------------------------|----|------------------------|---------|---------|
| Source | df | Sum of Squares | F Value | Pr > F |
| Model | 3 | 1.37 x 10 ⁴ | 11.5 | <0.0001 |
| dNT | 1 | 3.32 x 10 ³ | 8.40 | 0.005 |
| Soil Series | 2 | 1.03 x 10 ⁴ | 13.1 | <0.0001 |
| Error | 59 | 2.33 x 10 ⁴ | | |
| Total | 62 | 3.70 x 10 ⁴ | | |

| Parameter | Estimate | Standard Error | ± 95% CI |
|-------------|----------|---------------------------------|----------|
| | | ----- mg kg ⁻¹ ----- | |
| Intercept | 108 | 6.41 | 12.8 |
| dNT | 1.68 | 0.739 | 1.45 |
| Soil series | | | |
| Bojac | -29.2 | 6.51 | 13.0 |

†Main effect sum of squares are Type I.

‡Individual soil series were evaluated using t-test to determine significance (not shown).

3.8 Figures

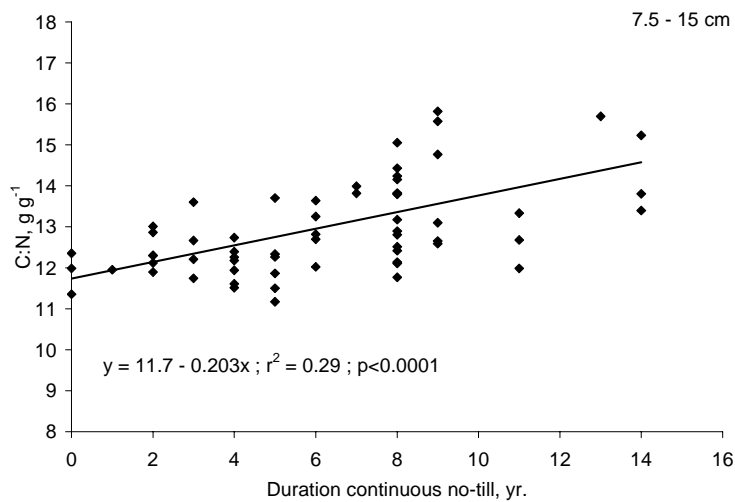
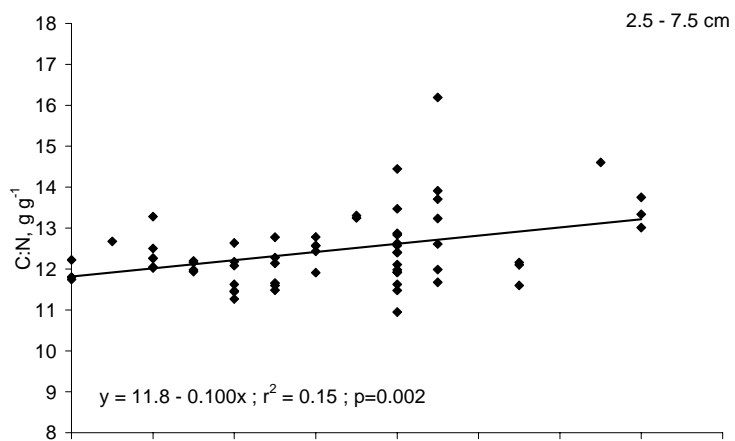
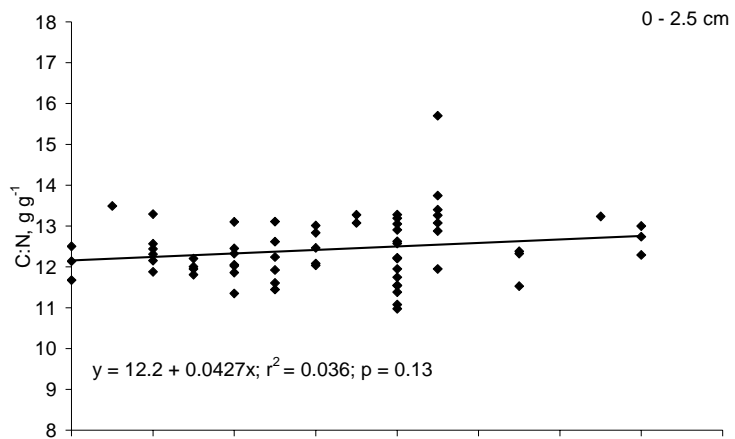


Figure 3-1. Relationship between the C:N ratio at 0 – 2.5, 2.5 – 7.5 and 7.5 – 15 cm sampling depths and the duration of continuous no – till.

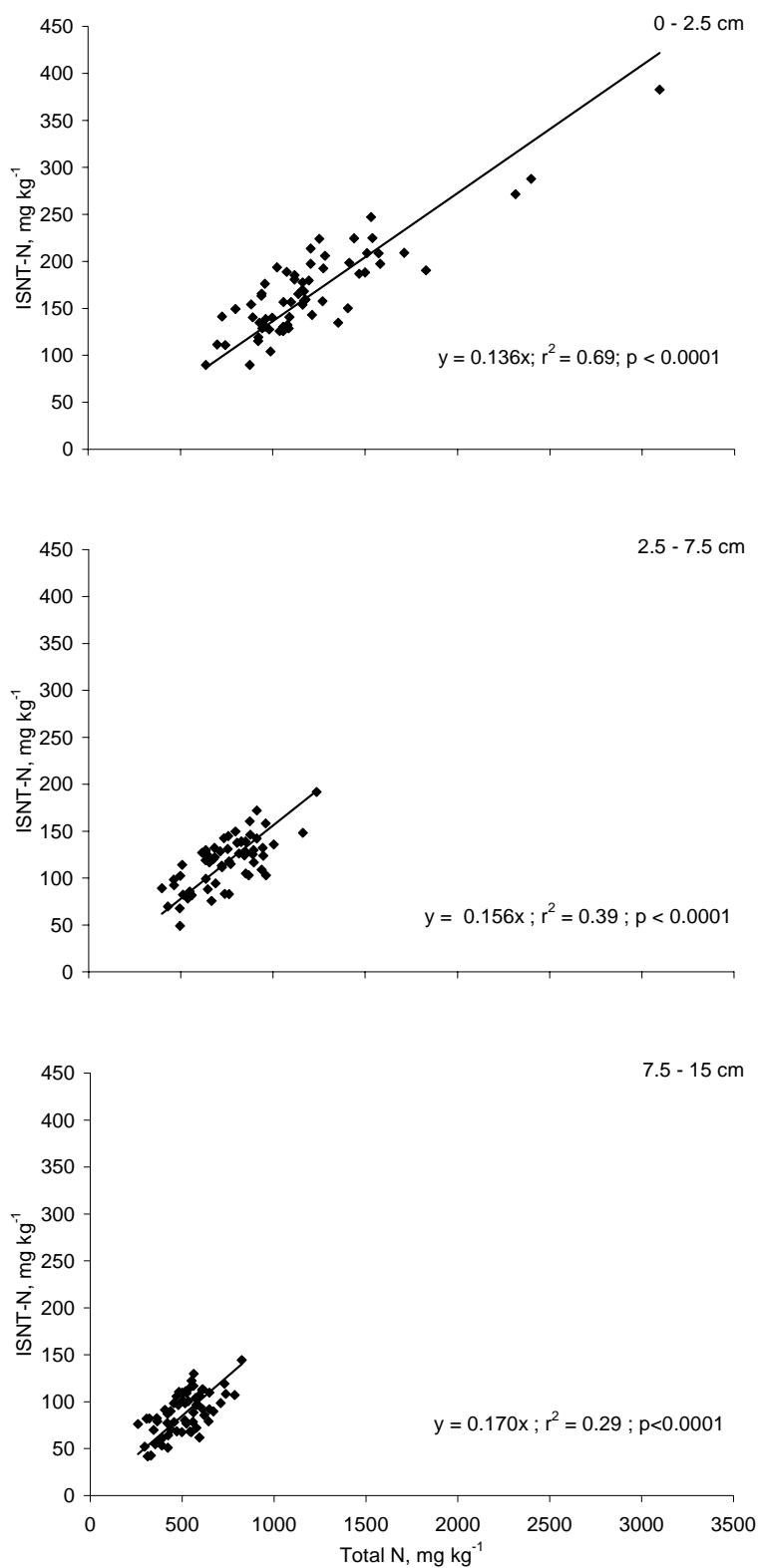


Figure 3-2. Relationship between the concentration of ISNT-N and the concentration of total N at the 0 – 2.5, 2.5 – 7.5 and 7.5 – 15 cm sampling depths.

4 Illinois Soil Nitrogen Test for Prediction of Fertilizer Nitrogen Needs of Corn in Virginia.

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4.1 Abstract

Current N needs for corn in Virginia are estimated based on expected yield and are adjusted to account for estimated amounts of N mineralized from organic N sources such as manures, biosolids and legumes. The dynamic nature of soil N creates significant uncertainty in estimates of N availability from these sources; and accurate quantification of organic N mineralization during the corn growing season would improve the precision of fertilizer N recommendations. The Illinois soil N test (ISNT) has shown promise as a useful tool for estimating mineralizable soil N and predicting corn fertilizer N needs. Other research has found the ISNT to be poorly related to labile soil N, and unrelated to corn response to fertilizer N. The objective of this study was to determine if the ISNT predicts fertilizer N response of corn grown in a diverse set of Virginia agroecosystems. We conducted 29 on-farm fertilizer N response trials in major corn producing areas of the Coastal Plain ($n = 22$), and Ridge and Valley ($n = 7$) regions of Virginia. The ISNT was significantly related to yield without fertilizer N ($r^2 = 0.57$; $p < 0.001$) and relative yield ($r^2 = 0.64$; $p < 0.0001$). We also found that the ISNT extracted a relatively consistent percentage of total soil N ($16.3 \pm 0.73\%$) suggesting that it is a poor indicator of labile N. In fact, total soil N did nearly as well as the ISNT predicting yield without fertilizer N ($r^2 = 0.53$; $p = 0.0002$) and equally well predicting relative yield ($r^2 = 0.64$; $p < 0.0001$). Modification of the assay, or use of other variables in conjunction with ISNT levels is needed for the ISNT to be of value for prediction of fertilizer N needs from soils similar to those in this study.

4.2 Introduction

Fertilizer N needs of corn may vary widely among and within fields (Scharf, 2001). Current N needs for corn in Virginia are estimated based on expected yield, adjusted to account for estimated amounts of N mineralized from organic materials such as manure, biosolids, and legumes (Donohue and Heckendorn, 1994; DCR, 2002). This method fails to account for variations in corn yield response to fertilizer N because the dynamic nature of organic soil N creates significant uncertainty in estimates of N mineralization (Agehara and Warncke, 2005). In addition, recommendations do not generally account for the influence of management practices such as tillage, and residue management on soil N status (Meisinger et al., 1985; Martens and Dick, 2003; Spargo et al., In review-a).

A number of chemical methods have been proposed for estimating soil N availability (Bundy and Meisinger, 1994). Soil NO₃-N testing is the most widely used method for identifying soils where yield response to fertilizer N may be limited. Preplant soil profile NO₃-N testing (PPNT) has long been recommended for assessment of N availability in drier areas of the western USA where leaching losses are minimal (Hergert, 1987; Bundy and Meisinger, 1994). The pre-sidedress soil NO₃-N test (PSNT) has shown potential for modifying fertilizer N recommendations in the humid eastern USA for corn grown on land receiving manure, or where legumes have been grown in the rotation (Magdoff et al., 1984; Fox et al., 1989; Meisinger et al., 1992; Roth et al., 1992; Sims et al., 1995; Evanylo and Alley, 1997; Andraski and Bundy, 2002; Klapwyk and Ketterings, 2006). The PSNT is a method currently recommended for identifying soils where yield response to fertilizer N may be limited in Virginia (Donohue and

Heckendorn, 1994; DCR, 2002). Use of the PSNT has been limited by the need to collect samples during the growing season and delay N fertilization until soil samples are analyzed. In addition to the logistical problems, the PSNT is also limited by the variability of soil NO₃-N due to its dependence on a number of factors such as temperature, moisture, and soil texture. Accurate prediction of soil N availability using a simple, preseason soil test has potential to significantly improve fertilizer N recommendations in Virginia. The Illinois soil N test (ISNT) might meet this need for corn grown in Virginia agroecosystems.

The ISNT has received a great deal of attention for its reported success (Khan et al., 2001b; Klapwyk and Ketterings, 2006; Mulvaney et al., 2006; Sharifi et al., 2007; Williams et al., 2007b; Williams et al., 2007a) and failure (Barker et al., 2006; Marriott and Wander, 2006) to predict fertilizer N response and/or measure labile soil N. The ISNT was developed through work that attempted to find a relationship between different fractions of hydrolysable soil N and corn yield response to fertilizer N (Mulvaney et al., 2001). Mulvaney et al. (2001) used acid hydrolysis to determine the concentration of hydrolysable NH₄⁺-N, amino acid-N, amino sugar-N, and total hydrolysable-N in soils collected from 18 fertilizer-N response studies. Their work showed that hydrolyzable amino sugar-N was highly correlated ($r = 0.79$) with check plot yield and fertilizer N response ($r = -0.82$). The hydrolysis and N fractionation procedures are complicated and time consuming; therefore, are unsuitable for routine soil analysis. For these reasons, Khan et al. (2001b) developed the simpler ISNT method to estimate amino sugar-N.

The ISNT, described in detail in Technical Note 02-01 (University of Illinois at Urbana Champaign [UIUC], 2004), and Khan et al. (2001b) uses direct diffusion to

measure alkali hydrolysable soil N, eliminating the acid hydrolysis procedures from earlier methods described by Mulvaney and Khan (2001). The test is thought to recover amino sugar-N, derived primarily from bacterial and fungal cell walls, plus extractable NH_4^+ -N (Khan et al., 2001b). However, most amino sugars in soil are believed to originate from polymeric compounds such as chitin which are insoluble in hot alkali but not acid (Stevenson, 1982; Greenfield, 2001) and some α -amino acid-N is also likely released by the ISNT (Greenfield, 2001).

Khan et al (2001a) used the ISNT to predict response to fertilizer N in 25 trials and positively identify soils non-responsive to fertilizer-N. They also indicated the ISNT showed promise as a tool to quantitatively determine fertilizer N rates in conjunction with expected yield goals. In follow-up studies, Mulvaney et al. (2006) tested the ISNT on soils from 102 N response trials and found that it correctly identified 94% of the 33 sites that were not responsive to fertilizer N. Klapwyk and Ketterings (2006) found the ISNT useful for identifying non-responsive corn silage fields on dairy farms in New York; however, soil organic matter had to be included in the model to accurately identify non-responsive locations. Working in North Carolina, Williams et al. (2007a) evaluated several soil N tests for corn. They found that the ISNT had the highest correlation with economic optimum N rate (EONR) when consideration was limited to sites with mineral soils. In a follow-up study, Williams et al.(2007b) successfully predicted the EONR for corn grown on well ($r^2 = 0.87$) or poorly drained soils ($r^2 = 0.78$).

The assay has not proven useful in all regions or cropping systems. For example, working in Iowa, Barker et al. (2006) found no relationship between the ISNT and relative corn grain yield, corn response to fertilizer N, or EONR. The soils used in their

study had relatively high levels of hydrolysable NH_4^+ -N relative to amino sugar-N and the authors suggested that this may partially explain the poor performance of the ISNT. Marriott and Wander (2006) used the assay to compare labile soil N in conventional and organic cropping systems and found that the ISNT was not a sensitive index of labile N. The ISNT fraction was not preferentially enriched by organic management, and its response was similar to that of total soil C and N. For these reasons it is not likely that the assay will be adopted as a universal soil N test. Rather, its use will be limited to regions and applications where the assay is proven useful.

The ISNT is a simple, convenient assay that should be tested on Virginia soils to determine if its application in the region is feasible. The objective of this research was to determine if the ISNT predicts fertilizer N response of corn grown in a diverse set of Virginia agroecosystems.

4.3 Materials and Methods

4.3.1 Experimental Design

Research was conducted at 29 on-farm locations over two growing seasons (2006-2007) in major corn producing areas of the Coastal Plain ($n = 22$), and Ridge and Valley ($n = 7$) regions of Virginia (Table 5-1). Locations were chosen to represent the broad range of corn growing environments found in the state. The Coastal Plain consists of deep soils formed in fluvial sediments occupying gently sloping, broad interstream areas. Soils of the Ridge and Valley are shallow to deep, formed from residual or colluvial sandstone, limestone, and shale or fluvial sediments. Agroecosystems of the Coastal Plain region are dominated by cash grain crop production while those of the Ridge and Valley are generally integrated with livestock production.

Each trial was established as a randomized complete block with 4 replications. Plots measured 6 rows by 7.6 m. Preplant and/or starter fertilizer was applied at all but 4 locations at rates ranging from 0 to 77 kg N ha⁻¹. Eight sidedress N treatments were applied at growth stage V6 as aqueous [CO(NH₂)₂]-NH₄NO₃ (30% N) solution at eight rates ranging from 0 to 210 kg N ha⁻¹ in equal increments of 30 kg N ha⁻¹.

Management history of each site was obtained prior to initiation of the N-trial experiments (Table 2). Information gathered included previous fertilizer and lime application rates, crop rotation, average yield, tillage management, and biosolids or manure application history and rate. The expected corn yield for each location was taken as the average yield for the previous 5 to 10 years.

4.3.2 Sampling and Analysis

Soil samples collected at each site from 0 – 15 and 0 – 90 cm prior to planting and from 0 – 30 cm immediately prior to sidedress N application were air-dried and sieved to pass 2 mm. Soil samples collected from 0 – 15 cm were analyzed for pH (1:1 soil:water ratio); Mehlich 1 extractable P, K, Ca, and Mg (Donohue and Friedericks, 1984); total soil C and N using a VarioMax CNS macro elemental analyzer (Elementar, New Jersey); and ISNT (Khan et al., 1997; Spargo and Alley, *In press*).

The ISNT was conducted in triplicate using the method described in Technical Note 02-01 (University of Illinois at Urbana Champaign [UIUC], 2004), and Khan et al. (2001b) and modified as described by (Spargo and Alley, *In press*). Briefly, 1 g of soil was treated with 10 mL of 2 M NaOH in a 473-mL wide-mouth Ball[®] jar, sealed within 10s, and heated for 15 hrs in a Precision 815 low temperature incubator (Precision; Winchester, VA) at 50° C to liberate alkali hydrolysable-N as gaseous NH₃. The liberated NH₃ was collected in a 4% w/v H₃BO₃ solution in a petri dish suspended above the

hydrolysate in each jar. The ISNT-N was subsequently determined by acidimetric titration of the H_3BO_3 solution with standardized 0.01 M H_2SO_4 using a Radiometer TIM 900 Titration Manager and ABU901 autoburette (Radiometer Analytical S.A., Lyon France).

Soil samples collected from 0 – 90 cm prior to planting and 0 – 30 cm prior to sidedress N application were used for PPNT and PSNT, respectively (Magdoff et al., 1984; Bundy and Meisinger, 1994). Soil $\text{NO}_3\text{-N}$ was extracted from duplicate samples with 2 M KCl for one hour on a reciprocating shaker and determined colorimetrically using a QuickChem Automated Ion Analyzer (Lachat Instruments, Milwaukee, WI). The PPNT values were calculated on an areal basis using an estimated bulk density of 1.49 Mg m^{-3} (Bundy and Meisinger, 1994).

Yield was determined by hand harvesting 3 m of the center two rows from each plot at physiological maturity. All trials were harvested for grain except Sites 25 and 28 which were harvested for silage. The equivalent grain yield was calculated assuming silage is 45% grain on a dry matter basis (Simpson et al., 1993). All yield data were adjusted to 150 g kg^{-1} moisture content. Plant population was determined at each location at harvest.

4.3.3 Statistical Analysis

The significance of yield response to applied N was determined by orthogonally contrasting yields where no sidedress N was applied with all other N rates using the PROC GLM procedure of SAS (SAS Institute, 2002). If not significant ($p > 0.1$) the site was identified as non-responsive. If significant, yield response to fertilizer N was modeled using a quadratic plateau function (Cerrato and Blackmer, 1990) using PROC NLIN of SAS.

The EONR was calculated for each site by equating the first derivative of the quadratic portion of the model to the price ratio of fertilizer N to corn of 7.4 kg kg^{-1} ($\$0.45 \text{ lb N}$, $\$3.4 \text{ bu}^{-1} \text{ corn}$) and solving for the quantity of fertilizer N and the economically optimum yield (EOY). The price ratio of 7.4 kg kg^{-1} was chosen to represent the regional average over the course of the study period. Non-responsive sites were assigned an EONR of zero. When the calculated EONR was greater than highest N rate applied (i.e., Sites 6 and 8), the highest N rate was taken as EONR.

Since most sites received starter N, yield without fertilizer N (Y_{N0}) was estimated from the intercept of the yield response function. Maximum yields (Y_{Max}) were taken as the plateau from the response models, or non N-limited yields. When the N rate corresponding to the plateau yield was greater than the highest N rate applied (i.e., Site 6, 8, 10, and 13) the plateau yield was calculated using the highest N rate. For non-responsive sites Y_{N0} and Y_{Max} were taken as the averaged site yield.

Yields were expressed on a relative basis in order to evaluate results across sites and years. The relative yield (RY) at each site was calculated as Y_{N0} divided by the Y_{Max} . Another variable we investigated was the fertilizer N application factor (N_{fF} ; $\text{kg N Mg}^{-1} \text{ grain}$) calculated as EONR divided by EOY. Non-responsive sites were assigned a RY of 1 and a N_{fF} of zero.

Linear and non-linear methods (linear, linear-plateau, quadratic, and quadratic-plateau) were used to determine the relationship between yield parameters and soil measurements using PROC REG and PROC NLIN of SAS. The coefficient of determination and residual mean square of the model were used to compare the quality of fit and select the appropriate model.

4.4 Results and Discussion

4.4.1 Site Characteristics

Sites were selected to represent the range of crop rotation and management practices employed in the region that affect soil N (Table 2). Corn grown on all of the Coastal Plain sites followed either double-crop or full season soybean. Corn grown in the Ridge and Valley followed continuous corn, alfalfa or grass pasture. Seven of the 22 Coastal Plain locations had a history of biosolids application and 6 of the 7 locations in the Ridge and Valley had a history of dairy manure or poultry litter application. All experimental sites except two were managed no-till; the duration of no-till management ranged from 0 to 25 years. Spargo et al. (In review-a) found that total soil N was conserved at a rate of $22 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ and ISNT increased by $1.68 \text{ mg N kg}^{-1} \text{ yr}^{-1}$ with continuous no-till management in the Virginia Coastal Plain. A portion of the N sequestered as soil organic matter (SOM) in no-till soils may become available for crops and offset a portion of fertilizer N needs (Franzluebbers et al., 1994a; Wienhold and Halvorson, 1999).

When soil test P, K, or pH were sub-optimal for a given location, fertilizer or lime applications were made prior to or shortly following planting according to Virginia Cooperative Extension (VCE) recommendations (Donohue and Heckendorn, 1994), thus ensuring N was the only yield limiting fertilizer nutrient (data not shown). Precipitation during the 2006 growing season was near average and did not severely limit yield at any of the sites. The 2007 growing season was especially dry throughout the U.S. Mid-Atlantic region and severe drought stress was observed at 3 sites (Sites 18, 19, and 22).

4.4.2 Yield

Corn is rarely grown without fertilizer N; however, a yield response to fertilizer N may not always be obtained. Eleven of the 29 experimental sites were non-responsive to fertilizer N (Table 3). Yield response to fertilizer N at sites 18, 19, and 22 was limited by drought conditions, not by available N. In order to prevent confounding error, drought afflicted locations were not considered in the evaluation of soil N tests to predict yield response to fertilizer N and will be excluded from further discussion. Of the 8 non-responsive sites, 7 had received manure or biosolids within two years prior to the experiment. Only 2 of the non-responsive sites (Sites 21 and 28) would have been identified by the current VCE recommendations due to early spring manure or biosolids application at rates determined to meet N needs.

The observed EONR ranged from 0 to 277 kg N ha⁻¹ and, among responsive sites, averaged 184 kg N ha⁻¹. The EOY exceeded the expected yield at 13 of 17 locations in 2006 and 6 of 9 locations in 2007 (Tables 2 and 3). The calculated N_fF ranged from 0 to 28.9 kg N Mg⁻¹ (Table 3). Averaged across only responsive sites, N_fF was 17.6 kg N Mg⁻¹ grain which is similar to the VCE recommendation of 17.9 kg N Mg⁻¹ grain (Simpson et al., 1993). The Y_{N0} over the 26 N-response trials ranged from 0.6 to 11.6 Mg ha⁻¹ and RY was from 0.07 to 1. The wide range in EONR, Y_{N0}, and RY indicate that the contribution of soil N to yield varied widely among sites. Accurate prediction of the soil N contribution to corn needs could significantly improve fertilizer N recommendations and thereby improve profit and reduce excessive N applications.

4.4.3 Soil Nitrogen

Preplant Nitrate Test

Preplant soil profile $\text{NO}_3\text{-N}$ testing has long been recommended for assessment of N availability in drier areas of the western USA where leaching losses are minimal but, the assay has not been widely used in humid eastern USA (Bundy and Meisinger, 1994). The PPNT has been shown to provide a useful evaluation of profile NO_3 contribution to crop N needs in eastern USA (Bundy and Malone, 1988; Khosla et al., 2000); however that was not the case for this set of experiments.

The PPNT ranged from 20.1 to 57.1 kg N ha^{-1} at N responsive sites and 34.5 to 117.9 for non-responsive sites (Table 3). There was no obvious break between responsive and non-responsive sites and there was no correlation between Y_{NO} , RY, or N_{rF} and PPNT. Where the the PPNT is employed, it is used to account for carryover $\text{NO}_3\text{-N}$ from previous cropping. It is not useful for estimating N contributions from soil organic matter, legumes or manures (Bundy and Meisinger, 1994). Another disadvantage of the PPNT in humid environments, such as the eastern USA, is the potential for NO_3 leaching between sampling and crop N need and uptake.

Presidedress Nitrate Test

The PSNT has proven useful for identifying N sufficient soils in the eastern USA that have received organic amendments, or where legumes have been grown in the rotation (Magdoff et al., 1984; Fox et al., 1989; Meisinger et al., 1992; Evanylo and Alley, 1997; Andraski and Bundy, 2002; Klapwyk and Ketterings, 2006). Evanylo and Alley (1997) conducted 47 fertilizer N response trials throughout Virginia and found that sites with a PSNT greater than 18 mg N kg^{-1} were non-responsive to fertilizer N. In our study, PSNT of only 3 sites was greater than 18 mg kg^{-1} (Sites 7, 20 and 21) and one of those was responsive to fertilizer N (Site 7; Table 3). This is a significant failure

considering PSNT of 6 out the 8 non-responsive sites was below 18 mg N kg^{-1} . We also considered the possibility of a quantitative relationship between PSNT and yield response to fertilizer N but, there was no relationship between Y_{N0} , RY, or N_fF and PSNT. One of the shortfalls of the PSNT is the temporal and spatial variability of soil $\text{NO}_3\text{-N}$ due to its dependence on myriad factors such as temperature, moisture, and soil texture. Other researchers have also found the usefulness of the PSNT as a quantitative index of N availability limited due to variability in the relationship between PSNT and RY (Fox et al., 1989; Meisinger et al., 1992).

Illinois Soil N Test

Where the ISNT has been shown to detect soils that are non-responsive to N fertilizer applications for corn growth, the critical range has varied. In development of the ISNT, Khan et al. (2001a) identified a critical range of 225 to 235 mg N kg^{-1} for the 25 sites they worked with. Of the 35 N-response trials conducted by Williams et al. (2007b), none were non-responsive. They did however find a significant relationship between ISNT and EONR. Solving their function for well drained sites ($\text{EONR, kg ha}^{-1} = 348 - 3.12 \times \text{ISNT, mg N kg}^{-1}$) for an EONR of zero gives 112 mg N kg^{-1} . Williams et al. (2007b) used a modified method to determine ISNT that reduced the recovery of N by approximately 50% (Spargo and Alley, *In press*). Assuming only 50% recovery of ISNT-N using their modified method, a critical value of 112 mg N kg^{-1} would be equivalent to approximately 224 mg N kg^{-1} using the original method. Klapwyck and Ketterings (2006) found that the critical ISNT for the 32 trials they conducted was related to SOM by a quadratic function [critical ISNT = $126.36 + (4.0944 \times \text{SOM}) - (0.0199 \times \text{SOM}^2)$]. Average SOM of the 29 sites we investigated was 19.6 g kg^{-1} (assuming SOM equals organic C x

1.7). Solving the quadratic equation developed by Klapwyck and Ketterings (2006) for 19.6 g SOM kg⁻¹ gives 199 mg ISNT-N kg⁻¹. Based on these findings, it is evident that multiple factors (including analytical method) may influence the critical concentration of ISNT for a given location. We expected that if a critical ISNT was identified for our locations, it would be somewhere between 200 and 250 mg kg⁻¹.

The ISNT of the 29 N-trials we conducted ranged from 102 to 371 mg N kg⁻¹ (Table 3). The ISNT of the 8 non-responsive trials ranged from 155 to 371 mg N kg⁻¹ with 2 of the non-responsive sites (Site 20 and 27) below 200 mg N kg⁻¹. We found a range of ISNT among non-responsive locations (102 to 224 mg N kg⁻¹) only one of which exceeded 200 mg N kg⁻¹ (Site 16). Khan et al (2001a) suggested, and Williams et al. (2007b) found, that the ISNT may be a useful tool to quantitatively determine fertilizer N rates for corn. The range of ISNT among responsive sites in our study allowed us to test for a quantitative relationship between ISNT and yield response to fertilizer N.

Evaluation of the ISNT To Predict Yield Response to Fertilizer N

There was a significant quadratic relationship between Y_{N0} and INST (Fig. 5-1; $r^2 = 0.56$; $p < 0.0001$). Our analysis of data reported by Khan et al (2001a) for 25 N-trials conducted in Illinois also revealed a weak, but significant relationship, between INST and Y_{N0} (Yield, Mg ha⁻¹ = 3.84 + .0214 x ISNT; $r^2 = 0.46$; $p = 0.0002$). Klapwyck and Ketterings (2006) and, Williams et al. (2007b) did not report yield with no-fertilizer N so we could not make a similar comparison.

We found a significant relationship between RY and ISNT using the split line model illustrated in Fig. 5-2 ($r^2 = 0.64$; $p < 0.0001$). The break-point ISNT concentration of the model, where no response to fertilizer N is expected, was 200 mg N kg⁻¹. As

previously stated, two non-responsive locations (Sites 20 and 27) had ISNT concentrations less than the 200 mg N kg⁻¹. There was considerable variation in the responsive portion of the model (ISNT < 200 mg kg⁻¹). When we considered only the responsive sites and regressed RY vs. ISNT we found a significant relationship, but it was much weaker ($r^2 = 0.33$; $p = 0.0126$).

We also found a significant relationship between the N_FF and ISNT using a split line model (Fig. 5-3; $r^2 = 0.57$; $p < 0.0001$). The break-point ISNT concentration, 206 mg N kg⁻¹, was only slightly higher than it was for RY. Again, there was a considerable amount of variation in the responsive portion of the model and when only responsive locations were considered the relationship between N_FF and ISNT was very weak ($p = 0.09$; $r^2 = 0.17$).

The poor relationship between ISNT and yield response to fertilizer N for the responsive sites, and the failure of the ISNT to identify 2 of the 8 non-responsive sites in this data set limits its potential to improve prediction of fertilizer N needs of corn. Yield response to fertilizer N can be affected by a number of factors other than soil N availability, e.g., plant population, previous crop, C:N ratio. Consideration of these factors could improve interpretation of the relationship between yield response to fertilizer N and ISNT. For example, Mulvaney et al. (2005) evaluated the effectiveness of the ISNT to predict corn yield response to N using 102 N-response trials conducted in Illinois. The sites had a range of manure management, crop rotation and planting density. The authors found that the relationship between the critical ISNT concentration and corn yield response to fertilizer N depended on previous crop, planting density, and the occurrence of a soil fertility limitation. Our data set did not lend itself to a rigorous

statistical analysis of interactions between yield response to fertilizer N vs. ISNT and crop rotation, but cursory review did not reveal any obvious trends. We did not find a relationship between plant population and Y_{N0} , RY, or N_fF . We also considered the possibility of a relationship between yield response to fertilizer N and an interaction between SOM and ISNT similar to that found by Klapwyk and Ketterings (2006). The addition of total soil N or C to the model did not improve the prediction of Y_{N0} , RY, or N_fF .

Barker et al. (2006) found no relationship between the ISNT and relative corn grain yield, corn response to fertilizer N, or EONR among 43 N response trials conducted in Iowa. They also found that the assay was unable to differentiate between fertilizer N responsive and non-responsive sites. The authors suggested that the failure of the ISNT to predict N response may be due to a highly significant relationship between ISNT and total soil N. Barker et al. (2006) also analyzed soils from a subset of 11 N response trials for hydrolysable NH_4 -N, and amino sugar-N using the direct diffusion methods of Mulvaney and Khan (2001). They found that ISNT was not significantly related to amino sugar- N but was highly correlated with hydrolysable NH_4 -N ($r = 0.87$).

We compared the relationship between ISNT and total hydrolysable-N and total soil N reported by Khan et al (2001a) for 25 N-trials used in the development of the ISNT. We found that the correlation between ISNT and total hydrolysable-N ($r = 0.90$; $p < 0.0001$) was nearly as strong the relationship between ISNT and hydrolysable amino-sugar-N ($r = 0.91$; $p < 0.0001$). There was also a strong relationship between ISNT and total N ($r = 0.88$; $p < 0.0001$).

Marriott and Wander (2006) used the ISNT to compare labile soil N in conventional and organic cropping systems and found that the ISNT was not a sensitive index of labile N. The ISNT fraction was not preferentially enriched by organic management and its response was similar to that of total soil C and N. Marriott and Wander (2006) also found ISNT to be highly correlated ($r = 0.98$) with total soil N and suggested this indicated that ISNT may extract some recalcitrant forms of soil N.

We found a very significant relationship between ISNT and both total N and total C ($r^2 = 0.99$ and 0.99 ; Fig. 5-4) among the 29 N-trials sites used in our research. The ISNT extracted 16.3 ± 0.73 % of total soil N. Barker et al. (2006) found that the ISNT extracted approximately 15% of total N and Marriot and Wander found that the ISNT extracted approximately 14% of total N. The strong correlation between total- and ISNT-N and the seemingly consistent relationship, prompted us to explore the correlation between total soil N and Y_{N0} , RY, and the N_fF .

We found that total soil N did nearly as well as ISNT predicting yield response to fertilizer N. There was a significant quadratic relationship between total soil N and Y_{N0} (Fig. 5-5; $p = 0.0002$; $r^2 = 0.53$). There was significant linear plateau relationship between total N and RY ($r^2=0.64$; $p<0.0001$; Fig. 5-6). There was also significant linear plateau relationship between total N and N_fF ($r^2=0.53$; $p=0.0002$; Fig. 5-7). Total soil N is typically considered a poor indicator of corn response to fertilizer N. The fact that we found a relationship here was surprising and may be an anomaly of this particular data set. It does however illustrate the limited value of the ISNT to differentiate between total and mineralizable soil N in these soils.

4.5 Summary and Conclusions

Fertilizer N needs of corn vary widely among fields in Virginia. Current VCE recommendations for corn fertilizer N needs fail to accurately account for this variation. Our research clearly indicates that there is a relationship between fertilizer N needs and soil N. Accurate quantification of organic N mineralization during the corn growing season should improve the precision of fertilizer N recommendations, as has been recognized by much previous work. We found that PSNT was of limited value to identify locations that were non-responsive to fertilizer N for the 26 N-trials we investigated. The ISNT was significantly related to Y_{N0} , RY, and N_fF but the relationship may not be strong enough to substantially improve fertilizer N recommendations. This may be because the ISNT measures a relatively consistent portion of total soil N (i.e., 14 to 16%) and is therefore a poor indicator of labile N (Barker et al., 2006; Marriott and Wander, 2006). In order for the INST to be a useful assay for prediction of fertilizer N needs from soils similar to those in this study, the assay needs to be modified to accurately reflect labile soil N where mineralizable soil N is derived from a variety of organic N sources.

4.6 References

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4.7 Tables

Table 4-1. Study site soil series and taxonomic classification for 29 corn response to fertilizer N-trials conducted in 2006 and 2007.

| Year | Site | Soil Series | Taxonomic Classification |
|-------------------------|------|-----------------|--|
| <u>Coastal Plain</u> | | | |
| 2006 | 1 | Pamunkey fsl | fine-loamy, mixed, semiactive, thermic Ultic Hapludalfs |
| 2006 | 2 | Kempsville sl | fine-loamy, siliceous, subactive, thermic Typic Hapludults |
| 2006 | 3 | Molena ls | fine-loamy mixed, thermic Psammentic Hapludults |
| 2006 | 4 | Kempsville l | fine-loamy, siliceous, subactive, thermic Typic Hapludults |
| 2006 | 5 | Altavista fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2006 | 6 | Altavista fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2006 | 7 | Altavista fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2006 | 8 | Kempsville sl | fine-loamy, siliceous, subactive, thermic Typic Hapludults |
| 2006 | 9 | Kempsville sl | fine-loamy, siliceous, subactive, thermic Typic Hapludults |
| 2006 | 10 | Tetotum l | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2006 | 11 | Slagle sil | fine-loamy, siliceous, subactive, thermic Aquic Hapludults |
| 2006 | 12 | Altavista fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2006 | 13 | Kempsville sl | fine-loamy, siliceous, subactive, thermic Typic Hapludults |
| 2006 | 14 | Angie l | fine, mixed, semiactive, thermic aquic Paleudults |
| 2006 | 15 | Slagle sil | fine-loamy, siliceous, subactive, thermic Aquic Hapludults |
| 2006 | 16 | Wickham fsl | fine-loamy, mixed, semiactive, thermic Typic Hapludults |
| 2007 | 17 | Pamunkey fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2007 | 18 | Tetotum l | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2007 | 19 | Emporia sl | fine-loamy, siliceous, subactive, thermic Typic Hapludults |
| 2007 | 20 | Pamunkey fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2007 | 21 | Tetotum l | fine-loamy, mixed, semiactive, thermic Aquic Hapludults |
| 2007 | 22 | Atlee sil | fine-loamy, siliceous, semiactive, thermic Fragiaquic Paleudults |
| <u>Ridge and Valley</u> | | | |
| 2007 | 23 | Hayter l | fine-loamy, mixed, active, mesic Ultic Hapludalfs |
| 2007 | 24 | Groseclose sil | fine, mixed, semiactive, mesic Typic Hapludults |
| 2006 | 25 | Frederick sil | fine, mixed, semiactive, mesic Typic Paleudults |
| 2007 | 26 | Endcav sil | very-fine, mixed, semiactive, mesic chromic Vertic Hapludalfs |
| 2007 | 27 | Wheeling fsl | fine-loamy, mixed, active, mesic Ultic Hapludalfs |
| 2007 | 28 | Edom sic | fine, illitic, mesic Typic Hapludalfs |
| 2007 | 29 | Timberville sil | fine, mixed, active, mesic Typic Hapludults |

Table 4-2. Site management practices employed at 29 corn response to fertilizer N-trial sites conducted in 2006 and 2007.

| Year | Site number | Previous Crop† | Duration of no-till yrs | Organic amendments | | | Expected Yield§ Mg ha ⁻¹ | Starter N rate# kg ha ⁻¹ | Population at harvest no. ha ⁻¹ |
|------|-------------|----------------|-------------------------|----------------------|----------------------|-----------------------------------|--|--|---|
| | | | | Type | Last application yrs | Rate, PAN‡ kg ha ⁻¹ | | | |
| | | | | <u>Coastal Plain</u> | | | | | |
| 2006 | 1 | DCB | 8 | – | n/a | n/a | 8.2 | 67 | 66103 |
| 2006 | 2 | DCB | 11 | – | n/a | n/a | 10.1 | 36 | 69667 |
| 2006 | 3 | DCB | 3 | Biosolids | 2 | 202 | 12.6 | 56 | 63547 |
| 2006 | 4 | DCB | 11 | – | n/a | n/a | 10.1 | 36 | 61261 |
| 2006 | 5 | DCB | 5 | Biosolids | 5 | 179 | 10.1 | 45 | 60454 |
| 2006 | 6 | DCB | 8 | – | n/a | n/a | 8.2 | 67 | 57159 |
| 2006 | 7 | DCB | 7 | – | n/a | n/a | 8.8 | 67 | 61664 |
| 2006 | 8 | DCB | 11 | – | n/a | n/a | 9.4 | 36 | 63413 |
| 2006 | 9 | DCB | >5 | Biosolids | 3 | 168 | 10.7 | 45 | 62875 |
| 2006 | 10 | DCB | >2 | – | n/a | n/a | 8.2¶ | 56 | 63211 |
| 2006 | 11 | DCB | 9 | – | n/a | n/a | 11.0 | 69 | 59983 |
| 2006 | 12 | DCB | 7 | Biosolids | 6 | 179 | 8.2 | 73 | 70070 |
| 2006 | 13 | DCB | >2 | – | n/a | n/a | 7.6¶ | 56 | 68815 |
| 2006 | 14 | DCB | 25 | – | n/a | n/a | 7.9 | 71 | 56935 |
| 2006 | 15 | DCB | 9 | – | n/a | n/a | 9.4 | 56 | 57831 |
| 2006 | 16 | DCB | 5 | – | n/a | n/a | 8.8 | 0 | 63816 |
| 2007 | 17 | FSB | 8 | – | n/a | n/a | 8.2 | 62 | 68523 |
| 2007 | 18 | DCB | 9 | Biosolids | 9 | 168 | 8.8 | 38 | 66035 |
| 2007 | 19 | DCB | 4 | Biosolids | 4 | 168 | 9.2 | 38 | 59647 |
| 2007 | 20 | DCB | 17 | – | n/a | n/a | 8.8¶ | 56 | 58168 |
| 2007 | 21 | FSB | 0 | Biosolids | 0 | 168 | 10.1 | 0 | 69532 |
| 2007 | 22 | DCB | >5 | – | n/a | n/a | 8.5 | 38 | 58638 |

Table 4-2. Continued.

| Year | Site number | Previous Crop† | Duration of no-till yrs | Organic amendments | | Rate, PAN‡ kg ha ⁻¹ | Expected Yield§ Mg ha ⁻¹ | Starter N rate# kg ha ⁻¹ | Population at harvest no. ha ⁻¹ |
|------|-------------|----------------|-------------------------|-------------------------|----------------------|-----------------------------------|--|--|---|
| | | | | Type | Last application yrs | | | | |
| | | | | <u>Ridge and Valley</u> | | | | | |
| 2007 | 23 | C | >2 | Dairy | 1 | 168 | 7.5 | 0 | 51846 |
| 2007 | 24 | C | >10 | Dairy | 1 | 168 | 9.4 | 40 | 64085 |
| 2006 | 25 | A | >20 | Dairy | 1 | 112 | 9.4 | 0 | 54604 |
| 2007 | 26 | FSB | >5 | – | n/a | n/a | 6.3¶ | 77 | 62001 |
| 2007 | 27 | C | 0 | Poultry Litter | 2 | 112 | 7.5 | 30 | 64690 |
| 2007 | 28 | C | >5 | Dairy | 0 | 168 | 11.3 | 37 | 52452 |
| 2007 | 29 | G | >10 | Dairy | 1 | 168 | 10.1 | 62 | 69599 |

† Double-crop soybean (*Glycine max* L.), DCB; full-season soybean, FSB; corn (*Zea mays* L.), C; alfalfa (*Medicago sativa* L.), A; and grass pasture, G.

‡ Estimated plant available N in the season of application.

§ Reported by the producer and taken as the average yield for the previous 5 to 10 years.

¶ When average yield records were unavailable, expected yield taken from Simpson et al. (1993).

Includes preplant plus starter fertilizer N application made by the producer.

Table 4-3. Soil characteristics and yield parameters of 29 corn response to fertilizer N-trials conducted in 2006 and 2007.

| Year | Site number | PPNT‡ | PSNT§ | ISNT¶ | Total | | EONR# | EOY†† | Y _{N0} ‡‡ | Y _{max} §§ | RY ¶¶ | N _F ## |
|----------------------|-------------|--------------------------------|-------|-------|-------------------------------|------|---------------------|--------------------------------|--------------------|---------------------|---------------------|-------------------|
| | | | | | C | N | | | | | | |
| | | -----mg kg ⁻¹ ----- | | | -----g kg ⁻¹ ----- | | kg ha ⁻¹ | -----Mg ha ⁻¹ ----- | | | kg Mg ⁻¹ | |
| <u>Coastal Plain</u> | | | | | | | | | | | | |
| 2006 | 1 | 34.1 | 13.3 | 102 | 6.1 | 0.47 | 221 | 10.4 | 0.72 | 10.5 | 0.07 | 21.1 |
| 2006 | 2 | 20.3 | 4.1 | 110 | 7.7 | 0.54 | 209 | 9.7 | 3.5 | 9.9 | 0.36 | 21.4 |
| 2006 | 3 | 26.4 | 9.2 | 113 | 6.1 | 0.53 | 170 | 11.8 | 9.5 | 12.5 | 0.76 | 14.3 |
| 2006 | 4 | 34.7 | 4.6 | 114 | 7.1 | 0.57 | 180 | 7.6 | 2.9 | 7.8 | 0.37 | 23.6 |
| 2006 | 5 | 26.3 | 6.7 | 120 | 8.1 | 0.66 | 91 | 10.0 | 1.1 | 10.0 | 0.11 | 9.1 |
| 2006 | 6 | 34.2 | 12.8 | 123 | 9.1 | 0.69 | 277 | 9.7 | 3.0 | 9.7 | 0.31 | 28.9 |
| 2006 | 7 | 32.9 | 24.5 | 125 | 9.6 | 0.72 | 173 | 10.6 | 6.4 | 10.7 | 0.59 | 16.3 |
| 2006 | 8 | 23.1 | 5.6 | 127 | 8.0 | 0.65 | 246 | 11.6 | 4.1 | 11.6 | 0.40 | 24.7 |
| 2006 | 9 | 37.6 | 4.7 | 128 | 7.3 | 0.62 | 168 | 11.0 | 0.06 | 11.1 | 0.01 | 15.3 |
| 2006 | 10 | 23.0 | 4.7 | 139 | 10.2 | 0.82 | 228 | 11.9 | 6.5 | 12.0 | 0.54 | 19.2 |
| 2006 | 11 | 29.5 | 12.2 | 149 | 9.7 | 0.83 | 163 | 13.1 | 3.8 | 13.1 | 0.29 | 12.4 |
| 2006 | 12 | 38.0 | 6.2 | 157 | 9.6 | 0.82 | 187 | 10.6 | 3.6 | 10.6 | 0.34 | 17.7 |
| 2006 | 13 | 50.1 | 7.4 | 158 | 15.6 | 0.96 | 222 | 11.7 | 7.3 | 12.3 | 0.59 | 19.0 |
| 2006 | 14 | 26.5 | 5.7 | 164 | 12.5 | 0.99 | 183 | 11.4 | 5.0 | 11.5 | 0.43 | 16.1 |
| 2006 | 15 | 30.4 | 9.7 | 199 | 13.3 | 1.12 | 106 | 10.8 | 9.5 | 11.2 | 0.85 | 9.8 |
| 2006 | 16 | 34.5 | 6.4 | 224 | 15.5 | 1.36 | 173 | 12.4 | 8.3 | 12.5 | 0.67 | 14.0 |
| 2007 | 17 | 29.1 | 7.6 | 105 | 6.4 | 0.49 | 143 | 9.0 | 0.76 | 9.0 | 0.08 | 15.9 |
| 2007 | 18† | 21.2 | 2.9 | 145 | 9.5 | 0.79 | 0 | 5.3 | 5.3 | 5.3 | 1 | 0 |
| 2007 | 19† | 71.7 | 6.8 | 162 | 11.7 | 1.02 | 0 | 2.7 | 2.7 | 2.7 | 1 | 0 |
| 2007 | 20 | 34.5 | 27.0 | 180 | 13.5 | 1.10 | 0 | 8.5 | 8.5 | 8.5 | 1 | 0 |
| 2007 | 21 | 117.9 | 19.2 | 200 | 12.1 | 1.03 | 0 | 9.4 | 9.4 | 9.4 | 1 | 0 |
| 2007 | 22† | 55.6 | 6.3 | 205 | 14.9 | 1.42 | 0 | 3.8 | 3.8 | 3.8 | 1 | 0 |

Table 4-3. Continued.

| Year | Site number | PPNT‡ | PSNT§ | ISNT¶ | Total | | EONR# | EOY†† | Y _{NO} ‡‡ | Y _{max} §§ | RY ¶¶ | N _F ## |
|------|-------------|--------------------------------|--------------------------------|-------|-------------------------------|-------------------------------|---------------------|-------|--------------------------------|---------------------|-------|---------------------|
| | | | | | C | N | | | | | | |
| | | -----mg kg ⁻¹ ----- | -----mg kg ⁻¹ ----- | ----- | -----g kg ⁻¹ ----- | -----g kg ⁻¹ ----- | kg ha ⁻¹ | ----- | -----Mg ha ⁻¹ ----- | ----- | ----- | kg Mg ⁻¹ |
| | | | | | <u>Ridge and Valley</u> | | | | | | | |
| 2007 | 23 | 39.4 | 4.0 | 200 | 14.1 | 1.24 | 0 | 8.4 | 8.4 | 8.4 | 1 | 0 |
| 2007 | 24 | 33.2 | 11.6 | 214 | 15.8 | 1.36 | 0 | 6.9 | 6.9 | 6.9 | 1 | 0 |
| 2006 | 25 | 40.7 | 17.2 | 265 | 18.8 | 1.82 | 0 | 9.6 | 9.6 | 9.6 | 1 | 0 |
| 2007 | 26 | 57.1 | 7.9 | 146 | 10.1 | 0.95 | 164 | 9.5 | 5.4 | 9.7 | 0.56 | 17.2 |
| 2007 | 27 | 24.0 | 13.8 | 155 | 9.9 | 0.89 | 0 | 9.3 | 9.3 | 9.3 | 1 | 0 |
| 2007 | 28 | 33.8 | 7.9 | 208 | 15.1 | 1.63 | 0 | 6.8 | 6.8 | 6.8 | 1 | 0 |
| 2007 | 29 | 54.7 | 15.8 | 371 | 25.1 | 2.39 | 0 | 11.7 | 11.7 | 11.7 | 1 | 0 |

† Drought affected sites

‡ Preplant NO₃-N test (Bundy and Meisinger, 1994)

§. Presidedress NO₃-N test (Magdoff et al., 1984)

¶ Illinois soil N test; determined using the modified method of Spargo and Alley (In press)

The economically optimum N rate; calculated by equating the first derivative of the crop yield function to ratio of the price ratio of fertilizer N to corn of 7.4 kg kg⁻¹ (\$0.45 lb N, \$3.4 bu⁻¹ corn) and solving for the quantity of fertilizer N.

†† Economically optimum yield; calculated using EONR

‡‡ Yield with no fertilizer N

§§ Maximum yields, or non N-limited yields; taken as the plateau from the response models.

¶¶ Relative yield; calculated as Y_{NO} divided by the Y_{Max}. Non-responsive sites were assigned a RY of 1.

Fertilizer N application factor, kg applied N fertilizer per Mg grain; calculated as EONR divided by the Y_{EONR}. Non-responsive sites were assigned a N_F of zero.

4.8 Figures

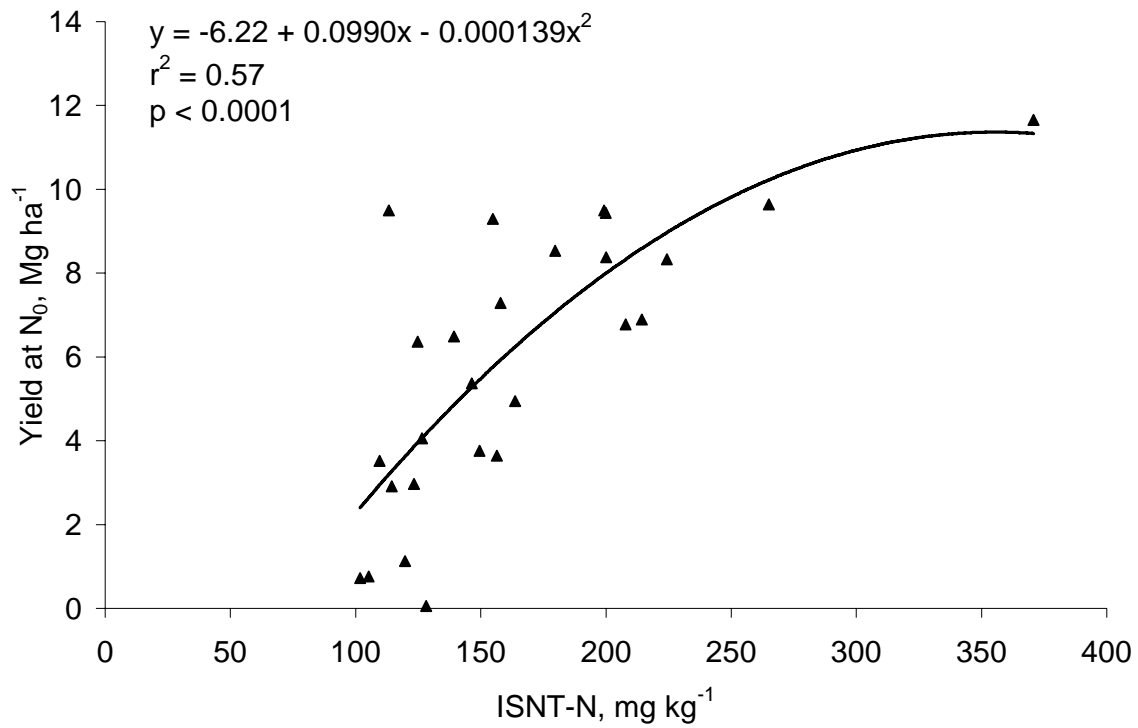


Figure 4-1. The relationship between yield with no fertilizer N (N₀) and ISNT-N for 26 corn response to fertilizer N trials conducted in 2006 and 2007.

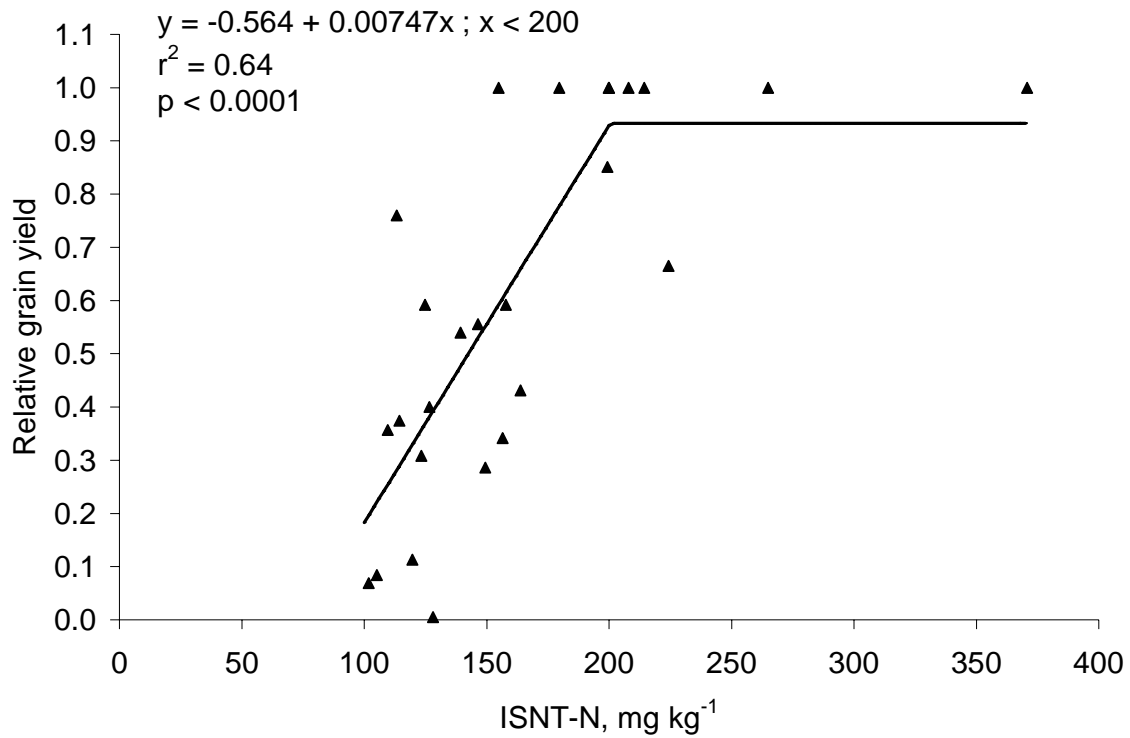


Figure 4-2. The relationship between relative yield and ISNT-N for 26 corn response to fertilizer N trials conducted in 2006 and 2007.

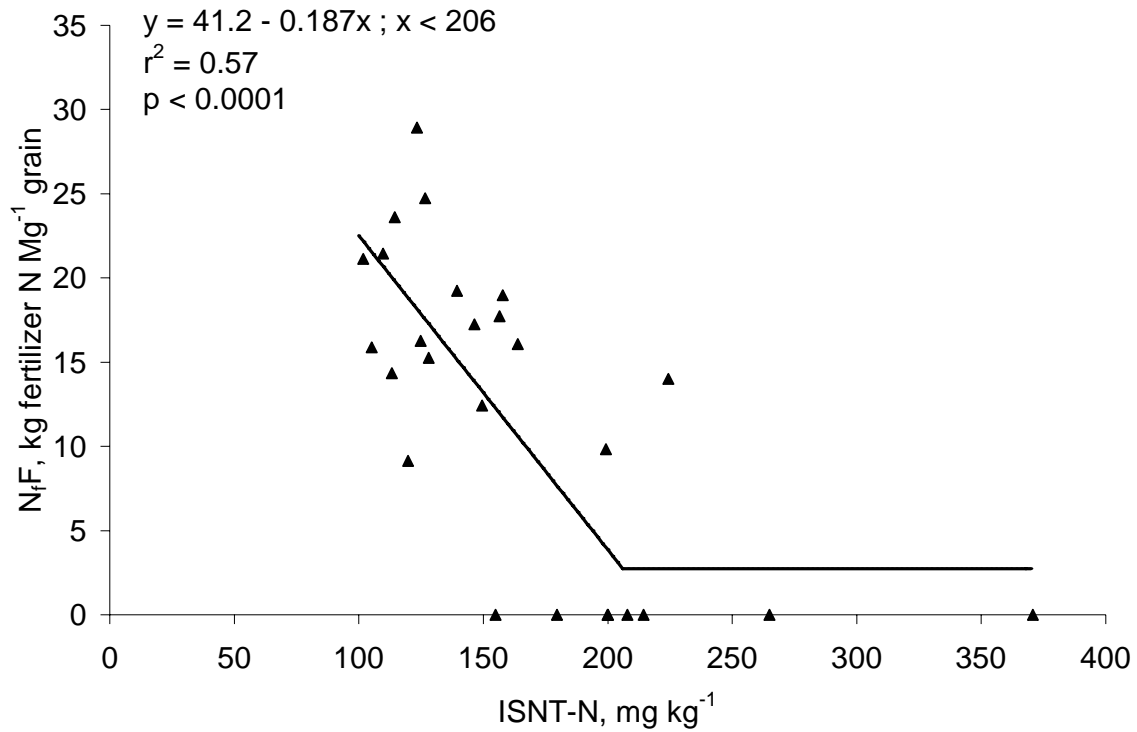


Figure 4-3. The relationship between the calculated fertilizer N application factor (kg fertilizer N Mg⁻¹ grain) and ISNT-N for 26 corn response to fertilizer N trials conducted in 2006 and 2007.

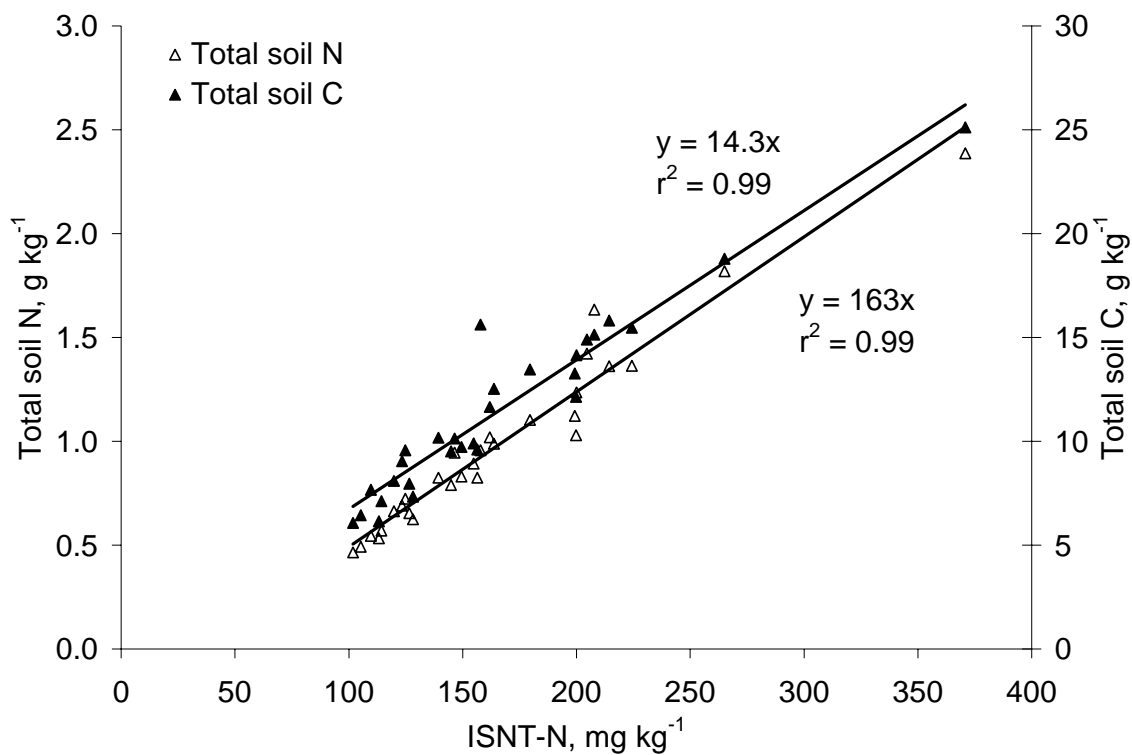


Figure 4-4. The relationship between Illinois soil N test-N (ISNT-N) and total soil N and C from the 26 corn response to fertilizer N trials conducted in 2006 and 2007.

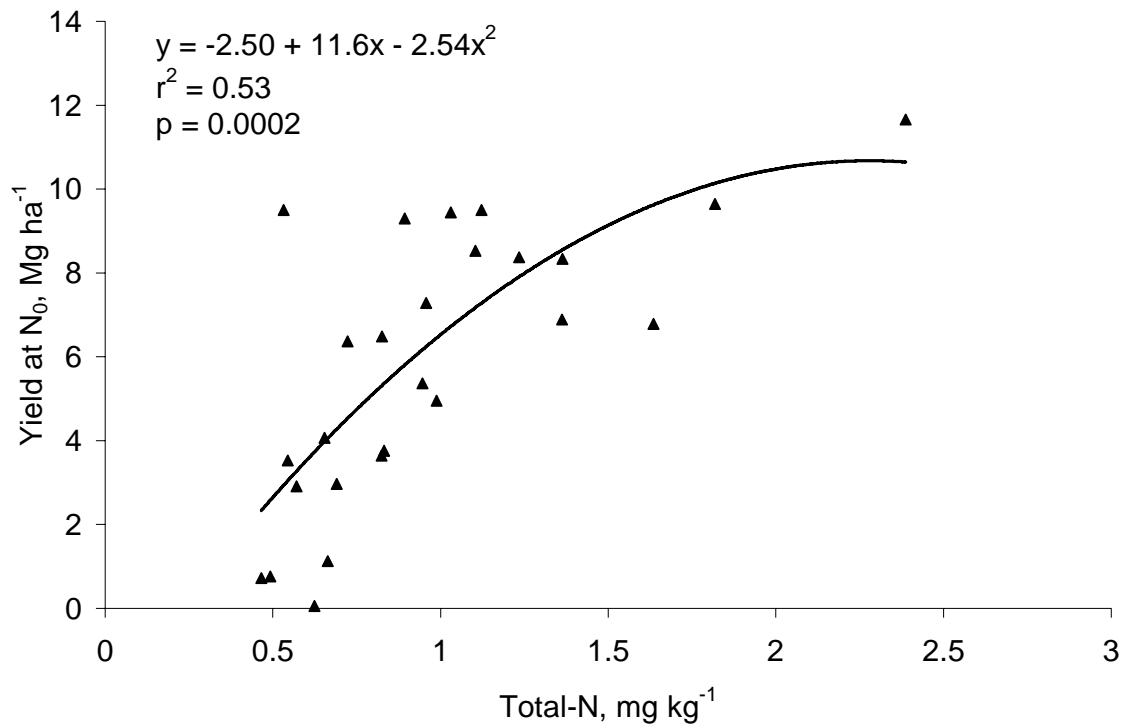


Figure 4-5. The relationship between yield with no fertilizer N (N_0) and total soil N for 26 corn response to fertilizer N trials conducted in 2006 and 2007.

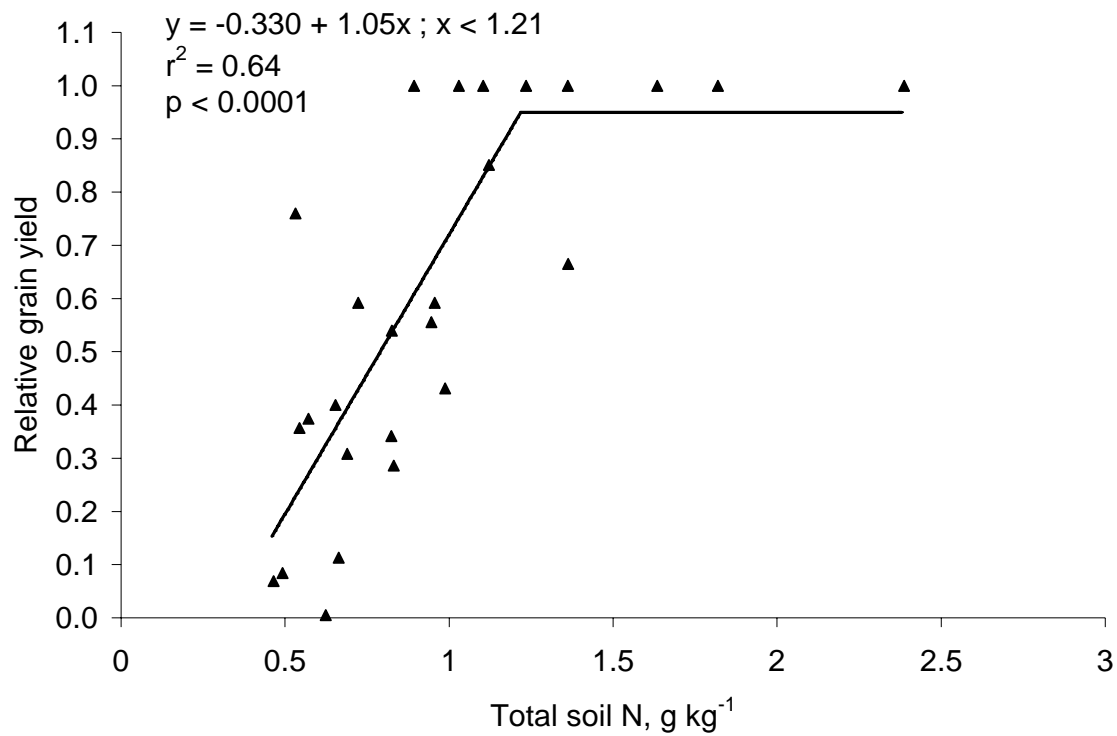


Figure 4-6. The relationship between relative yield and total soil N for 26 corn response to fertilizer N trials conducted in 2006 and 2007.

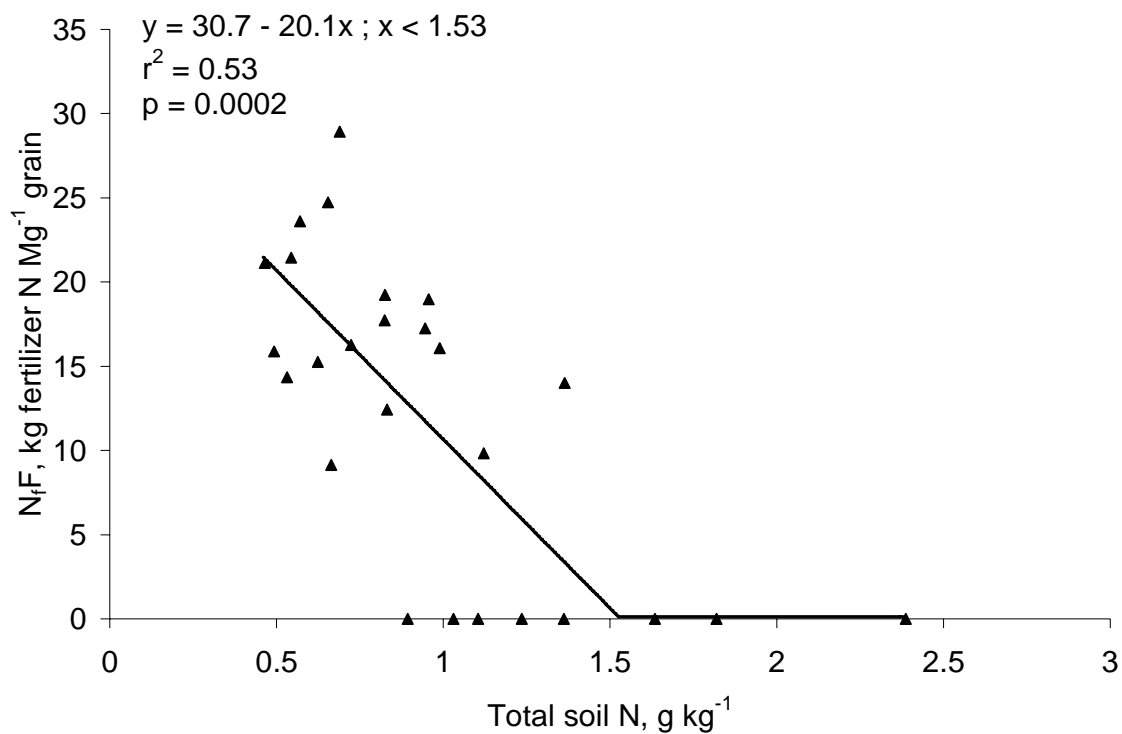


Figure 4-7. The relationship between the calculated fertilizer N application factor (kg fertilizer N Mg⁻¹ grain) and total soil N for 26 corn response to fertilizer N trials conducted in 2006 and 2007.

5 Modification of the Illinois Soil Nitrogen Test to Improve Measurement Precision and Increase Sample Throughput.

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5.1 Abstract

Quantification of organic N mineralization during the corn growing season should improve the precision of fertilizer N recommendations. The Illinois soil N test (ISNT) has shown promise in some regions as a useful tool for estimating mineralizable soil N; however, the procedure needs to be modified for use in routine soil testing labs that must process hundreds of samples per day. The assay determines alkali hydrolysable N by treating 1 g of soil with 10 mL of 2 M NaOH in a 473-mL wide-mouth Ball[®] jar, and heating for 5 h at 50° C on a hotplate to liberate $[\text{NH}_4^+ + \text{amino sugar}] - \text{N}$ as gaseous NH_3 which is collected in H_3BO_3 solution, and subsequently determined by acidimetric titration. The objectives of this study were to determine if variance in measurement values could be reduced and sample throughput increased while maintaining accuracy by using an incubator to replace a hotplate as the heat source. Thirty-five soils collected from N-response trials in Virginia were used in this study. Jars were heated in an incubator at 50° C for 5, 6, 7, 8, 9, 10 or 15 h. Soil samples were also analyzed with the un-modified method for comparison. All determinations were conducted in triplicate. Use of an incubator set to 50° C reduced the total recovery of N from the samples, but increasing the diffusion period increased N recovery. The 15 h diffusion period resulted in quantitative recovery of ISNT-N with significantly ($p < 0.05$) improved measurement precision compared to the unmodified method (CV = 4.3 vs. 7.4, respectively). Modifying the ISNT by using an incubator instead of a hotplate increases measurement precision and allows for greater sample throughput.

5.2 Introduction

Fertilizer N applications for corn are generally based on expected yield. This method fails to account for variations in soil N supplies and often results in over- or under-fertilizer N application (Mulvaney et al., 2005). Fertilizer N needs of corn often differ widely among and within fields (Scharf, 2001) due to variations in soil N supply. Fertilizer N application recommendations are generally adjusted to account for estimated amounts of N mineralized from organic N sources such as manures, biosolids and legumes but there is a great deal of uncertainty in estimates of N availability from soil N supplies due to its dynamic nature. In addition, recommendations do not generally account for the influence of management practices such as tillage, the use of cover crops, and crop residue management on mineralizable soil organic N.

A soil based approach that attempts to quantify organic N turnover could improve the precision of fertilizer N recommendations and increase N use efficiency. A number of chemical methods have been proposed for estimating soil N availability (Stevenson and Cole, 1999). Chemical methods designed to estimate potentially mineralizable N have been based on an empirical approach, and their use has been limited due to low correlations with mineral N and crop N uptake (Stevenson and Cole, 1999; Khan et al., 2001a). Soil NO₃-N testing is currently the best method for identifying soils where yield response to fertilizer N may be limited. Preplant soil profile NO₃-N testing has long been recommended for assessment of N availability in drier areas of the western USA where leaching losses are minimal (Hergert, 1987; Bundy and Meisinger, 1994) and the pre-sidedress soil NO₃-N test (PSNT) has shown potential for modifying fertilizer N recommendations in the humid eastern USA for corn grown on land receiving manure, or

where legumes have been grown in the rotation (Magdoff et al., 1984; Fox et al., 1989; Meisinger et al., 1992; Roth et al., 1992; Sims et al., 1995; Evanylo and Alley, 1997; Andraski and Bundy, 2002) Use of the PSNT has been limited by the need to collect samples during the growing season and delay N fertilization until soil samples are analyzed. In addition to the logistical problems, the PSNT is also limited by the variability of soil $\text{NO}_3\text{-N}$ due to its dependence on a number of factors such as temperature, moisture, and soil texture (Khan et al., 2001b).

Ideally, a soil N test would estimate a labile organic fraction that supplies plant available N during the growing season (Khan et al., 2001b). This approach depends on fewer N-cycle processes and is therefore less variable. The Illinois soil N test (ISNT) was developed by Khan et al. (2001b) as a simple soil assay to identify soils that are non-responsive to N-fertilization. Khan et al (2001a) were able to identify soils non-responsive to fertilizer-N using the ISNT with a critical range of 225 to 235 mg N kg^{-1} . They found a wide range of N-test values for both responsive and non-responsive sites and suggested the possibility of using the soil test to quantitatively determine fertilizer N rates in conjunction with expected yield goals.

The ISNT has also been found to provide useful data in other regions of the U.S. Klapwyk and Ketterings (2006) were able to identify non-responsive corn silage fields on dairy farms in New York using the ISNT; however, soil organic matter had to be included in the model to accurately identify non-responsive locations. Williams et al.(2007b) successfully predicted the economic optimum N rate (EONR) for corn grown on well ($r^2 = 0.87$) or poorly drained soils ($r^2 = 0.78$) in North Carolina.

The assay has not proven useful in all regions or cropping systems. For example, working in Iowa Barker et al. (2006) found no relationship between the ISNT and relative corn grain yield, corn response to fertilizer N, or EONR. The soils used in their study had relatively high levels of hydrolysable $\text{NH}_4\text{-N}$ relative to amino sugar-N and the authors suggested that this may partially explain the poor performance of the ISNT. Marriott and Wander (2006) used the assay to compare labile soil N in conventional and organic cropping systems and found that the ISNT was not a sensitive index of labile N. The ISNT fraction was not preferentially enriched by organic management and its response was similar to that of total soil C and N. For these reasons it is not likely that the assay will be adopted as a universal soil N test. Rather, its use will be limited to regions and applications where the assay has proven useful.

The ISNT was developed through work that attempted to find a relationship between different fractions of hydrolysable soil N and corn yield response to fertilizer N (Mulvaney et al., 2001). Mulvaney et al. (2001) used acid hydrolysis to determine the concentration of hydrolysable NH_4^+ , amino acid N, amino sugar N, and total hydrolyzable N in soils collected from 18 fertilizer-N response studies. Their work showed that hydrolyzable amino sugar N was highly correlated ($r = 0.79$) with check plot yield and fertilizer N response ($r = - 0.82$). The hydrolysis and N fractionation procedures are complicated and time consuming and are therefore unsuitable for routine soil analysis. For these reasons, Khan et al. (2001b) developed the simpler ISNT method to estimate amino sugar N.

The ISNT, described in detail in Technical Note 02-01 (University of Illinois at Urbana Champaign [UIUC], 2004), and Khan et al. (2001b) directly diffuses alkali

hydrolysable soil N, eliminating the acid hydrolysis procedures from earlier methods described by Mulvaney and Khan (2001). The test is thought to recover amino sugar-N, derived primarily from bacterial and fungal cell walls, plus extractable $\text{NH}_4\text{-N}$ (Khan et al., 2001b). It is likely that some α -amino-N is also released (Greenfield, 2001). The ISNT uses hotplate griddles, Ball[®] jars, Pyrex[®] petri dishes, a microburette or automatic titrator, and commonly available chemical reagents. The test is relatively simple; however, throughput is limited by the number of samples that can be heated on a single hotplate (n=10 to 12) and precision of analysis is reduced by uneven heating of the hotplates and environmental fluctuations within the laboratory (i.e., ambient air temperature, and drafts) (Klapwyk and Ketterings, 2005).

Several modifications have been made to the original ISNT method in an attempt to reduce variability. The method originally published by Khan et al. (2001b) was modified by rotating the position of the jars following heating for 1.5 and 3 h to ensure more even heating among samples (Technical Note 02-01; University of Illinois at Urbana Champaign [UIUC], 2004). Klapwyk and Ketterings (2005) enclosed the griddles in a plywood box to eliminate drafts, reduce the effects of ambient laboratory temperature, and eliminate the need to rotate jars. They found that use of the enclosed griddle method slightly reduced the coefficient of variability (3.8% with open griddles, 2.5% with enclosed griddles; $p=0.013$). While these modifications have improved precision of the ISNT, they have done nothing to increase throughput. In order for the method to be adopted for routine use in commercial and institutional soil testing laboratories, where thousands of samples are processed per year, throughput must be increased.

Replacing the griddle with an incubator as the heat source is a way to increase sample throughput, as a single laboratory incubator can easily heat 100 samples simultaneously with uniform heating, eliminating the need to rotate the jars. Khan et al. (1997) found that using an incubator reduced the amount of NH_3 diffused from the soil samples. They attributed the reduced N recovery to a lack of temperature gradient within jars in the incubator.

Williams et al. (2007b; 2007a) used an incubator to replace the griddle as the heat source, but did not report data comparing the incubator procedure with the original method. Williams et al. (2007b) did not find any sites that were non-responsive to fertilizer N but, extrapolation of their EONR vs. ISNT-N regression equation for well drained sites ($\text{EONR, kg ha}^{-1} = 348 - 3.12 \times \text{ISNT, mg N kg}^{-1}$) and solving for an economically optimum N rate of 0 gives an ISNT critical value of 112 mg N kg⁻¹. This is approximately 50% of critical levels identified by Khan et al. (2001b) and Klapwyk and Ketterings (2006) and suggests that replacement of the griddle with an incubator may lead to a reduction in recovered ISNT-N. Reduced recovery of N may decrease sensitivity of the assay since soil test levels would represent a narrower range than the original method.

The objectives of this research were to determine if variance in measurement values could be reduced and sample throughput increased while maintaining accuracy by using an incubator to replace the hotplate as the heat source for the ISNT procedure.

5.3 Materials and Methods

5.3.1 Soils

Sample Collection and Preparation

The 35 soils used in this study (Table 4-1) were collected from locations throughout Virginia used for corn (*Zea mays* L.) fertilizer N-response trials. Locations were selected to represent the wide range of climatic conditions, soil properties, and management practices existing in the region. Soil samples were collected from late March to early April of 2006 or 2007 and consist of a composite of ten to fifteen soil cores collected to a depth of 15 cm from each location. Soil samples were stored at 4⁰ C immediately following collection then rapidly air-dried upon returning to the lab. All soils were ground to pass a 2mm sieve.

In addition to the 35 soils used in this study, two quality control samples were included in the analysis: i) a finely ground (<0.15 mm), thoroughly mixed internal quality control standard soil; and, ii) a standard glucosamine solution (1 mg N mL⁻¹) prepared according to Technical Note 02-01 (University of Illinois at Urbana Champaign [UNIC], 2004) and Khan et al. (1997).

Sample Characterization

Soil samples were analyzed for pH, total C and N, and 2 M KCl extractable NH₄-N and NO₃-N. Soil pH was measured on 1:1 soil:water mixtures after equilibration for 30 minutes. Total soil C and N were determined using a VarioMax CNS macro elemental analyzer (Elementar, Hanau, Germany). Soil NH₄-N and NO₃-N were extracted with 2 M KCl for one hour on a reciprocating shaker and determined colorimetrically using a QuickChem Automated Ion Analyzer (Lachat Instruments, Milwaukee, WI).

5.3.2 Illinois Soil N Test Procedures

Standard Method

The unmodified ISNT was conducted using the procedures described in detail in Technical Note 02-01 (University of Illinois at Urbana Champaign [UNIC], 2004) and Khan et al. (1997). Briefly, commercial West Bend[®] griddles with the original temperature controls (Model 76220; West Bend, WI) and 473 ml (1-pint) wide mouth Ball[®] jars (cat. no. 14400-66000; Alltrista, Muncie, IN) were used. Ball jar lids were fitted with machine screws and cable ties to secure 60 mm diam. Pyrex[®] petri dishes (Corning Glass Works, Corning, NY) as described by Khan et al. (1997). The forward legs of the griddles were slightly elevated to allow condensation to run down the screw supporting the petri dish and not into the dish (Khan et al., 1997). Before use, temperature controls were set so that a temperature of $50^{\circ} \pm 2^{\circ}$ C was achieved when a thermometer was placed in 100 mL of deionized water in an open jar placed in the center of the griddle. Two griddles were used for our research. The griddles were placed side by side oriented in the same direction and placed under a laboratory fume hood.

A 1-g sample was weighed in to each Ball[®] jar and spread evenly around the bottom before adding 10.0 mL of 2 M NaOH. The NaOH solution was added in such a way as to thoroughly mix with the soil while preventing soil adherence to the walls of the jar. Immediately following the addition of the NaOH solution, the jars were fitted with the lid and petri dish apparatus, containing 5.0 mL of 4% w/v H₃BO₃, and tightly secured with a metal screw band. Twelve sample jars were placed on the griddle and rotated at 1.5 and 3 h after initiation of heating.

In addition to the 12 unknown soil samples, 2 additional jars containing a quality control soil standard and 1mL of standard glucosamine solution (1 mg N mL⁻¹) were

placed in the center of each griddle during every run for quality control. The position of the quality control jars was fixed within and between runs to limit the effect of temperature variance across the griddle on recovered N (Klapwyk and Ketterings, 2005).

Following 5 h of heating, jars were removed from the griddles, allowed to cool to room temperature and opened to release petri dishes from lids. The H_3BO_3 solution was diluted with 5.0 mL of deionized water and titrated with standardized 0.01 M H_2SO_4 . Titrations were conducted using a Radiometer TIM 900 Titration Manager and ABU901 autoburette (Radiometer Analytical S.A., Lyon France). Prior to titration, the end-point was established by measuring the pH of a solution prepared by mixing 5 mL of 4% w/v H_3BO_3 with 5 mL of deionized water. Soil test N (mg N kg^{-1}) was determined as $S \times T$, where S is mL of titrant and T is the titer ($\mu\text{g N mL}^{-1}$) of the standardized H_2SO_4 .

Incubator Method.

The modified ISNT was conducted using the same procedures described above except that the heat during diffusion was provided by a Precision 815 low temperature incubator (Precision; Winchester, VA) set to 50° C. In order to determine if N recovery changed with diffusion period in the incubator, a 6 sample subset (samples 1-6, Table 4-2) were placed in jars and heated in the incubator for 5, 6, 7, 8, 9, 10 and 15 h (referred to hereafter as INC5-, INC6-, INC7-, INC8-, INC9-, INC10-, INC15-ISNT, respectively). All 35 samples were heated using the INC15-ISNT method. Both quality control samples were also included in duplicate with each run in the incubator.

5.3.3 Data analysis

Data from triplicate determinations were analyzed by calculating means and coefficients of variance (CV). Mean values and CVs of the two methods were compared using PROC GLM of SAS (SAS Institute, 2002) on the basis of least significant

differences (LSD; $p < 0.05$). Linear and non-linear methods were used to determine the relationship between diffusion period and recovered N using PROC REG and PROC NLIN of SAS. Of the four models tested (linear-plateau, quadratic, quadratic-plateau, and the Mitscherlich equation), the Mitscherlich equation gave the best fit (lowest residual mean square). The relationship between the griddle method and the incubator method was assessed using PROC REG of SAS. The residual mean square was used to compare the quality of fit of no-intercept (i.e., proportional) to intercept models (Hahn, 1979). When the intercept was not significant ($p > 0.05$) and the residual mean square of the no-intercept model was less than the intercept model, the no-intercept model was used.

5.4 Results and Discussion

5.4.1 Analytical Accuracy

Based on our preliminary work and the reports of others (Khan et al., 1997; Klapwyk and Ketterings, 2005; Williams et al., 2007b; Williams et al., 2007a), we expected replacing the griddle with an incubator as the heat source during alkaline hydrolysis would result in decreased diffusion rates due to the lack of thermal gradient experienced by the diffusion jars in the incubator. Thus, to recover a similar quantity of N using the incubator, the diffusion period needs to be increased. We also expected that recovery of N using an incubator, regardless of diffusion period, would be well correlated to that recovered using a griddle. In order to test our initial proposition we used 6 samples (soils 1-6; Table 4-1) with a range of ISNT-N from 96 to 278 mg N kg⁻¹ (Table 4-2) and the glucosamine standard.

Nitrogen recovery was lower when diffusion was carried out in the incubator relative to the griddle for the five hour time period utilized in the original method.

Average recovery of ISNT-N for the six soil samples we examined was only 58% for INC5-ISNT (Table 4-2). There was a near perfect relationship between ISNT-N and INC5-INST-N ($r^2=0.9996$) as well as all other incubation periods (Fig. 4-1). As diffusion period in the incubator increased the percentage of recovered ISNT-N from the six soils examined increased (Table 4-2) and is described well by the Mitscherlich equation (Fig. 4-2; $r^2 = 0.995$). Recovered ISNT-N was 99.9% using INC15-ISNT for the initial 6 soils we analyzed (Table 4-2) and the relationship between ISNT-N and INC15-ISNT-N was near unity (slope = 1.01, $r^2=0.9998$; Fig. 4-1). During the development of the ISNT method, Khan et al. (1997) found a similar relationship between N determined and diffusion period.

The relationship between diffusion period and percentage recovery of N from the glucosamine standard using the incubator method was also described well by the Mitscherlich equation (Fig. 4-3; $r^2=0.994$). A comparison between Figs. 4-2 and 4-3 reveals an interesting difference. Recovery of N from the glucosamine standard approached a plateau much faster with incubation time than did the average recovery of ISNT-N from the six soils tested. For example, following 10 h of diffusion in the incubator the average recovery of INST-N from the six-soils was 83% of that recovered following 15 h of diffusion. Recovery of N from the glucosamine standard following 10 h of diffusion was 98% of that recovered following 15 h of diffusion. A possible explanation is that the alkaline hydrolysable N in the soil is more complex and resistant to extraction than the pure glucosamine standard.

The relationship between the standard ISNT values using the griddle and our modified method using the incubator was strong for all diffusion periods (Fig. 4-1). Thus,

any of the diffusion periods may be used with a correction factor to estimate ISNT-N; however, the sensitivity of the analysis is reduced by using diffusion periods less than 15 h. For example, samples 1-6 had a range of ISNT-N of 96.2 to 278 mg kg⁻¹ compared to a range of INC5-ISNT-N of 56.4 to 153 mg kg⁻¹, or a 47% reduction in soil test range.

Recovery of glucosamine-N following 15 h of diffusion in the incubator was equivalent to that recovered using the original method; however, there was a significant difference between the two methods for our quality control soil standard (Table 4-3). The ISNT-N of the quality control soil standard was about 8% higher than INC15. This may have resulted due to the fixed position of the quality control soil standard near the center of the griddle. Klapwick and Ketterings (2005) found that elevated temperature of jars placed in the center position resulted in higher measured ISNT-N when jars were not rotated. The reason this difference was not observed for the glucosamine standard could be because all N in the standard was recovered by both methods. Quantitative recovery of N from a standard glucosamine solution confirms that ISNT-N has not been underestimated, but it does not address over-estimation. For this reason, a standard soil may be a better quality control sample for routine use.

The reasons outlined in the previous paragraph support the use of the 15 h diffusion period in the incubator to compare the methods using the entire sample set (n=35; Table 4-4). The relationship between ISNT-N and INC15-ISNT-N is illustrated in Fig. 4-4. There was a near perfect linear relationship ($r^2 = 0.9992$) that approached unity (slope=0.989).

5.4.2 Measurement Precision

During our preliminary work with the standard ISNT we discovered that sample variance could often be unacceptably high. Using an incubator should eliminate several

potential sources of analytical error (e.g., drafts, day to day changes in ambient air temperature, and subtle differences in temperature between griddles; Klapwyk and Ketterings, 2005). Measurement precision was significantly increased by use of the 15 hour diffusion period in the incubator (CV = 4.28%) compared to the standard ISNT method (CV = 7.41%) using a griddle (Table 4-5).

The measurement precision for the glucosamine standard for both the standard ISNT method and the INC15-ISNT method are similar (CV = 1.6 and 1.5, respectively; Table 4-3). For reasons discussed earlier, this only confirms that recovery of glucosamine-N was complete for both methods. The quality control soil standard CV for the ISNT method was significantly higher than INC15-ISNT. The position of the jars containing both quality control standards on the griddles were fixed within and between runs suggesting that some of this variance is likely due to differential heating between locations on the griddles.

5.5 Conclusions

The purpose of this research was to determine if measurement precision could be improved and sample throughput increased while maintaining accuracy by using an incubator to replace a hotplate as the heat source for the ISNT.

Use of an incubator set to 50° C reduced both the quantity of recovered N and the sensitivity of the assay when compared to the standard ISNT. Increasing the diffusion period increased N recovery and a 15 h diffusion period resulted in quantitative recovery of ISNT-N with significantly improved measurement precision. Since there was no significant difference between ISNT-N and INC15-INST-N for a set of 35 soil samples

with a wide range of ISNT-N, no correction factor is needed to compare values obtained by either of the two methods.

In addition to improved measurement precision there are several ancillary benefits to using the INC15-ISNT method. Rotation of jars is not necessary for the incubation method, thus reducing labor demand. On an average day, one person can titrate approximately 100 samples using an autotitrator similar to the one used in our research. A standard upright laboratory incubator can easily accommodate 100 diffusion jars. To run the same number of samples using the standard ISNT method would require 9 or 10 griddles with a technician to rotate the jars throughout the incubation period. Thus, greater sample throughput may be achieved with a smaller laboratory foot print using the incubator method. Logistically, the 15 h incubation period works well with an average 8 h work day. Samples may be placed in the incubator at the end of the standard work day, incubated for 15 h, and titrated the following morning. One of the most attractive characteristics of the ISNT is its simplicity and convenience and our modification of the assay does not change this.

It is clear that the assay will not likely be adopted as a universal soil N test (Barker et al., 2006; Marriott and Wander, 2006); however, the assay has shown promise for prediction of corn N needs, particularly in the eastern US (Khan et al., 2001b; Klapwyk and Ketterings, 2006; Williams et al., 2007b). Our modification of the ISNT improves measurement precision and throughput making the assay more appropriate for routine use in commercial and institutional soil testing laboratories.

5.6 References

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5.7 Tables

Table 5-1. Soil series, classification, pH, NO₃-N, NH₄-N and total C and N contents for 35 soil samples used in the evaluation of the ISNT modification.

| Soil | Soil Series | Subgroup | pH† | NO ₃ -N‡ | NH ₄ -N‡ | Total§ | |
|------|-----------------|---|-----|---------------------|---------------------|--------------------|-------|
| | | | | | | C | N |
| | | | | mg kg ⁻¹ | | g kg ⁻¹ | |
| 1 | Pamunkey fsl | fine-loamy, mixed, semiactive, thermic Ultic Hapludalfs | 6.1 | 2.1 | 2.0 | 6.07 | 0.465 |
| 2 | Angie l | fine, mixed, semiactive, thermic Aquic Paleudults | 6.6 | 1.9 | 1.0 | 12.5 | 0.989 |
| 3 | Wickham fsl | fine-loamy, mixed, semiactive, thermic Typic Hapludults | 6.3 | 2.8 | 2.8 | 15.5 | 1.364 |
| 4 | Frederick sil | fine, mixed, semiactive, mesic Typic Paleudults | 7.6 | 8.1 | 2.0 | 18.8 | 1.82 |
| 5 | Kempsville sil | fine-loamy, siliceous, subactive, thermic, Typic Hapludult fine | 5.9 | 6.9 | 1.4 | 15.6 | 0.957 |
| 6 | Slagle sil | fine-loamy, siliceous, subactive, thermic Aquic Hapludults | 6.0 | 3.7 | 2.3 | 9.73 | 0.831 |
| 7 | Altavista fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults | 6.2 | 2.9 | 4.2 | 9.61 | 0.824 |
| 8 | Timberville sil | fine, mixed, active, mesic Typic Hapludults | 6.8 | n/a | n/a | 25.1 | 2.39 |
| 9 | Tetotum l | fine-loamy, mixed, semiactive, thermic Aquic Hapludults | 5.6 | 22 | 7.1 | 12.1 | 1.03 |
| 10 | Molena ls | mixed, thermic Psammentic Hapludults | 7.7 | 3.9 | 1.6 | 6.15 | 0.532 |
| 11 | Altavista fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults | 5.3 | 4.7 | 2.7 | 9.05 | 0.670 |
| 12 | Kempsville l | fine-loamy, siliceous, subactive, thermic Typic Hapludults | 6.4 | 3.5 | 2.6 | 7.11 | 0.571 |

Table 5-1. Continued.

| Soil | Soil Series | Subgroup | pH† | NO ₃ -N‡ | NH ₄ -N‡ | Total§ | |
|------|----------------|---|-----|---------------------|---------------------|--------------------|-------|
| | | | | | | C | N |
| | | | | mg kg ⁻¹ | | g kg ⁻¹ | |
| 13 | Endcav sil | very-fine, mixed, semiactive, mesic chromic Vertic Hapludalfs | 5.9 | 4.8 | 1.1 | 10.1 | 0.946 |
| 14 | Emporia sl | fine-loamy, siliceous, subactive, thermic Typic Hapludults | 6.8 | 6.8 | 2.7 | 11.7 | 1.02 |
| 15 | Altavista fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults | 6.3 | 3.2 | 4.3 | 8.10 | 0.664 |
| 16 | Groseclose sil | fine, mixed, semiactive, mesic Typic Hapludults | 6.9 | 2.4 | 3.9 | 19.3 | 1.67 |
| 17 | Altavista fsl | fine-loamy, mixed, semiactive, thermic Aquic Hapludults | 6.2 | 4.5 | 2.7 | 9.58 | 0.723 |
| 18 | Wheeling fsl | fine-loamy, mixed, active, mesic Ultic Hapludalfs | 6.8 | 6.9 | 3.4 | 9.91 | 0.893 |
| 19 | Guernsey sil | fine, mixed, superactive, mesic Aquic Hapludalfs | 6.4 | 2.7 | 4.8 | 15.1 | 1.32 |
| 20 | Frederick sil | fine, mixed, semiactive, mesic Typic Paleudults | 7.3 | 4.2 | 6.8 | 15.8 | 1.36 |
| 21 | Groseclose sil | fine, mixed, semiactive, mesic Typic Hapludults | 6.2 | 4.6 | 5.7 | 15.2 | 1.31 |
| 22 | Suffolk sl | fine-loamy, siliceous, semiactive, thermic Typic Hapludults | 6.0 | 4.1 | 2.1 | 7.94 | 0.687 |
| 23 | Pamunkey fsl | fine-loamy, mixed, semiactive, thermic Ultic Hapludalfs | 6.1 | 5.4 | 6.0 | 6.43 | 0.493 |
| 24 | Kempsville sil | fine-loamy, siliceous, subactive, thermic Typic Hapludults | 6.4 | 6.4 | 3.4 | 7.33 | 0.624 |

Table 5-1. Continued.

| Soil | Soil Series | Subgroup | pH† | NO ₃ -N‡ | NH ₄ -N‡ | Total§ | |
|------|----------------|--|-----|---------------------|---------------------|--------------------|-------|
| | | | | | | C | N |
| | | | | mg kg ⁻¹ | | g kg ⁻¹ | |
| 25 | Tetotum l | fine-loamy, mixed, semiactive, thermic Aquic Hapludults | 6.3 | 4.4 | 0.8 | 10.2 | 0.825 |
| 26 | Atlee sil | fine-loamy, siliceous, semiactive, thermic Fragiaquic Paleudults | 6.0 | 6.3 | 3.6 | 14.9 | 1.42 |
| 27 | Kempsville sil | fine-loamy, siliceous, subactive, thermic Typic Hapludults | 6.8 | 3.4 | 2.6 | 7.96 | 0.654 |
| 28 | Pamunkey fsl | fine-loamy, mixed, semiactive, thermic Ultic Hapludalfs | 6.1 | 5.5 | 2.2 | 13.5 | 1.10 |
| 29 | Pamunkey l | fine-loamy, mixed, semiactive, thermic Ultic Hapludalfs | 5.1 | 9.3 | 13 | 8.41 | 0.786 |
| 30 | Slagle silt l | fine-loamy, siliceous, subactive, thermic Aquic Hapludults | 6.3 | 3.9 | 2.4 | 13.3 | 1.12 |
| 31 | Kempsville sil | fine-loamy, siliceous, subactive, thermic Typic Hapludults | 6.6 | 2.4 | 3.0 | 7.67 | 0.544 |
| 32 | Caverns sil | coarse-loamy, siliceous, semiactive, mesic Ultic Hapludalfs | 7.3 | 5.0 | 1.8 | 12.7 | 1.28 |
| 33 | Tetotum l | fine-loamy, mixed, semiactive, thermic Aquic Hapludults | 6.6 | 3.0 | 2.0 | 9.52 | 0.791 |
| 34 | Hayter l | fine-loamy, mixed, active, mesic Ultic Hapludalfs | 7.0 | 3.3 | 2.3 | 14.1 | 1.24 |
| 35 | Edom sic | fine, illitic, mesic Typic Hapludalfs | 7.1 | 4.2 | 2.3 | 15.1 | 1.64 |

† 1:1 (w/v) soil:water

‡ KCl extractable NO₃-N and NH₄-N

§ Determined by dry combustion using CN autoanalyzer

Table 5-2. Measured Illinois soil N test – N using the standard method (ISNT-N) and the percentage of ISNT-N recovered using an incubator with 5, 6, 7, 8, 9, 10 and 15 h. of diffusion (INC5, INC6, INC7, INC8, INC9, INC10, and INC15, respectively) of a subset of selected sites.

| Soil | ISNT-N mg kg ⁻¹ | INC5 | INC6 | INC7 | INC8 | INC9 | INC10 | INC15 |
|---------|-------------------------------|----------------------|------|------|------|------|-------|-------|
| | | -----% recovery----- | | | | | | |
| 1 | 96.2 | 57.0 | 65.5 | 70.5 | 76.5 | 78.9 | 80.2 | 102.9 |
| 2 | 179.8 | 56.5 | 63.1 | 71.0 | 78.4 | 79.1 | 84.3 | 101.6 |
| 3 | 234.0 | 57.9 | 66.0 | 70.3 | 75.3 | 78.6 | 82.0 | 98.8 |
| 4 | 277.6 | 56.9 | 64.1 | 70.1 | 75.5 | 79.6 | 82.2 | 98.7 |
| 5 | 152.8 | 58.6 | 63.8 | 69.3 | 72.7 | 77.6 | 78.6 | 99.0 |
| 6 | 141.3 | 60.3 | 62.6 | 66.4 | 73.8 | 87.5 | 80.2 | 98.8 |
| Average | | 57.9 | 64.2 | 69.6 | 75.4 | 80.2 | 81.2 | 99.9 |

Table 5-3. Average (n = 6)† and coefficient of variance (CV; n = 3)† of recovered N from two quality control samples using the standard Illinois soil N test method (ISNT-N) with fixed griddle position or the modified method using an incubator with 15 h. of diffusion (INC15).

| Method | Glucosamine-N‡ % N recovered | CV % | QC soil§ mg N kg ⁻¹ | CV % |
|--------|---------------------------------|---------|-----------------------------------|---------|
| ISNT | 96.7 | 1.07 | 204 | 8.15 |
| INC15 | 96.6 | 1.18 | 189 | 0.773 |
| LSD¶ | 1.02 | 0.748 | 11.4 | 6.26 |

† Two of each quality control standards were included with every set of samples analyzed and each set was run in triplicate.

‡ Percentage of recovered N from a standard glucosamine solution (1 mg N mL⁻¹).

§ Quality control soil standard.

¶ Least significant difference (p<0.05).

Table 5-4. Measured N using the standard Illinois soil N test method (ISNT-N) or the modified method using an incubator with 15 h. of diffusion period (INC15).

| Soil | ISNT | | INC15 | |
|------|--------------------------|----------|--------------------------|----------|
| | N mg kg ⁻¹ | CV† % | N mg kg ⁻¹ | CV† % |
| 1 | 99 | 10.0 | 102 | 8.8 |
| 2 | 161 | 4.3 | 164 | 5.1 |
| 3 | 227 | 6.2 | 224 | 2.0 |
| 4 | 269 | 7.1 | 265 | 1.2 |
| 5 | 159 | 7.3 | 158 | 5.4 |
| 6 | 151 | 8.9 | 149 | 3.4 |
| 7 | 153 | 7.9 | 157 | 2.8 |
| 8 | 362 | 11.5 | 371 | 2.5 |
| 9 | 188 | 4.3 | 200 | 2.3 |
| 10 | 108 | 6.6 | 113 | 7.0 |
| 11 | 125 | 12.9 | 123 | 9.3 |
| 12 | 113 | 6.1 | 114 | 5.3 |
| 13 | 143 | 10.7 | 146 | 3.5 |
| 14 | 161 | 2.0 | 162 | 5.2 |
| 15 | 118 | 9.0 | 120 | 4.5 |
| 16 | 259 | 2.9 | 265 | 1.2 |
| 17 | 120 | 4.0 | 125 | 6.4 |
| 18 | 147 | 11.6 | 155 | 2.4 |
| 19 | 212 | 9.8 | 214 | 3.1 |
| 20 | 230 | 7.4 | 227 | 4.7 |
| 21 | 210 | 9.0 | 214 | 5.8 |
| 22 | 126 | 2.3 | 131 | 5.8 |
| 23 | 106 | 2.2 | 105 | 3.0 |
| 24 | 129 | 9.8 | 128 | 8.4 |
| 25 | 142 | 4.5 | 139 | 5.4 |
| 26 | 200 | 4.3 | 205 | 1.5 |
| 27 | 126 | 9.2 | 127 | 1.9 |
| 28 | 188 | 5.7 | 180 | 1.1 |
| 29 | 161 | 9.8 | 150 | 5.2 |
| 30 | 187 | 13.4 | 180 | 10.0 |
| 31 | 106 | 10.6 | 110 | 6.7 |
| 32 | 164 | 6.4 | 164 | 2.4 |
| 33 | 135 | 5.4 | 145 | 1.1 |
| 34 | 195 | 7.6 | 200 | 3.4 |
| 35 | 215 | 9.2 | 208 | 2.0 |

† Coefficient of variance for triplicate determinations

Table 5-5. Average measured N and coefficient of variability using the standard Illinois soil N test method (ISNT-N) or the modified method using an incubator with 15 h. of diffusion period (INC15) of all 35 selected sites.

| Method | Recovered N | CV† |
|--------|---------------------|------|
| | mg kg ⁻¹ | % |
| ISNT | 168.5 | 7.41 |
| INC15 | 169.7 | 4.28 |
| LSD | 1.8 | 1.11 |

† Average coefficient of variance for triplicate determinations on 35 samples

5.8 Figures

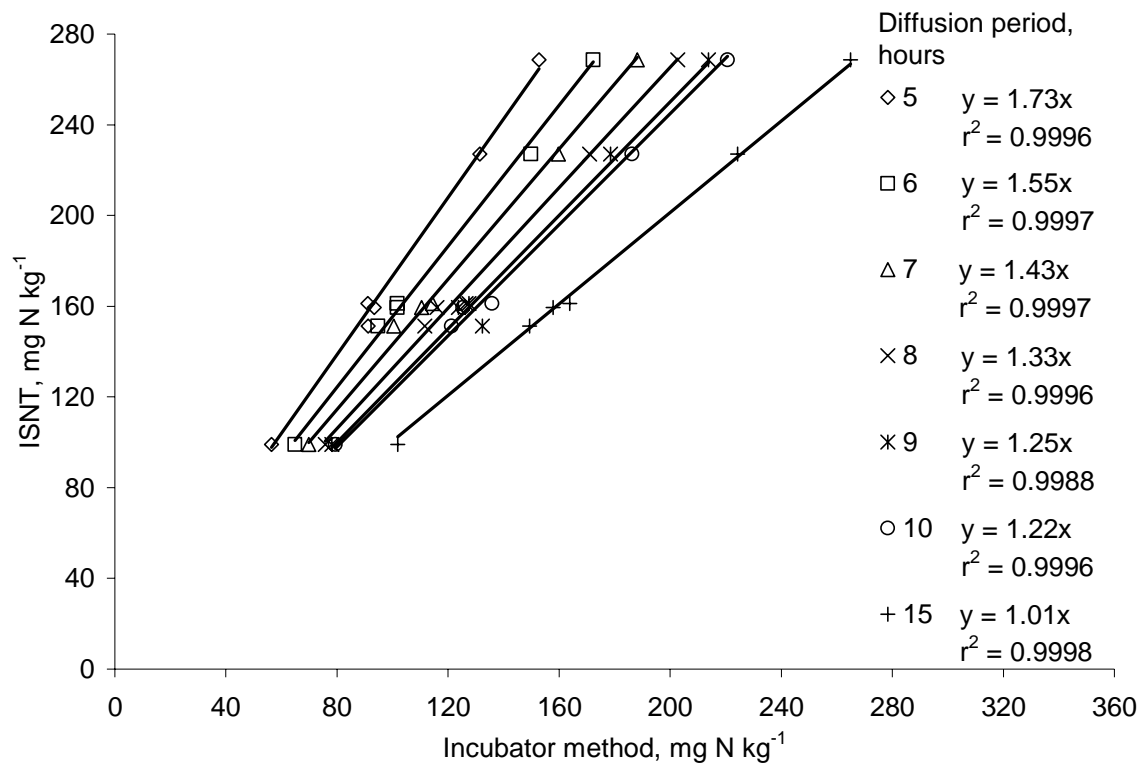


Figure 5-1. Standard Illinois soil N test method (ISNT-N) vs. the modified method using an incubator with a diffusion period of 5, 6, 7, 8, 9, 10 and 15 h. for a subset of selected sites (site 1-6, Table 4-1).

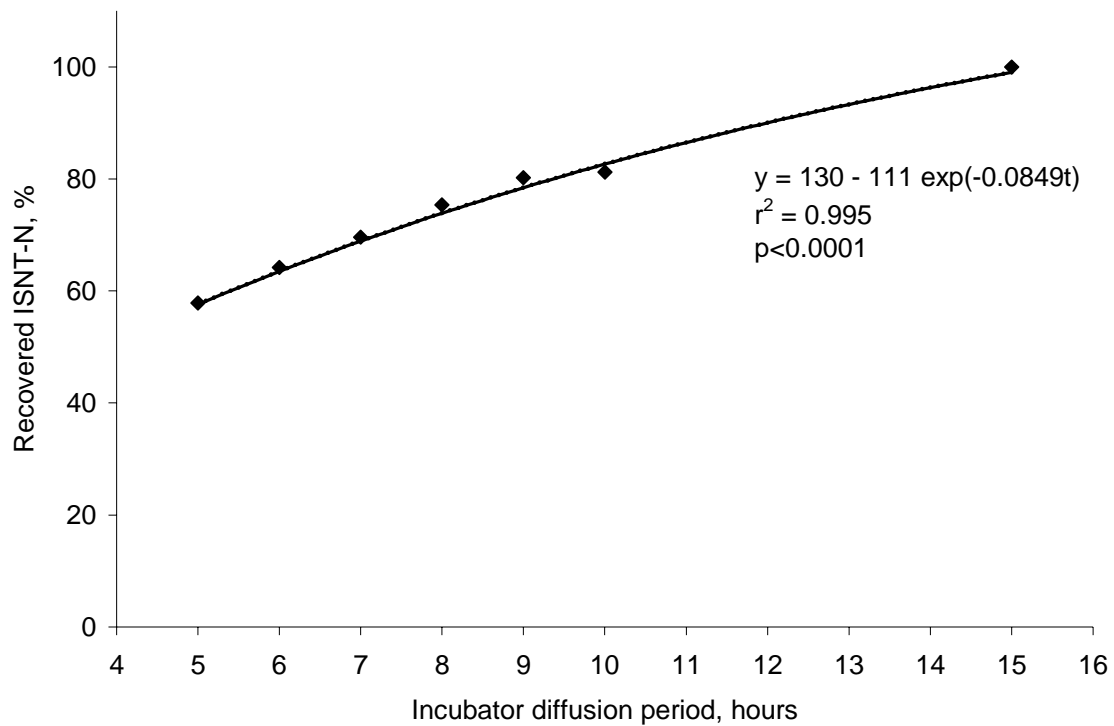


Figure 5-2. Average percentage of Illinois soil N test – N (ISNT-N) recovered using the incubator method with a diffusion period of 5, 6, 7, 8, 9, 10, or 15 h. on a subset of selected sites (sites 1-6, Table 4-1).

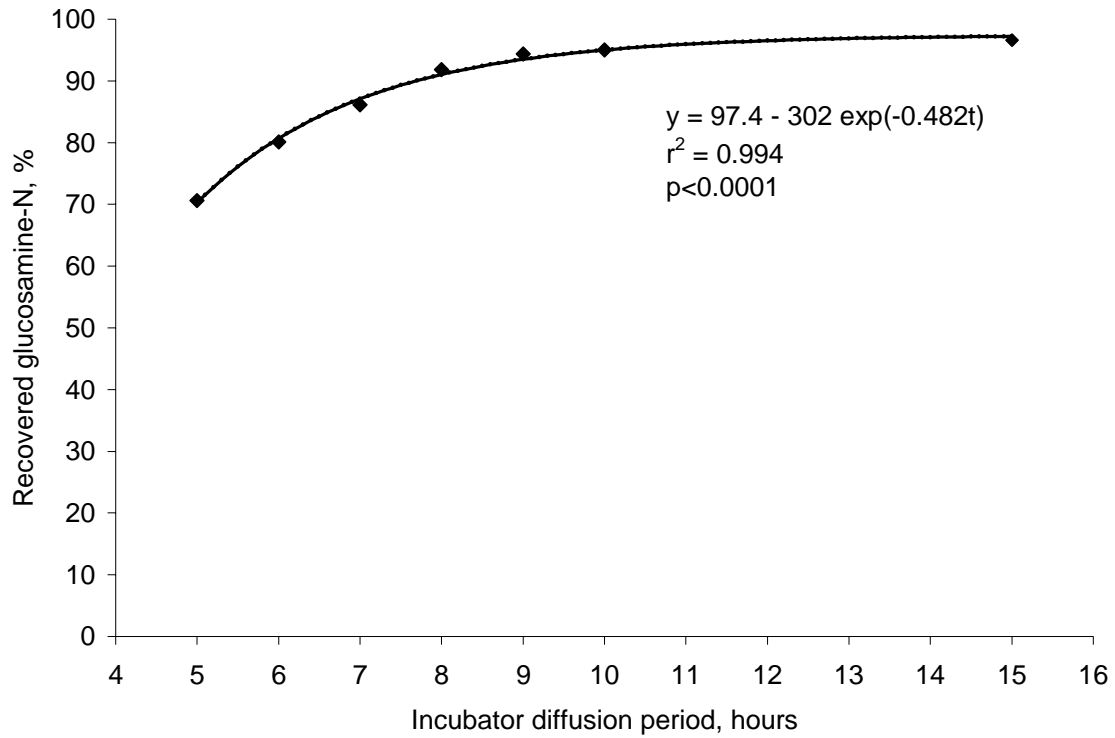


Figure 5-3. Percentage of recovered N from the glucosamine standard (1 mg N ml⁻¹) using the incubator method with a diffusion period of 5, 6, 7, 8, 9, 10, or 15 h.

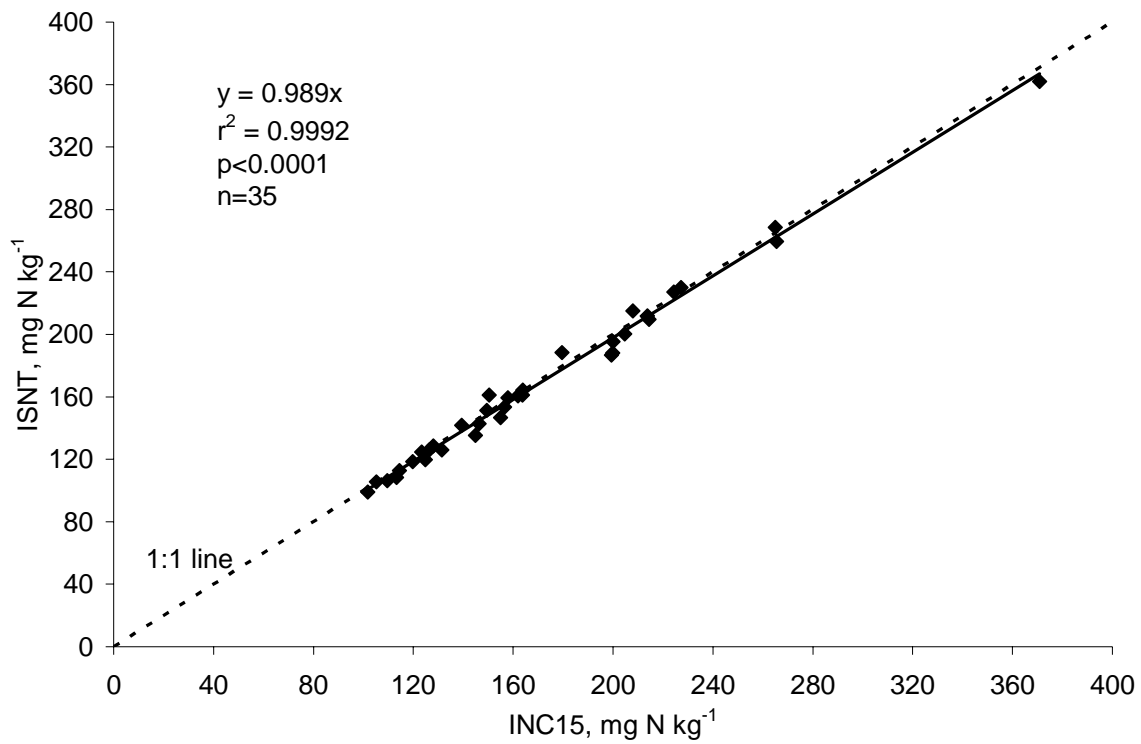


Figure 5-4. The relationship between measured N using the standard Illinois soil N test method (ISNT) vs the modified method using an incubator with a 15 h. diffusion period (INC15).

6 Dissertation Summary and Conclusions

6.1 Introduction

No-till is recognized as an effective management practice to regain a portion of the SOM lost following decades of intensive cultivation (Follett, 2001; Franzluebbers, 2005) because tillage is an important regulator of organic matter decomposition in agroecosystems. For this reason, no-till management is an effective strategy to partially offset anthropogenic carbon dioxide emissions (West and Marland, 2002), improve soil quality (Wander and Bollero, 1999; Franzluebbers, 2002a; Franzluebbers, 2002b) and conserve soil N (Fixen and West, 2002; Franzluebbers, 2004).

Agriculture in the Virginia Coastal Plain can be highly productive due to a warm, moist climate. These conditions are conducive for both high rates of photosynthetic CO₂ fixation and rapid SOM decomposition (Franzluebbers, 2005). There is potential to conserve a substantial amount of SOM in this agroecosystem by employing continuous no-till management on farms previously using rotational or intermittent tillage.

The goals of this research were to: i) quantify C sequestration rate with duration of continuous no-till; ii) measure C stratification with continuous no-till as an indicator of soil quality; iii) measure the amount of total and labile soil N retained with duration of continuous no-till; and iv) evaluate the Illinois soil N test (ISNT) as a tool for predicting of fertilizer N needs of corn in Virginia cropping systems using continuous no-till management.

6.2 Carbon Sequestration, Stratification, and Soil Quality

There is potential to sequester a substantial amount of C, and concomitantly improve soil quality, using no-till management in the intensive cropping systems of the

Virginia Coastal Plain. The purpose of this research was to quantify the rate of C sequestration with duration of continuous no-till management on farms previously using rotational or intermittent tillage. We were also interested in measuring the effect of no-till management on C stratification as an indicator of soil quality.

We found that the implementation of continuous no-till resulted in the sequestration of $0.308 \pm 0.280 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ (0 – 15 cm). These data provide a quantitative estimate of the sequestration rate with duration of no-till following its adoption on land previously managed using rotational tillage. The observed rate, based upon on-farm observations, is similar to that determined by Franzluebbers (2005), who conducted a meta analysis of research conducted in the southeastern United States for conversion of conventional-to no-tillage ($0.42 \pm 0.46 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$; n=96). The C sequestration rate observed in this work is also similar to the offset issuance rate of 0.4 Mg C ha^{-1} used by the Chicago Climate Exchange (CCX) for conversion of conventionally tilled land to continuous no-till.

We also found that continuous no-till management had a positive impact on soil quality as measured by the C stratification ratio discussed previously. Soil C is being concentrated at the soil surface in the continuous no-till production systems. The soil surface is the vital interface that buffers precipitation impact, solar radiation and gas exchange, and receives most production inputs such as fertilizer nutrients and pesticides. The degree of C stratification (0-2.5 cm:7.5-15 cm) was positively related to the duration of continuous no-till management ($0.133 \pm 0.0564 \text{ yr}^{-1}$) due to the accumulation of C in the surface 2.5 cm of the soil ($0.678 \pm 0.261 \text{ g C kg}^{-1} \text{ yr}^{-1}$). The accumulation of soil C at the soil surface has the potential to improve capture and retention of precipitation, reduce erosion, and increase nutrient retention (Franzluebbers, 2002b).

6.3 Conservation of Soil Nitrogen

Tillage has resulted in the loss of considerable organic N from surface soils. There is potential to rebuild and conserve substantial amounts of soil N by adopting continuous no-till management. We found that the implementation of continuous no-till on farms in the Virginia Coastal Plain previously using rotational or intermittent tillage resulted in the conservation of $22.2 \pm 21.2 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ (0 – 15 cm). Our observed rate is similar to the average no-till N sequestration rate of $28 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ ($n = 26$) reported by Franzluebbbers (2004). The conservation of soil N with continuous no-till management indicates improved N use efficiency of the cropping system, which has both agronomic and environmental implications.

Nitrogen use efficiency of a cropping system is determined as the proportion of applied N recovered in the harvested crop, contained in recycled crop residues, and incorporated into soil organic matter (SOM). The N not recovered or conserved in these pools is lost from the system and contributes to the reactive N load in the environment external to the cropping system, where it may impair air and/or water quality. Thus, conserving N as soil organic N with no-till management should result in improved environmental quality and agronomic efficiency.

6.4 Illinois Soil Nitrogen Test

Current N needs for corn in Virginia are estimated based on expected yield and adjusted to account for estimated amounts of N mineralized from organic N sources such as manures, biosolids and legumes. A portion of the additional N retained as SOM in no-till soils may also potentially become available for crops (Franzluebbbers et al., 1994a; Wienhold and Halvorson, 1999). The dynamic nature of soil N creates significant uncertainty in estimates of N availability from these sources. Accurate quantification of

organic N mineralization during the corn-growing season would improve the precision of fertilizer N recommendations. The ISNT has shown some promise as a tool to predict N-mineralization (Sharifi et al., 2007), and a reduction in fertilizer N needs (Khan et al., 2001b; Mulvaney et al., 2005; Klapwyk and Ketterings, 2006; Williams et al., 2007b). The ISNT has not always proven useful for the prediction of fertilizer N needs (Barker et al., 2006) or quantification of labile organic N (Marriott and Wander, 2006). For these reasons, it is not likely that the assay will be adopted as a universal soil N test; its use will be limited to regions and applications where the assay is proven useful.

The purpose of this work was to determine if the ISNT predicts fertilizer N response of corn grown in a diverse range of Virginia agroecosystems. We also wanted to determine if measurement precision could be improved and sample throughput increased by modifying the assay.

6.4.1 Modification of the Illinois Soil Nitrogen Test to Improve Measurement Precision and Increase Sample Throughput

The ISNT is relatively simple; however, throughput is limited by the number of samples that can be heated on a single hotplate (n=10 to 12), and analytical precision may be reduced by uneven heating of the hotplates and environmental fluctuations within the laboratory. The purpose of this research was to determine if variance in measurement values could be reduced and sample throughput increased while maintaining accuracy by replacing the hotplates with an incubator as the heat source for the ISNT procedure.

Use of an incubator set to 50° C and a 15 hr diffusion period resulted in quantitative recovery of ISNT-N with significantly improved measurement precision. Since there was no significant difference between the N recovered using the original and modified method for a set of 35 soil samples with a wide range of ISNT-N, no correction factor is needed to compare values obtained by either of the two methods. In addition to

improving measurement precision, modification of the method also improved labor efficiency by increasing the number of samples one person can process in a given time period. Our modification of the ISNT improves measurement precision and throughput making the assay more appropriate for routine use in commercial and institutional soil testing laboratories.

6.4.2 Illinois Soil Nitrogen Test for Prediction of Fertilizer Nitrogen Needs of Corn in Virginia

Fertilizer N needs of corn vary widely among fields in Virginia. Current Virginia Cooperative Extension recommendations for corn fertilizer N needs fail to accurately account for this variation. Accurate quantification of organic N mineralization during the corn-growing season should improve the precision of fertilizer N recommendations, as has been recognized by previous work.

The ISNT was significantly related to yield without fertilizer N ($r^2 = 0.57$; $p < 0.001$) and relative yield ($r^2 = 0.64$; $p < 0.0001$). We also found that the ISNT extracted a relatively consistent percentage of total soil N (16.3 ± 0.73 %) suggesting that it is a poor indicator of labile N. In fact, total soil N did nearly as well as the ISNT for predicting yield without fertilizer N ($r^2 = 0.53$; $p = 0.0002$), and equally well predicting relative yield ($r^2 = 0.64$; $p < 0.0001$).

In order for a soil N test to be a useful assay for prediction of fertilizer N needs, the assay needs to accurately reflect labile N where mineralizable soil N is derived from a variety of organic N sources. Our results do not suggest that the ISNT is a useful test for improving fertilizer N recommendations in Virginia, but they do indicate a negative relationship between fertilizer N needs and organic soil N. This relationship warrants further investigation.

6.5 Implications of the Research

Findings from this research have a number of environmental and agronomic implications. These data provide a quantitative estimate of the sequestration rate with duration of no-till following adoption of no-till on land previously managed using rotational tillage. The adoption of no-till on land previously managed using rotational or intermittent tillage is an effective strategy to sequester C, improve soil quality, and conserve soil N.

Sequestration of C and conservation of N on land managed using continuous no-till will help to offset anthropogenic CO₂ emissions and may reduce N losses to the environment, respectively. Implementation of a trading system offering economic incentives for C sequestration and N conservation will encourage producers not currently employing continuous no-till management to adopt the practice, and reward those that already are. The CCX has initiated a voluntary, legally binding trading system that recognizes no-till management as an eligible sequestration practice (CCX, 2007). Observations from this research validate the CCX offset issuance rate of 0.4 Mg C ha⁻¹ for no-till management currently applied to the region. In an attempt to mitigate pollution of the Chesapeake Bay, Virginia House Bill 2862 was introduced in 2005 to initiate a nutrient (e.g., N) credit exchange program among point source polluters (e.g., water treatment facilities), or between point sources and non-point sources, such as agricultural land (Chesapeake Bay Watershed Nutrient Credit Exchange Program, 2005). This research offers evidence that soils managed using continuous no-till conserve soil N. It also provides a quantitative basis for establishment of an offset issuance that can be used for N credit trading in the region.

It is important to recognize that a substantial portion of the SOM conserved with continuous no-till management can become rapidly available and potentially lost from the system when intermittent tillage is used to address perceived soil compaction, remove ruts, control weeds or incorporate residues (Gilley et al., 1997; Pierce and Fortin, 1997; Grandy et al., 2006). The value of periodic or intermittent tillage of no-till cropping systems must be weighed against the cost to soil and environmental quality, and should only be practiced when absolutely necessary. The ephemeral nature of SOM in these systems should be considered when establishing guidelines for C and N trading programs.

A portion of the organic N conserved with continuous no-till management in this agroecosystem may potentially become available for crops. While the ISNT was not sensitive enough to be used for predicting fertilizer N needs, our data clearly illustrates that there is a negative relationship between fertilizer N needs and organic soil N. More research is needed in order to resolve this relationship and develop effective methods for determining fertilizer N needs based on soil N availability.

Continuous no-till is a sustainable management practice in Virginia, has a number of agronomic and environmental benefits, and based upon the data presented here, implementation of continuous no-till should be encouraged on all crop production fields where the elimination of tillage is practical.

6.6 Future Research

There are a number of questions and concerns regarding the effect of no-till management on SOM cycling that need to be addressed. Some of the key questions that require further investigation are: i) What is the effect of periodic tillage of no-till systems on SOM cycling and soil quality (Gilley et al., 1997; Pierce and Fortin, 1997; Grandy et

al., 2006)?; ii) How does excessive N fertilization influence conservation of SOM in no-till systems (Khan et al., 2007)?; iii) How does continuous no-till management affect N leaching (Angle et al., 1993; Randall and Iragavarapu, 1995; Zhu et al., 2003)? Further, the increased cost of fertilizer N and public concern about environmental quality necessitate the development of methods for accurately determining fertilizer N needs. Future research must address these issues in order to provide critical information to land managers to assist them in making wise management decisions.

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Appendix

Appendix A. Sampling date and geographic coordinates of sites referenced in Chapters 2 and 3.

| Site | Sampling Date | Geographic coordinates | |
|------|---------------|------------------------|------------|
| | | N | W |
| 1 | 9/13/2006 | 37°20.143' | 77o07.185' |
| 2 | 9/13/2006 | 37°20.143' | 77o07.175' |
| 3 | 9/21/2005 | 37°36.575' | 77o07.328' |
| 4 | 9/20/2005 | 37°31.163' | 76o49.052' |
| 5 | 9/20/2005 | 37°31.139' | 76o49.092' |
| 6 | 9/19/2005 | 37°34.509' | 77o01.981' |
| 7 | 9/5/2006 | 37°32.849' | 76o55.726' |
| 8 | 9/6/2006 | 37°30.638' | 76o49.470' |
| 9 | 9/21/2005 | 37°32.697' | 76o58.903' |
| 10 | 9/6/2006 | 37°32.821' | 76o56.129' |
| 11 | 9/14/2006 | 37°23.665' | 77o12.198' |
| 12 | 9/15/2006 | 37°23.521' | 77o12.308' |
| 13 | 9/16/2006 | 37°23.679' | 77o12.378' |
| 14 | 11/2/2005 | 37y22.460' | 77o01.888' |
| 15 | 9/20/2005 | 37°32.400' | 76o52.880' |
| 16 | 9/20/2005 | 37°32.337' | 76o53.215' |
| 17 | 9/20/2006 | 37°32.539' | 76o53.327' |
| 18 | 9/6/2006 | 37°32.540' | 76o53.352' |
| 19 | 9/20/2006 | 37°32.442' | 76o53.255' |
| 20 | 9/20/2005 | 37°32.018' | 76o53.325' |
| 21 | 9/20/2005 | 37°31.999' | 76o53.223' |
| 22 | 9/20/2005 | 37°32.557' | 76o53.427' |
| 23 | 9/21/2005 | 37°32.630' | 76o53.222' |
| 24 | 11/2/2005 | 37°22.460' | 77o01.888' |
| 25 | 9/19/2005 | 37°34.530' | 77o01.919' |
| 26 | 9/19/2005 | 37°34.511' | 77o01.759' |
| 27 | 9/21/2005 | 37°22.460' | 77o01.888' |
| 28 | 9/13/2006 | 37°17.312' | 77o03.632' |
| 29 | 9/13/2006 | 37°17.298' | 77o03.671' |
| 30 | 11/2/2005 | 37°22.460' | 77o01.888' |
| 31 | 9/20/2005 | 37°31.995' | 76o53.448' |
| 32 | 9/20/2005 | 37°32.472' | 76o52.898' |

Appendix A. Continued.

| Site | Sampling Date | Geographic coordinates | |
|------|---------------|------------------------|------------|
| | | N | W |
| 33 | 9/20/2005 | 37°32.476' | 76°52.963' |
| 34 | 9/20/2005 | 37°32.673' | 76°53.162' |
| 35 | 9/13/2006 | 37°37.353' | 77°06.654' |
| 36 | 9/20/2005 | 37°22.460' | 77°01.888' |
| 37 | 9/20/2005 | 37°22.460' | 77°01.888' |
| 38 | 9/20/2005 | 37°22.460' | 77°01.888' |
| 39 | 9/21/2005 | 37°22.460' | 77°01.888' |
| 40 | 11/2/2005 | 37°22.460' | 77°01.888' |
| 41 | 12/19/2006 | | |
| 42 | 9/29/2006 | 37°37.770' | 76°55.463' |
| 43 | 9/22/2005 | 37°30.195' | 77°06.696' |
| 44 | 9/22/2005 | 37°30.209' | 77°06.609' |
| 45 | 9/22/2005 | 37°30.206' | 77°06.572' |
| 46 | 9/22/2005 | 37°30.219' | 77°06.506' |
| 47 | 10/20/2006 | 37°31.642' | 77°11.154' |
| 48 | 9/21/2006 | 37°37.661' | 76°56.023' |
| 49 | 9/29/2006 | 37°37.733' | 76°55.437' |
| 50 | 12/19/2006 | | |
| 51 | 8/18/2006 | 37°40.699 | 76°40.967 |
| 52 | 8/18/2006 | 37°41.694 | 76°43.281 |
| 53 | 8/18/2006 | 37°41.365 | 76°46.095 |
| 54 | 9/21/2005 | 37°22.137' | 76°58.518' |
| 55 | 9/21/2005 | 37°22.210' | 76°58.420' |
| 56 | 9/21/2005 | 37°22.084' | 76°58.523' |
| 57 | 9/13/2006 | 37°22.745' | 76°57.132' |
| 58 | 9/20/2006 | 37°22.243' | 77°02.200' |
| 59 | 9/20/2006 | 37°22.303' | 77°02.116' |
| 60 | 9/20/2006 | 37°22.412' | 77°01.894' |
| 61 | 9/20/2006 | 37°22.253' | 77°02.153' |
| 62 | 9/20/2006 | 37°22.460' | 77°01.888' |
| 63 | 9/19/2005 | 37°22.460' | 77°01.888' |

Appendix B. Sampling depth bulk density, and concentration of total soil C and N of sites referenced in Chapters 2 and 3.

| Site | Bulk density -----Mg m ⁻³ ----- | | | Soil C -----g kg ⁻¹ ----- | | | Soil N -----g kg ⁻¹ ----- | | |
|------|---|------------|-----------|---|------------|-----------|---|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 1 | 1.12 | 1.24 | 1.55 | 9.78 | 7.79 | 6.21 | 0.725 | 0.615 | 0.519 |
| 2 | 1.01 | 1.46 | 1.65 | 9.42 | 6.15 | 5.91 | 0.797 | 0.506 | 0.503 |
| 3 | 1.38 | 1.48 | 1.61 | 11.77 | 9.45 | 8.67 | 0.960 | 0.770 | 0.786 |
| 4 | 1.44 | 1.51 | 1.68 | 11.49 | 6.88 | 5.71 | 0.892 | 0.548 | 0.420 |
| 5 | 1.24 | 1.40 | 1.63 | 14.55 | 10.70 | 8.31 | 1.168 | 0.850 | 0.648 |
| 6 | 1.39 | 1.49 | 1.61 | 12.53 | 6.85 | 4.68 | 1.037 | 0.550 | 0.374 |
| 7 | 1.11 | 1.51 | 1.58 | 12.29 | 6.56 | 4.43 | 0.939 | 0.497 | 0.322 |
| 8 | 0.92 | 1.43 | 1.64 | 20.04 | 11.67 | 8.53 | 1.510 | 0.877 | 0.611 |
| 9 | 1.29 | 1.55 | 1.68 | 14.64 | 8.17 | 5.98 | 1.162 | 0.636 | 0.456 |
| 10 | 0.98 | 1.39 | 1.50 | 15.31 | 9.74 | 7.75 | 1.161 | 0.675 | 0.516 |
| 11 | 1.04 | 1.47 | 1.56 | 20.28 | 11.74 | 8.99 | 1.532 | 0.805 | 0.573 |
| 12 | 1.15 | 1.55 | 1.61 | 15.05 | 6.37 | 4.74 | 1.158 | 0.464 | 0.344 |
| 13 | 0.97 | 1.48 | 1.55 | 19.33 | 9.77 | 8.15 | 1.573 | 0.754 | 0.609 |
| 14 | 1.33 | 1.40 | 1.59 | 11.27 | 11.14 | 8.88 | 0.928 | 0.944 | 0.738 |
| 15 | 1.21 | 1.43 | 1.61 | 13.73 | 12.30 | 8.70 | 1.090 | 1.004 | 0.710 |
| 16 | 1.27 | 1.39 | 1.57 | 13.20 | 11.13 | 8.34 | 1.080 | 0.896 | 0.648 |
| 17 | 1.03 | 1.41 | 1.48 | 13.93 | 7.73 | 5.76 | 1.118 | 0.635 | 0.470 |
| 18 | 1.06 | 1.40 | 1.55 | 14.63 | 8.61 | 6.66 | 1.117 | 0.682 | 0.524 |
| 19 | 1.12 | 1.45 | 1.45 | 13.57 | 7.83 | 6.94 | 1.075 | 0.646 | 0.563 |
| 20 | 1.10 | 1.43 | 1.58 | 27.15 | 10.69 | 7.19 | 2.314 | 0.894 | 0.558 |
| 21 | 1.08 | 1.38 | 1.54 | 28.59 | 11.55 | 8.83 | 2.398 | 0.960 | 0.730 |
| 22 | 1.18 | 1.44 | 1.67 | 19.79 | 10.40 | 6.82 | 1.712 | 0.912 | 0.582 |
| 23 | 1.17 | 1.39 | 1.54 | 16.20 | 9.87 | 7.14 | 1.468 | 0.850 | 0.578 |

Appendix B. Continued.

| Site | Bulk density -----Mg m ⁻³ ----- | | | Soil C -----g kg ⁻¹ ----- | | | Soil N -----g kg ⁻¹ ----- | | |
|------|---|------------|-----------|---|------------|-----------|---|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 24 | 1.12 | 1.56 | 1.68 | 18.31 | 10.11 | 6.47 | 1.414 | 0.844 | 0.514 |
| 25 | 1.28 | 1.51 | 1.62 | 10.61 | 5.66 | 4.48 | 0.922 | 0.494 | 0.390 |
| 26 | 1.31 | 1.54 | 1.62 | 12.57 | 6.51 | 4.33 | 1.086 | 0.560 | 0.354 |
| 27 | 1.31 | 1.56 | 1.68 | 13.31 | 5.79 | 4.26 | 1.056 | 0.430 | 0.296 |
| 28 | 0.98 | 1.39 | 1.48 | 14.27 | 5.73 | 4.20 | 1.169 | 0.462 | 0.306 |
| 29 | 1.07 | 1.39 | 1.51 | 12.78 | 5.10 | 3.58 | 0.980 | 0.397 | 0.259 |
| 30 | 1.35 | 1.41 | 1.58 | 7.45 | 7.60 | 5.34 | 0.638 | 0.646 | 0.470 |
| 31 | 1.25 | 1.43 | 1.54 | 11.69 | 6.59 | 5.46 | 0.876 | 0.496 | 0.422 |
| 32 | 1.30 | 1.44 | 1.62 | 11.82 | 9.19 | 7.25 | 0.996 | 0.762 | 0.612 |
| 33 | 1.33 | 1.47 | 1.61 | 11.69 | 8.83 | 6.46 | 0.942 | 0.722 | 0.524 |
| 34 | 1.33 | 1.47 | 1.56 | 12.01 | 8.82 | 8.11 | 0.988 | 0.738 | 0.644 |
| 35 | 1.18 | 1.40 | 1.51 | 13.30 | 8.09 | 6.37 | 1.022 | 0.634 | 0.482 |
| 36 | 1.06 | 1.37 | 1.55 | 16.31 | 7.90 | 4.41 | 1.500 | 0.666 | 0.312 |
| 37 | 1.10 | 1.46 | 1.57 | 14.81 | 6.21 | 4.12 | 1.212 | 0.512 | 0.330 |
| 38 | 1.29 | 1.43 | 1.57 | 16.26 | 9.61 | 7.02 | 1.406 | 0.762 | 0.498 |
| 39 | 1.12 | 1.36 | 1.54 | 21.24 | 9.91 | 6.55 | 1.830 | 0.938 | 0.542 |
| 40 | 1.14 | 1.46 | 1.64 | 18.83 | 10.31 | 5.51 | 1.582 | 0.890 | 0.438 |
| 41 | 1.15 | 1.28 | 1.51 | 8.72 | 8.35 | 6.58 | 0.699 | 0.684 | 0.533 |
| 42 | 1.22 | 1.54 | 1.60 | 11.42 | 8.81 | 5.50 | 0.940 | 0.733 | 0.454 |
| 43 | 1.42 | 1.54 | 1.71 | 11.12 | 8.00 | 5.17 | 0.920 | 0.688 | 0.424 |
| 44 | 1.46 | 1.58 | 1.69 | 13.46 | 9.16 | 6.82 | 1.138 | 0.816 | 0.592 |
| 45 | 1.51 | 1.48 | 1.64 | 11.56 | 8.73 | 6.69 | 0.962 | 0.724 | 0.562 |
| 46 | 1.50 | 1.58 | 1.63 | 9.16 | 6.16 | 4.77 | 0.742 | 0.538 | 0.392 |

Appendix B. Continued.

| Site | Bulk density -----Mg m ⁻³ ----- | | | Soil C -----g kg ⁻¹ ----- | | | Soil N -----g kg ⁻¹ ----- | | |
|------|---|------------|-----------|---|------------|-----------|---|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 47 | 1.21 | 1.48 | 1.51 | 12.54 | 8.11 | 6.84 | 0.957 | 0.635 | 0.499 |
| 48 | 1.17 | 1.49 | 1.66 | 14.24 | 11.31 | 7.46 | 1.178 | 0.948 | 0.620 |
| 49 | 1.01 | 1.46 | 1.51 | 16.01 | 10.42 | 7.44 | 1.205 | 0.829 | 0.545 |
| 50 | 1.02 | 1.39 | 1.54 | 16.51 | 9.37 | 6.12 | 1.283 | 0.757 | 0.479 |
| 51 | 1.01 | 1.31 | 1.54 | 14.80 | 9.98 | 6.37 | 1.196 | 0.827 | 0.503 |
| 52 | 1.03 | 1.30 | 1.53 | 16.56 | 10.55 | 6.60 | 1.440 | 0.912 | 0.551 |
| 53 | 1.06 | 1.38 | 1.58 | 13.52 | 7.82 | 5.55 | 1.099 | 0.645 | 0.420 |
| 54 | 1.32 | 1.51 | 1.66 | 12.62 | 10.17 | 8.15 | 1.056 | 0.852 | 0.670 |
| 55 | 1.16 | 1.42 | 1.73 | 16.31 | 11.73 | 8.02 | 1.354 | 0.962 | 0.594 |
| 56 | 1.15 | 1.57 | 1.72 | 14.49 | 9.94 | 6.65 | 1.270 | 0.868 | 0.578 |
| 57 | 0.89 | 1.28 | 1.61 | 14.93 | 10.15 | 6.65 | 1.252 | 0.873 | 0.561 |
| 58 | 1.12 | 1.43 | 1.53 | 11.70 | 8.15 | 5.73 | 0.882 | 0.646 | 0.438 |
| 59 | 1.24 | 1.62 | 1.71 | 16.58 | 10.90 | 6.00 | 1.206 | 0.796 | 0.406 |
| 60 | 1.06 | 1.45 | 1.53 | 24.20 | 20.03 | 15.02 | 1.539 | 1.237 | 0.824 |
| 61 | 1.24 | 1.57 | 1.65 | 14.17 | 9.43 | 5.72 | 1.057 | 0.713 | 0.363 |
| 62 | 1.24 | 1.65 | 1.71 | 16.65 | 9.09 | 5.68 | 1.273 | 0.654 | 0.365 |
| 63 | 0.99 | 1.42 | 1.70 | 39.14 | 15.40 | 8.29 | 3.094 | 1.162 | 0.550 |

Appendix C. Sampling depth concentration of Illinois soil N test (ISNT) and 2 M KCl extractable soil NO₃ and NH₄ for sites referenced in Chapters 2 and 3.

| Site | ISNT-N -----mg kg ⁻¹ ----- | | | NO ₃ -N -----mg kg ⁻¹ ----- | | | NH ₄ -N -----mg kg ⁻¹ ----- | | |
|------|--|------------|-----------|--|------------|-----------|--|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 1 | 141.2 | 126.9 | 111.1 | 7.18 | 4.85 | 3.09 | 3.02 | 2.48 | 2.12 |
| 2 | 149.4 | 114.1 | 108.9 | 10.87 | 5.06 | 2.75 | 3.86 | 2.69 | 2.11 |
| 3 | 130.4 | 114.9 | 107.1 | 11.83 | 11.03 | 8.68 | 4.68 | 4.98 | 7.80 |
| 4 | 140.3 | 85.7 | 77.5 | 37.46 | 17.03 | 16.65 | 7.90 | 7.16 | 6.83 |
| 5 | 158.1 | 138.9 | 109.6 | 16.17 | 10.56 | 9.82 | 9.86 | 6.55 | 6.59 |
| 6 | 125.7 | 81.1 | 58.2 | 12.47 | 10.75 | 9.70 | 7.37 | 9.95 | 5.57 |
| 7 | 163.4 | 102.3 | 82.3 | 3.86 | 1.93 | 1.35 | 4.39 | 2.97 | 2.71 |
| 8 | 208.8 | 146.3 | 113.5 | 4.12 | 3.24 | 3.65 | 4.56 | 2.88 | 2.10 |
| 9 | 153.8 | 99.3 | 78.1 | 15.71 | 7.96 | 8.06 | 6.69 | 8.52 | 4.58 |
| 10 | 177.7 | 120.0 | 98.4 | 8.41 | 3.66 | 2.02 | 4.39 | 2.91 | 2.47 |
| 11 | 247.2 | 137.6 | 103.9 | 16.93 | 8.83 | 6.26 | 4.70 | 3.28 | 2.67 |
| 12 | 169.5 | 92.3 | 70.0 | 16.33 | 8.64 | 5.65 | 2.74 | 1.77 | 1.44 |
| 13 | 208.6 | 131.0 | 112.2 | 17.07 | 8.69 | 6.03 | 4.23 | 2.69 | 2.44 |
| 14 | 134.8 | 132.0 | 108.3 | 8.43 | 6.43 | 4.01 | 3.74 | 2.23 | 2.09 |
| 15 | 140.8 | 135.9 | 98.5 | 20.19 | 17.86 | 17.07 | 4.70 | 4.98 | 6.89 |
| 16 | 132.4 | 116.6 | 91.9 | 26.98 | 17.84 | 10.69 | 4.29 | 3.40 | 3.70 |
| 17 | 185.3 | 128.4 | 105.8 | 14.64 | 9.48 | 6.30 | 3.03 | 2.30 | 1.71 |
| 18 | 180.9 | 132.3 | 109.1 | 4.33 | 3.35 | 2.38 | 3.24 | 2.47 | 1.94 |
| 19 | 188.8 | 124.4 | 129.9 | 9.97 | 5.13 | 5.08 | 4.32 | 3.49 | 3.15 |
| 20 | 271.4 | 130.0 | 78.6 | 23.78 | 14.43 | 9.56 | 8.07 | 4.72 | 4.40 |
| 21 | 287.8 | 158.3 | 119.1 | 16.11 | 9.09 | 8.23 | 9.39 | 6.95 | 7.13 |
| 22 | 209.2 | 142.2 | 97.4 | 14.79 | 10.24 | 8.13 | 7.39 | 6.80 | 7.42 |
| 23 | 186.9 | 128.2 | 96.6 | 32.96 | 12.77 | 8.64 | 7.37 | 7.17 | 6.07 |

Appendix C. Continued.

| Site | ISNT-N -----mg kg ⁻¹ ----- | | | NO ₃ -N -----mg kg ⁻¹ ----- | | | NH ₄ -N -----mg kg ⁻¹ ----- | | |
|------|--|------------|-----------|--|------------|-----------|--|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 24 | 198.6 | 124.1 | 80.2 | 8.20 | 6.90 | 3.44 | 7.52 | 6.87 | 1.60 |
| 25 | 119.3 | 67.6 | 53.1 | 36.61 | 15.78 | 12.89 | 13.47 | 5.49 | 5.89 |
| 26 | 128.8 | 81.6 | 54.7 | 36.12 | 20.84 | 13.11 | 12.80 | 5.59 | 4.06 |
| 27 | 130.5 | 69.7 | 52.2 | 27.90 | 7.44 | 9.59 | 8.59 | 5.22 | 6.17 |
| 28 | 168.1 | 98.4 | 82.0 | 11.13 | 4.96 | 2.99 | 3.49 | 2.07 | 1.95 |
| 29 | 127.6 | 89.1 | 76.2 | 11.86 | 8.49 | 3.09 | 3.24 | 4.07 | 1.95 |
| 30 | 89.9 | 88.0 | 68.5 | 4.95 | 4.76 | 3.20 | 3.17 | 3.22 | 1.57 |
| 31 | 89.8 | 49.1 | 51.1 | 13.36 | 10.26 | 10.21 | 5.34 | 5.05 | 4.51 |
| 32 | 140.3 | 117.8 | 92.4 | 41.21 | 24.33 | 19.67 | 13.67 | 7.90 | 4.31 |
| 33 | 128.8 | 113.3 | 76.9 | 20.65 | 12.79 | 9.57 | 5.17 | 4.48 | 4.16 |
| 34 | 104.1 | 83.2 | 79.0 | 18.10 | 11.60 | 10.31 | 5.39 | 5.86 | 5.60 |
| 35 | 193.8 | 119.1 | 110.5 | 14.95 | 8.47 | 2.90 | 3.16 | 3.73 | 2.59 |
| 36 | 188.3 | 75.7 | 41.7 | 77.33 | 14.24 | 8.22 | 14.24 | 6.94 | 6.33 |
| 37 | 143.1 | 82.2 | 42.7 | 25.76 | 10.92 | 9.04 | 12.21 | 8.12 | 7.19 |
| 38 | 150.3 | 82.8 | 67.6 | 37.83 | 12.30 | 9.24 | 5.89 | 7.43 | 7.50 |
| 39 | 190.6 | 108.8 | 68.3 | 20.99 | 10.28 | 7.20 | 5.89 | 5.53 | 5.37 |
| 40 | 197.3 | 125.1 | 70.1 | 6.52 | 4.40 | 2.20 | 3.93 | 1.24 | 1.25 |
| 41 | 111.7 | 122.2 | 100.7 | 4.78 | 4.12 | 4.63 | 3.43 | 2.20 | 2.30 |
| 42 | 165.5 | 142.4 | 98.1 | 5.88 | 3.65 | 2.92 | 3.92 | 2.09 | 2.12 |
| 43 | 115.4 | 94.3 | 64.2 | 8.68 | 9.51 | 8.51 | 8.64 | 7.39 | 5.43 |
| 44 | 165.3 | 126.2 | 107.0 | 17.83 | 11.37 | 10.29 | 8.06 | 5.39 | 5.28 |
| 45 | 138.7 | 111.5 | 88.7 | 8.73 | 9.49 | 9.53 | 6.66 | 5.76 | 4.63 |
| 46 | 111.0 | 78.4 | 61.0 | 10.17 | 7.08 | 7.94 | 6.80 | 4.11 | 4.00 |

Appendix C. Continued.

| Site | ISNT-N -----mg kg ⁻¹ ----- | | | NO ₃ -N -----mg kg ⁻¹ ----- | | | NH ₄ -N -----mg kg ⁻¹ ----- | | |
|------|--|------------|-----------|--|------------|-----------|--|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 47 | 176.1 | 129.7 | 109.7 | 7.90 | 5.28 | 3.15 | 5.85 | 6.04 | 5.07 |
| 48 | 159.4 | 123.7 | 85.5 | 17.74 | 13.05 | 12.48 | 10.00 | 7.77 | 4.77 |
| 49 | 197.4 | 139.1 | 115.2 | 10.53 | 5.45 | 5.69 | 0.24 | 2.25 | 2.23 |
| 50 | 205.9 | 144.6 | 96.4 | 7.55 | 4.18 | 2.73 | 2.18 | 1.53 | 1.14 |
| 51 | 179.7 | 138.6 | 101.2 | 13.28 | 6.37 | 3.11 | 4.41 | 3.42 | 2.32 |
| 52 | 224.5 | 171.8 | 122.2 | 11.42 | 10.53 | 5.88 | 5.74 | 0.00 | 3.17 |
| 53 | 156.7 | 120.2 | 87.1 | 8.55 | 4.27 | 2.79 | 3.19 | 0.00 | 0.00 |
| 54 | 125.9 | 105.0 | 89.8 | 14.99 | 11.72 | 10.24 | 8.32 | 7.00 | 5.26 |
| 55 | 134.8 | 102.8 | 61.9 | 14.68 | 10.62 | 8.58 | 5.99 | 4.16 | 5.46 |
| 56 | 157.7 | 103.0 | 72.2 | 25.62 | 14.94 | 11.77 | 5.92 | 5.12 | 4.41 |
| 57 | 224.0 | 160.6 | 116.8 | 9.38 | 6.81 | 3.46 | 6.88 | 4.39 | 2.99 |
| 58 | 154.3 | 122.0 | 90.0 | 16.39 | 10.56 | 4.52 | 5.03 | 4.00 | 3.05 |
| 59 | 213.7 | 149.7 | 91.3 | 10.20 | 9.12 | 4.93 | 5.50 | 5.38 | 4.18 |
| 60 | 224.8 | 191.7 | 144.4 | 15.54 | 11.26 | 6.92 | 2.82 | 2.30 | 2.24 |
| 61 | 156.7 | 128.5 | 82.6 | 15.85 | 12.35 | 5.37 | 2.69 | 2.45 | 1.44 |
| 62 | 192.5 | 116.5 | 79.2 | 13.73 | 8.85 | 4.33 | 2.54 | 2.38 | 1.74 |
| 63 | 382.8 | 148.3 | 67.5 | 22.83 | 8.46 | 10.58 | 7.84 | 6.72 | 6.48 |

Appendix D. Sampling depth soil pH and concentration of Mehlich 1 extractable P, and K for sites referenced in Chapters 2 and 3.

| Site | pH | | | P | | | K | | |
|------|----------|------------|-----------|----------|------------|-----------|----------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 1 | 6.04 | 6.29 | 6.29 | 28.4 | 21.3 | 20.0 | 97.6 | 81.3 | 62.72 |
| 2 | 6.25 | 5.99 | 6.09 | 28.3 | 22.2 | 19.9 | 85.6 | 87.6 | 78.73 |
| 3 | 6.34 | 6.51 | 6.36 | 48.5 | 52.2 | 49.3 | 51.2 | 39.2 | 32.13 |
| 4 | 6.18 | 5.57 | 5.98 | 40.3 | 41.9 | 40.2 | 50.6 | 37.7 | 32.99 |
| 5 | 6.25 | 6.16 | 6.31 | 26.6 | 22.2 | 18.6 | 65.7 | 47.9 | 50.45 |
| 6 | 5.67 | 5.55 | 5.60 | 22.7 | 18.0 | 19.3 | 53.7 | 33.3 | 33.12 |
| 7 | 6.96 | 6.75 | 6.57 | 18.3 | 10.7 | 11.0 | 86.4 | 77.7 | 59.38 |
| 8 | 6.13 | 6.13 | 6.27 | 35.6 | 24.6 | 22.1 | 105.5 | 59.3 | 49.21 |
| 9 | 6.40 | 6.20 | 6.03 | 19.6 | 24.9 | 11.0 | 94.2 | 66.6 | 48.72 |
| 10 | 6.45 | 5.65 | 5.62 | 30.8 | 11.7 | 7.0 | 82.9 | 55.6 | 46.15 |
| 11 | 6.09 | 5.50 | 5.33 | 45.4 | 48.2 | 55.1 | 94.1 | 68.9 | 72.88 |
| 12 | 6.79 | 6.68 | 6.50 | 16.6 | 10.8 | 9.7 | 91.9 | 59.7 | 54.36 |
| 13 | 6.49 | 6.25 | 5.82 | 23.4 | 24.1 | 24.7 | 73.3 | 62.8 | 63.42 |
| 14 | NA | NA | NA | 100.2 | 55.3 | 47.9 | 148.9 | 108.3 | 79.20 |
| 15 | 6.41 | 6.68 | 6.48 | 113.6 | 138.0 | 100.7 | 80.3 | 41.4 | 38.76 |
| 16 | 6.54 | 6.54 | 6.57 | 37.1 | 55.6 | 37.9 | 82.2 | 49.5 | 37.74 |
| 17 | 6.78 | 6.90 | 6.75 | 76.5 | 70.3 | 53.0 | 103.5 | 77.8 | 61.9 |
| 18 | 6.70 | 6.69 | 6.57 | 44.4 | 43.9 | 41.5 | 118.4 | 69.2 | 61.3 |
| 19 | 6.56 | 6.04 | 5.39 | 78.2 | 54.5 | 40.3 | 175.2 | 119.7 | 89.0 |
| 20 | 6.74 | 6.36 | 6.11 | 149.4 | 122.4 | 89.7 | 56.6 | 45.2 | 48.2 |
| 21 | 7.02 | 6.93 | 6.51 | 149.8 | 96.0 | 69.2 | 55.8 | 53.9 | 51.3 |
| 22 | 6.48 | 6.78 | 6.57 | 154.3 | 119.6 | 89.2 | 65.6 | 45.7 | 41.8 |
| 23 | 5.98 | 6.32 | 6.56 | 180.9 | 133.2 | 115.8 | 74.3 | 42.8 | 40.2 |

Appendix D. Continued.

| Site | pH | | | P | | | K | | |
|------|----------|------------|-----------|----------|------------|-----------|----------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 24 | NA | NA | NA | 100.2 | 55.3 | 47.9 | 148.9 | 108.3 | 79.2 |
| 25 | 5.35 | 5.15 | 5.64 | 28.8 | 26.9 | 21.9 | 38.5 | 35.1 | 43.3 |
| 26 | 5.40 | 5.20 | 6.03 | 24.3 | 28.1 | 29.6 | 61.5 | 47.9 | 46.9 |
| 27 | 6.64 | 6.80 | 6.37 | 22.3 | 17.2 | 11.0 | 50.6 | 46.1 | 47.0 |
| 28 | 6.84 | 5.84 | 5.74 | 25.4 | 19.0 | 23.0 | 84.5 | 72.6 | 78.0 |
| 29 | 6.60 | 5.60 | 5.37 | 28.7 | 29.4 | 31.0 | 95.2 | 78.7 | 74.7 |
| 30 | NA | NA | NA | 142.0 | 152.6 | 120.8 | 59.3 | 47.4 | 25.7 |
| 31 | 6.85 | 6.59 | 6.58 | 50.1 | 44.7 | 42.6 | 67.9 | 51.4 | 41.8 |
| 32 | 5.91 | 6.55 | 6.60 | 151.3 | 171.0 | 145.6 | 88.1 | 51.6 | 40.8 |
| 33 | 6.33 | 6.32 | 6.44 | 153.9 | 169.5 | 149.1 | 60.0 | 38.1 | 31.7 |
| 34 | 6.23 | 6.71 | 7.38 | 84.8 | 89.2 | 93.3 | 60.5 | 38.1 | 38.4 |
| 35 | 6.14 | 5.73 | 5.40 | 84.8 | 74.9 | 87.6 | 118.6 | 98.3 | 103.6 |
| 36 | 6.17 | 7.20 | 6.94 | 119.0 | 68.1 | 56.6 | 57.3 | 25.2 | 27.2 |
| 37 | 5.46 | 5.52 | 6.25 | 25.2 | 17.0 | 13.6 | 79.2 | 44.4 | 41.9 |
| 38 | 6.65 | 6.73 | 6.57 | 164.3 | 168.9 | 142.9 | 108.9 | 70.2 | 48.5 |
| 39 | 7.37 | 7.05 | 7.09 | 218.0 | 151.1 | 116.1 | 67.3 | 32.9 | 28.3 |
| 40 | NA | NA | NA | 77.4 | 53.4 | 46.4 | 174.7 | 100.5 | 51.8 |
| 41 | 6.38 | 6.50 | 6.65 | 24.7 | 14.6 | 10.2 | 158.9 | 126.0 | 90.3 |
| 42 | 6.75 | 6.43 | 6.52 | 22.6 | 12.5 | 8.6 | 119.6 | 92.5 | 58.5 |
| 43 | 6.09 | 6.43 | 6.47 | 20.3 | 22.0 | 21.0 | 22.1 | 18.4 | 16.0 |
| 44 | 6.22 | 6.51 | 6.23 | 16.1 | 16.1 | 14.6 | 41.1 | 29.8 | 23.1 |
| 45 | 6.01 | 6.28 | 6.46 | 38.4 | 40.8 | 40.6 | 41.5 | 34.5 | 30.6 |
| 46 | 6.26 | 6.24 | 6.33 | 28.3 | 27.6 | 35.8 | 21.0 | 11.7 | 11.3 |

Appendix D. Continued.

| Site | pH | | | P | | | K | | |
|------|--------------------------------|------------|-----------|--------------------------------|------------|-----------|--------------------------------|------------|-----------|
| | -----mg kg ⁻¹ ----- | | | -----mg kg ⁻¹ ----- | | | -----mg kg ⁻¹ ----- | | |
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 47 | 6.56 | 6.02 | 5.83 | 42.5 | 37.9 | 17.8 | 86.9 | 66.2 | 55.0 |
| 48 | 6.97 | 7.22 | 7.32 | 21.9 | 4.1 | 4.2 | 64.2 | 30.9 | 27.7 |
| 49 | 6.57 | 6.05 | 6.04 | 20.9 | 15.2 | 14.4 | 100.5 | 83.6 | 66.9 |
| 50 | 6.90 | 6.73 | 6.81 | 36.1 | 19.3 | 15.1 | 161.2 | 111.5 | 71.2 |
| 51 | 6.79 | 6.73 | 6.32 | 23.4 | 21.0 | 20.5 | 106.9 | 88.5 | 75.5 |
| 52 | 5.04 | 5.05 | 5.03 | 59.1 | 32.0 | 18.6 | 65.6 | 62.7 | 59.4 |
| 53 | 5.06 | 5.02 | 5.04 | 16.2 | 14.7 | 11.7 | 97.0 | 79.0 | 71.1 |
| 54 | 6.58 | 6.78 | 6.75 | 66.5 | 58.8 | 34.6 | 32.1 | 18.7 | 14.9 |
| 55 | 6.23 | 6.99 | 6.77 | 110.8 | 90.3 | 29.2 | 34.5 | 21.1 | 23.4 |
| 56 | 5.82 | 6.63 | 6.51 | 79.9 | 67.8 | 34.9 | 46.5 | 30.5 | 27.7 |
| 57 | 6.09 | 6.06 | 6.02 | 42.3 | 37.2 | 11.6 | 72.8 | 49.4 | 49.1 |
| 58 | 6.67 | 6.10 | 5.86 | 13.5 | 11.8 | 12.8 | 52.0 | 46.4 | 45.3 |
| 59 | 6.38 | 6.03 | 6.13 | 92.5 | 69.7 | 18.1 | 67.0 | 50.2 | 52.9 |
| 60 | 6.81 | 6.24 | 6.36 | 42.4 | 29.9 | 8.8 | 91.8 | 68.9 | 50.3 |
| 61 | 6.61 | 6.04 | 6.01 | 43.3 | 33.8 | 14.3 | 41.0 | 43.1 | 34.9 |
| 62 | 6.36 | 5.94 | 5.79 | 99.2 | 55.5 | 12.6 | 63.6 | 41.4 | 37.2 |
| 63 | 6.54 | 6.37 | 6.45 | 220.4 | 154.8 | 105.9 | 68.0 | 21.1 | 16.4 |

Appendix E. Sampling depth concentration of Mehlich 1 extractable Ca, Mg and Al for sites referenced in Chapters 2 and 3.

| Site | Ca -----mg kg ⁻¹ ----- | | | Mg -----mg kg ⁻¹ ----- | | | Al -----mg kg ⁻¹ ----- | | |
|------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 1 | 576.30 | 567.98 | 466.59 | 145.74 | 145.42 | 102.46 | 337.3 | 334.5 | 350.1 |
| 2 | 641.08 | 407.10 | 415.90 | 182.63 | 96.88 | 84.49 | 322.0 | 343.6 | 301.0 |
| 3 | 562.88 | 522.23 | 399.62 | 84.12 | 76.10 | 51.93 | 213.8 | 234.7 | 238.3 |
| 4 | 455.69 | 233.14 | 289.90 | 123.15 | 57.93 | 63.55 | 140.5 | 170.4 | 155.4 |
| 5 | 484.97 | 422.55 | 458.89 | 108.61 | 90.03 | 76.69 | 180.2 | 206.8 | 200.1 |
| 6 | 331.86 | 234.00 | 191.26 | 43.71 | 29.41 | 24.66 | 112.3 | 114.2 | 124.8 |
| 7 | 1301.21 | 552.91 | 405.50 | 207.03 | 129.62 | 105.91 | 123.8 | 121.5 | 136.3 |
| 8 | 803.50 | 611.77 | 521.81 | 126.02 | 92.20 | 73.64 | 216.7 | 233.3 | 240.2 |
| 9 | 681.81 | 388.47 | 270.11 | 149.19 | 86.71 | 61.41 | 112.0 | 140.6 | 132.3 |
| 10 | 842.62 | 302.98 | 246.71 | 154.85 | 72.10 | 62.13 | 289.0 | 337.1 | 353.8 |
| 11 | 771.31 | 314.56 | 266.25 | 198.41 | 82.87 | 59.94 | 286.1 | 337.2 | 383.3 |
| 12 | 984.64 | 430.01 | 331.07 | 200.64 | 86.02 | 70.37 | 106.4 | 104.5 | 101.4 |
| 13 | 1182.02 | 498.95 | 322.42 | 239.17 | 100.48 | 72.36 | 260.9 | 322.5 | 342.8 |
| 14 | 592.91 | 520.13 | 503.82 | 51.56 | 36.87 | 46.94 | 151.7 | 160.8 | 156.8 |
| 15 | 767.48 | 825.16 | 606.07 | 123.89 | 136.66 | 90.63 | 215.6 | 249.8 | 236.6 |
| 16 | 717.69 | 649.16 | 540.07 | 131.05 | 124.34 | 75.10 | 155.3 | 198.8 | 165.5 |
| 17 | 1195.65 | 782.21 | 567.06 | 193.14 | 100.86 | 60.17 | 168.2 | 165.6 | 161.0 |
| 18 | 1070.40 | 730.80 | 576.14 | 169.94 | 93.23 | 65.82 | 134.2 | 133.6 | 146.7 |
| 19 | 862.28 | 491.32 | 414.30 | 122.30 | 62.91 | 49.30 | 230.4 | 236.2 | 243.9 |
| 20 | 2191.65 | 838.32 | 538.81 | 62.69 | 27.59 | 19.08 | 285.4 | 315.6 | 303.6 |
| 21 | 3516.08 | 1404.88 | 644.32 | 53.96 | 28.81 | 22.48 | 353.1 | 419.5 | 358.8 |
| 22 | 1321.15 | 957.33 | 592.29 | 45.11 | 34.38 | 18.84 | 297.2 | 267.9 | 204.1 |
| 23 | 1192.63 | 812.47 | 604.64 | 55.71 | 36.35 | 40.53 | 348.1 | 285.3 | 289.2 |

Appendix E. Continued.

| Site | Ca -----mg kg ⁻¹ ----- | | | Mg -----mg kg ⁻¹ ----- | | | Al -----mg kg ⁻¹ ----- | | |
|------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 24 | 592.91 | 520.13 | 503.82 | 51.56 | 36.87 | 46.94 | 151.7 | 160.8 | 156.8 |
| 25 | 291.09 | 190.71 | 155.99 | 37.82 | 22.02 | 17.51 | 135.4 | 129.4 | 124.8 |
| 26 | 299.85 | 217.95 | 190.87 | 38.29 | 27.34 | 24.25 | 112.8 | 127.5 | 116.2 |
| 27 | 720.06 | 365.32 | 255.08 | 188.77 | 89.16 | 62.00 | 134.5 | 151.4 | 160.2 |
| 28 | 1624.91 | 388.24 | 247.27 | 247.95 | 77.95 | 54.90 | 121.8 | 136.7 | 157.6 |
| 29 | 965.05 | 307.57 | 204.72 | 171.84 | 68.85 | 51.93 | 126.2 | 158.1 | 176.6 |
| 30 | 483.08 | 535.70 | 397.21 | 92.83 | 106.92 | 74.02 | 207.9 | 219.0 | 199.6 |
| 31 | 751.18 | 472.43 | 412.13 | 168.69 | 85.74 | 50.65 | 155.4 | 159.7 | 167.6 |
| 32 | 730.80 | 740.94 | 640.67 | 115.26 | 113.37 | 91.14 | 246.5 | 262.2 | 251.1 |
| 33 | 633.76 | 631.28 | 494.77 | 114.93 | 111.05 | 76.06 | 230.8 | 259.4 | 257.0 |
| 34 | 917.76 | 950.69 | 1528.04 | 39.44 | 26.89 | 23.49 | 254.6 | 270.7 | 315.7 |
| 35 | 971.54 | 473.61 | 366.59 | 133.70 | 65.12 | 50.52 | 358.6 | 367.5 | 406.8 |
| 36 | 1913.27 | 818.99 | 562.62 | 77.11 | 31.85 | 36.73 | 176.2 | 151.0 | 145.0 |
| 37 | 353.12 | 209.07 | 284.90 | 44.15 | 24.65 | 28.48 | 105.2 | 101.5 | 93.0 |
| 38 | 1436.86 | 1104.94 | 788.08 | 67.53 | 57.06 | 57.93 | 321.1 | 373.8 | 384.2 |
| 39 | 2371.34 | 1233.74 | 760.15 | 58.88 | 32.78 | 35.57 | 370.4 | 304.4 | 245.8 |
| 40 | 858.60 | 575.35 | 483.61 | 75.48 | 44.70 | 45.73 | 156.0 | 152.5 | 150.9 |
| 41 | 464.90 | 481.89 | 454.80 | 82.20 | 82.51 | 83.86 | 123.6 | 121.3 | 126.6 |
| 42 | 382.10 | 399.88 | 352.42 | 70.74 | 76.86 | 76.50 | 173.5 | 159.8 | 160.4 |
| 43 | 343.54 | 313.86 | 251.81 | 53.07 | 53.64 | 39.57 | 97.5 | 109.8 | 105.9 |
| 44 | 424.10 | 414.27 | 318.50 | 72.10 | 69.31 | 54.78 | 111.3 | 119.2 | 115.9 |
| 45 | 437.68 | 419.07 | 394.44 | 64.00 | 62.25 | 57.95 | 123.8 | 131.8 | 140.2 |
| 46 | 307.08 | 206.49 | 260.75 | 55.69 | 37.45 | 35.40 | 75.3 | 81.3 | 91.3 |

Appendix E. Continued.

| Site | Ca -----mg kg ⁻¹ ----- | | | Mg -----mg kg ⁻¹ ----- | | | Al -----mg kg ⁻¹ ----- | | |
|------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 47 | 825.64 | 360.21 | 247.00 | 145.61 | 59.90 | 37.82 | 218.0 | 250.9 | 272.1 |
| 48 | 3999.26 | 4599.03 | 4522.65 | 269.84 | 233.96 | 245.85 | 112.2 | 44.6 | 61.8 |
| 49 | 997.35 | 540.42 | 413.05 | 172.82 | 88.38 | 69.96 | 196.8 | 226.2 | 229.5 |
| 50 | 974.09 | 633.67 | 465.04 | 165.44 | 106.26 | 89.32 | 158.8 | 174.2 | 165.9 |
| 51 | 1051.89 | 708.92 | 453.96 | 186.87 | 106.53 | 65.52 | 156.7 | 162.1 | 161.1 |
| 52 | 1737.34 | 1020.43 | 656.61 | 58.92 | 36.57 | 33.69 | 188.7 | 172.6 | 172.0 |
| 53 | 845.31 | 530.25 | 368.87 | 140.05 | 73.15 | 48.47 | 107.6 | 118.9 | 132.6 |
| 54 | 819.47 | 886.76 | 680.22 | 27.48 | 18.67 | 11.48 | 191.8 | 198.8 | 161.1 |
| 55 | 1350.28 | 1390.80 | 811.11 | 40.61 | 24.64 | 17.74 | 297.7 | 279.1 | 202.8 |
| 56 | 721.45 | 737.84 | 515.08 | 28.02 | 22.33 | 20.14 | 180.3 | 172.1 | 129.2 |
| 57 | 1309.71 | 1224.64 | 532.56 | 62.20 | 40.31 | 32.43 | 214.1 | 215.0 | 176.6 |
| 58 | 872.20 | 428.64 | 229.51 | 145.80 | 80.16 | 42.86 | 125.1 | 136.9 | 150.7 |
| 59 | 1089.06 | 465.03 | 323.59 | 158.27 | 71.09 | 58.52 | 216.4 | 200.0 | 154.2 |
| 60 | 1607.04 | 843.90 | 762.40 | 225.87 | 110.36 | 95.85 | 250.2 | 265.9 | 231.6 |
| 61 | 957.86 | 430.51 | 238.28 | 142.34 | 72.41 | 40.68 | 148.5 | 146.0 | 136.8 |
| 62 | 947.29 | 353.72 | 224.24 | 142.64 | 58.52 | 40.21 | 241.6 | 222.8 | 171.5 |
| 63 | 2086.30 | 965.26 | 667.32 | 273.24 | 113.99 | 63.79 | 361.3 | 346.0 | 290.1 |

Appendix F. Sampling depth concentration of Mehlich 1 extractable Zn, Mn and Cu for sites referenced in Chapters 2 and 3.

| Site | Zn -----mg kg ⁻¹ ----- | | | Mn -----mg kg ⁻¹ ----- | | | Cu -----mg kg ⁻¹ ----- | | |
|------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 1 | 2.10 | 1.78 | 1.41 | 63.85 | 54.32 | 43.51 | 4.33 | 6.53 | 32.31 |
| 2 | 2.27 | 1.47 | 1.37 | 63.17 | 55.32 | 43.39 | 13.72 | 21.76 | 48.29 |
| 3 | 3.32 | 3.64 | 3.44 | 11.28 | 11.00 | 10.93 | 3.72 | 6.45 | 6.09 |
| 4 | 1.54 | 0.98 | 0.93 | 21.29 | 22.21 | 15.67 | 5.51 | 16.93 | 12.11 |
| 5 | 1.43 | 1.01 | 0.83 | 22.07 | 20.39 | 15.69 | 3.13 | 4.03 | 4.34 |
| 6 | 2.62 | 1.32 | 1.94 | 20.27 | 12.80 | 10.54 | 1.51 | 2.10 | 2.10 |
| 7 | 2.17 | 1.77 | 2.09 | 26.17 | 18.71 | 14.42 | 7.71 | 10.10 | 9.60 |
| 8 | 1.95 | 1.16 | 0.77 | 19.79 | 14.03 | 9.01 | 16.82 | 20.31 | 16.30 |
| 9 | 8.29 | 3.52 | 1.39 | 14.31 | 11.27 | 7.00 | 2.17 | 3.27 | 2.88 |
| 10 | 2.50 | 1.51 | 1.21 | 28.00 | 20.26 | 20.97 | 26.61 | 39.80 | 32.24 |
| 11 | 7.57 | 2.90 | 2.46 | 32.12 | 21.13 | 17.91 | 83.56 | 152.68 | 141.27 |
| 12 | 2.55 | 1.43 | 0.74 | 27.09 | 17.48 | 13.41 | 67.41 | 71.79 | 51.43 |
| 13 | 3.80 | 1.93 | 1.64 | 44.57 | 28.67 | 30.11 | 35.42 | 102.51 | 88.91 |
| 14 | 10.09 | 2.99 | 1.20 | 21.71 | 16.55 | 10.62 | 6.68 | 12.91 | 11.27 |
| 15 | 3.78 | 3.88 | 2.53 | 17.81 | 15.41 | 13.05 | 2.92 | 4.30 | 6.43 |
| 16 | 2.08 | 1.82 | 1.32 | 23.24 | 20.92 | 17.60 | 2.16 | 2.88 | 5.27 |
| 17 | 4.23 | 3.83 | 1.96 | 23.67 | 15.26 | 12.50 | 62.04 | 65.37 | 88.27 |
| 18 | 3.18 | 2.54 | 1.82 | 23.77 | 15.63 | 12.59 | 5.39 | 5.98 | 19.83 |
| 19 | 4.45 | 1.79 | 2.00 | 41.26 | 34.23 | 24.14 | 112.11 | 96.77 | 78.39 |
| 20 | 13.36 | 5.77 | 3.73 | 24.00 | 15.12 | 13.73 | 2.93 | 4.22 | 5.81 |
| 21 | 10.44 | 4.61 | 3.53 | 15.21 | 18.27 | 12.16 | 1.51 | 4.12 | 6.28 |
| 22 | 8.75 | 5.22 | 3.01 | 22.06 | 20.23 | 14.94 | 2.09 | 3.38 | 4.75 |
| 23 | 10.54 | 6.07 | 4.49 | 31.55 | 20.04 | 18.30 | 2.56 | 2.86 | 3.55 |

Appendix F. Continued.

| Site | Zn -----mg kg ⁻¹ ----- | | | Mn -----mg kg ⁻¹ ----- | | | Cu -----mg kg ⁻¹ ----- | | |
|------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 24 | 10.09 | 2.99 | 1.20 | 21.71 | 16.55 | 10.62 | 6.68 | 12.91 | 11.27 |
| 25 | 2.68 | 1.73 | 1.70 | 28.36 | 21.12 | 16.55 | 1.42 | 2.50 | 3.11 |
| 26 | 2.34 | 1.54 | 1.39 | 28.43 | 18.44 | 10.35 | 1.31 | 2.55 | 2.94 |
| 27 | 6.09 | 0.78 | 0.54 | 15.97 | 9.53 | 7.23 | 2.94 | 3.19 | 4.45 |
| 28 | 11.15 | 3.29 | 2.61 | 49.01 | 37.70 | 33.29 | 4.21 | 8.33 | 18.13 |
| 29 | 7.27 | 2.62 | 2.88 | 41.90 | 32.64 | 31.11 | 20.92 | 33.58 | 27.12 |
| 30 | 5.15 | 5.12 | 3.37 | 10.47 | 9.84 | 8.35 | 3.93 | 3.85 | 12.40 |
| 31 | 3.12 | 2.37 | 2.69 | 15.79 | 11.51 | 10.46 | 1.56 | 2.90 | 3.14 |
| 32 | 4.75 | 4.41 | 3.16 | 24.89 | 20.51 | 17.69 | 2.99 | 5.21 | 5.31 |
| 33 | 5.37 | 4.91 | 4.05 | 20.16 | 20.27 | 17.50 | 4.35 | 6.79 | 6.07 |
| 34 | 5.02 | 3.24 | 3.73 | 25.39 | 18.94 | 17.43 | 1.92 | 2.52 | 2.80 |
| 35 | 3.87 | 2.10 | 2.35 | 22.24 | 12.41 | 12.51 | 67.55 | 75.23 | 73.66 |
| 36 | 8.37 | 2.97 | 1.42 | 31.02 | 17.15 | 12.89 | 1.55 | 2.64 | 2.53 |
| 37 | 3.52 | 1.24 | 0.81 | 32.94 | 24.08 | 16.65 | 2.05 | 3.60 | 3.50 |
| 38 | 7.42 | 4.53 | 3.49 | 40.30 | 30.87 | 26.77 | 1.39 | 2.96 | 4.22 |
| 39 | 12.88 | 6.50 | 3.95 | 16.10 | 16.56 | 14.20 | 2.15 | 10.58 | 20.85 |
| 40 | 6.10 | 2.98 | 1.35 | 20.55 | 13.90 | 11.29 | 9.80 | 10.06 | 13.09 |
| 41 | 2.13 | 1.36 | 0.81 | 9.05 | 8.30 | 6.89 | 5.76 | 3.03 | 29.56 |
| 42 | 1.24 | 1.32 | 0.82 | 11.36 | 10.20 | 8.77 | 43.66 | 43.25 | 27.29 |
| 43 | 1.50 | 1.15 | 1.03 | 17.41 | 14.82 | 9.61 | 1.42 | 2.31 | 2.69 |
| 44 | 1.72 | 1.38 | 1.09 | 15.12 | 12.73 | 9.05 | 3.52 | 4.14 | 2.58 |
| 45 | 1.75 | 1.48 | 1.28 | 16.38 | 13.27 | 11.58 | 1.66 | 2.91 | 2.33 |
| 46 | 1.80 | 1.32 | 1.21 | 7.94 | 5.67 | 4.01 | 1.30 | 2.00 | 1.74 |

Appendix F. Continued.

| Site | Zn -----mg kg ⁻¹ ----- | | | Mn -----mg kg ⁻¹ ----- | | | Cu -----mg kg ⁻¹ ----- | | |
|------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|--------------------------------------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 47 | 3.19 | 4.62 | 2.53 | 27.33 | 16.51 | 14.26 | 17.22 | 31.86 | 36.09 |
| 48 | 1.46 | 0.62 | 0.52 | 14.70 | 9.41 | 5.48 | 6.16 | 1.03 | 0.60 |
| 49 | 1.44 | 0.91 | 0.66 | 20.62 | 15.35 | 11.33 | 12.52 | 45.54 | 35.79 |
| 50 | 3.10 | 1.81 | 0.73 | 17.55 | 11.88 | 7.63 | 5.57 | 19.90 | 45.99 |
| 51 | 4.40 | 3.77 | 2.57 | 32.11 | 24.73 | 18.02 | 3.66 | 9.15 | 27.00 |
| 52 | 5.41 | 2.73 | 1.51 | 36.32 | 27.39 | 20.46 | 4.77 | 5.72 | 10.79 |
| 53 | 6.04 | 4.30 | 3.23 | 25.26 | 19.24 | 17.55 | 4.11 | 5.79 | 13.44 |
| 54 | 3.76 | 2.94 | 1.91 | 15.51 | 12.97 | 12.92 | 3.69 | 4.54 | 6.36 |
| 55 | 5.82 | 4.34 | 1.43 | 21.74 | 18.47 | 15.43 | 4.50 | 5.51 | 6.70 |
| 56 | 5.19 | 3.62 | 2.24 | 13.75 | 10.91 | 9.59 | 5.98 | 13.18 | 21.58 |
| 57 | 6.39 | 5.32 | 2.07 | 34.14 | 30.61 | 25.11 | 15.04 | 20.84 | 46.73 |
| 58 | 3.38 | 2.36 | 2.13 | 10.00 | 7.63 | 6.25 | 17.13 | 29.50 | 60.27 |
| 59 | 13.01 | 8.41 | 2.53 | 12.01 | 10.65 | 7.13 | 41.41 | 61.18 | 75.46 |
| 60 | 7.67 | 6.84 | 3.01 | 10.27 | 11.24 | 9.61 | 21.40 | 73.49 | 82.15 |
| 61 | 6.79 | 4.96 | 1.84 | 8.73 | 6.42 | 4.77 | 21.10 | 27.37 | 33.20 |
| 62 | 13.34 | 6.07 | 2.02 | 7.16 | 6.47 | 4.33 | 26.69 | 66.87 | 53.34 |
| 63 | 47.21 | 15.62 | 8.11 | 20.28 | 13.98 | 11.11 | 8.42 | 22.32 | 33.53 |

Appendix G. Sampling depth concentration of Mehlich 1 extractable Fe and B for sites referenced in Chapters 2 and 3.

| Site | Fe -----mg kg ⁻¹ ----- | | | B -----mg kg ⁻¹ ----- | | |
|------|--------------------------------------|------------|-----------|-------------------------------------|------------|-----------|
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 1 | 13.13 | 13.47 | 11.76 | 0.217 | 0.201 | 0.164 |
| 2 | 23.70 | 22.78 | 14.40 | 0.241 | 0.150 | 0.152 |
| 3 | 32.73 | 37.06 | 37.53 | 0.180 | 0.097 | 0.069 |
| 4 | 10.36 | 14.59 | 11.22 | 0.120 | 0.023 | 0.023 |
| 5 | 14.02 | 15.60 | 12.00 | 0.161 | 0.078 | 0.078 |
| 6 | 13.69 | 12.42 | 12.51 | 0.101 | 0.032 | 0.028 |
| 7 | 7.35 | 11.01 | 11.87 | 0.369 | 0.201 | 0.129 |
| 8 | 11.45 | 13.46 | 12.85 | 0.310 | 0.212 | 0.147 |
| 9 | 7.40 | 10.94 | 11.60 | 1.442 | 0.253 | 0.129 |
| 10 | 8.42 | 13.21 | 13.38 | 0.255 | 0.128 | 0.097 |
| 11 | 17.12 | 29.63 | 36.39 | 0.370 | 0.181 | 0.127 |
| 12 | 8.29 | 13.57 | 10.87 | 0.387 | 0.139 | 0.100 |
| 13 | 17.75 | 30.43 | 24.70 | 0.393 | 0.162 | 0.113 |
| 14 | 42.06 | 42.93 | 20.16 | 0.251 | 0.179 | 0.143 |
| 15 | 42.20 | 47.04 | 31.58 | 0.221 | 0.152 | 0.097 |
| 16 | 27.54 | 27.97 | 28.30 | 0.226 | 0.134 | 0.092 |
| 17 | 10.16 | 14.08 | 14.61 | 0.323 | 0.202 | 0.114 |
| 18 | 6.67 | 9.02 | 14.52 | 0.336 | 0.201 | 0.127 |
| 19 | 24.40 | 30.14 | 24.08 | 0.229 | 0.128 | 0.093 |
| 20 | 35.23 | 39.36 | 29.61 | 2.363 | 0.276 | 0.106 |
| 21 | 13.83 | 36.06 | 36.51 | 0.751 | 0.216 | 0.111 |
| 22 | 40.02 | 45.74 | 33.96 | 1.027 | 0.322 | 0.157 |
| 23 | 45.21 | 39.52 | 34.31 | 0.345 | 0.193 | 0.134 |
| 24 | 42.06 | 42.93 | 20.16 | 0.251 | 0.179 | 0.143 |
| 25 | 15.92 | 16.22 | 15.44 | 0.060 | 0.014 | 0.014 |
| 26 | 16.38 | 16.08 | 13.24 | 0.069 | 0.028 | 0.014 |
| 27 | 8.02 | 8.45 | 9.37 | 0.495 | 0.141 | 0.039 |
| 28 | 5.66 | 11.16 | 12.53 | 0.666 | 0.260 | 0.152 |
| 29 | 7.81 | 12.59 | 12.59 | 0.429 | 0.179 | 0.113 |
| 30 | 61.84 | 65.32 | 46.48 | 0.108 | 0.108 | 0.072 |
| 31 | 13.84 | 16.99 | 16.89 | 0.470 | 0.189 | 0.152 |
| 32 | 62.79 | 75.58 | 46.25 | 0.170 | 0.101 | 0.078 |
| 33 | 73.71 | 84.59 | 62.90 | 0.147 | 0.106 | 0.060 |
| 34 | 32.58 | 33.62 | 39.10 | 0.239 | 0.207 | 0.180 |

Appendix G. Continued.

| Site | Fe | | | B | | |
|------|--------------------------------|------------|-----------|--------------------------------|------------|-----------|
| | -----mg kg ⁻¹ ----- | | | -----mg kg ⁻¹ ----- | | |
| | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm | 0-2.5 cm | 2.5-7.5 cm | 7.5-15 cm |
| 35 | 14.97 | 17.31 | 18.64 | 0.180 | 0.105 | 0.084 |
| 36 | 38.55 | 32.00 | 18.40 | 0.424 | 0.147 | 0.092 |
| 37 | 27.04 | 15.72 | 9.88 | 0.345 | 0.152 | 0.111 |
| 38 | 31.71 | 29.19 | 24.96 | 0.398 | 0.272 | 0.141 |
| 39 | 30.18 | 43.44 | 34.05 | 0.695 | 0.272 | 0.175 |
| 40 | 34.99 | 26.37 | 14.17 | 0.359 | 0.251 | 0.179 |
| 41 | 10.79 | 9.20 | 11.09 | 0.160 | 0.146 | 0.114 |
| 42 | 13.25 | 15.57 | 10.74 | 0.152 | 0.131 | 0.105 |
| 43 | 10.07 | 11.61 | 9.01 | 0.129 | 0.078 | 0.037 |
| 44 | 11.17 | 11.58 | 8.33 | 0.184 | 0.124 | 0.078 |
| 45 | 8.99 | 9.17 | 9.16 | 0.161 | 0.120 | 0.097 |
| 46 | 8.26 | 9.90 | 9.57 | 0.106 | 0.037 | 0.037 |
| 47 | 7.13 | 10.69 | 11.89 | 0.271 | 0.131 | 0.086 |
| 48 | 4.38 | 0.85 | 0.87 | 0.290 | 0.111 | 0.078 |
| 49 | 7.64 | 13.49 | 12.40 | 0.310 | 0.159 | 0.112 |
| 50 | 7.96 | 11.48 | 8.71 | 0.354 | 0.212 | 0.133 |
| 51 | 5.20 | 6.95 | 7.00 | 0.441 | 0.255 | 0.148 |
| 52 | 28.26 | 16.83 | 8.92 | 0.426 | 0.247 | 0.139 |
| 53 | 4.66 | 6.72 | 7.68 | 0.370 | 0.197 | 0.124 |
| 54 | 43.01 | 47.36 | 33.26 | 0.253 | 0.203 | 0.124 |
| 55 | 47.39 | 51.65 | 30.18 | 0.382 | 0.276 | 0.239 |
| 56 | 55.12 | 59.21 | 41.15 | 0.216 | 0.175 | 0.129 |
| 57 | 49.29 | 57.21 | 18.99 | 0.236 | 0.168 | 0.135 |
| 58 | 6.20 | 11.07 | 15.35 | 0.304 | 0.174 | 0.098 |
| 59 | 75.96 | 80.07 | 33.89 | 0.327 | 0.166 | 0.131 |
| 60 | 31.32 | 47.47 | 26.48 | 0.497 | 0.325 | 0.269 |
| 61 | 28.63 | 27.48 | 12.61 | 0.319 | 0.193 | 0.105 |
| 62 | 75.43 | 60.31 | 19.42 | 0.270 | 0.122 | 0.080 |
| 63 | 46.20 | 55.49 | 44.77 | 0.563 | 0.151 | 0.049 |

Appendix H. Geographic coordinates and producer applied fertilizer of 29 corn response to fertilizer N-trials conducted in 2006 and 2007 referenced in Chapter 4.

| Site | Geographic coordinates N W | | Fertilizer Applied | | | | | |
|--------------------------------|-------------------------------|------------|--------------------|----|-----|---------|----|---|
| | | | Broadcast† | | | In-Row‡ | | |
| | | | N | P | K | N | P | K |
| -----kg ha ⁻¹ ----- | | | | | | | | |
| 1 | 37°32.849' | 76°55.726' | 67 | 20 | 56 | 0 | 0 | 0 |
| 2 | 37°46.365' | 76°46.095' | 0 | 0 | 84 | 36 | 16 | 0 |
| 3 | 38°07.506' | 77°04.215' | 22 | 0 | 0 | 34 | | |
| 4 | 37°40.699' | 76°40.967' | 0 | 0 | 84 | 36 | 16 | 0 |
| 5 | 37°32.540' | 76°53.352' | 0 | 0 | 56 | 45 | 15 | 0 |
| 6 | 37°32.821' | 76°56.129' | 67 | 20 | 56 | 0 | 0 | 0 |
| 7 | 37°30.638' | 76°49.470' | 67 | 20 | 56 | 0 | 0 | 0 |
| 8 | 37°41.694' | 76°43.281' | 0 | 0 | 84 | 36 | 16 | 0 |
| 9 | 38°00.112' | 77°01.864' | 0 | 0 | 0 | 45 | | |
| 10 | 37°53.223' | 76°51.242' | 0 | 0 | 0 | 56 | 0 | 0 |
| 11 | 37°37.668' | 76°33.961' | 0 | 0 | 93 | 69 | 20 | 0 |
| 12 | 37°32.411' | 76°52.722' | 28 | 15 | 50 | 45 | 0 | 0 |
| 13 | 37°45.064' | 76°44.837' | 0 | 98 | 0 | 56 | 0 | 0 |
| 14 | 37°24.689' | 77°21.131' | 15 | 20 | 84 | 56 | 0 | 0 |
| 15 | 37°39.140' | 76°35.966' | 0 | 0 | 93 | 56 | 39 | 0 |
| 16 | 37°20.006' | 77°07.567' | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 37°32.768' | 76°55.573' | 28 | 15 | 50 | 33.6 | 0 | 0 |
| 18 | 38°04.066' | 76°59.763' | 0 | 0 | 38 | 38 | 17 | 0 |
| 19 | 38°00.414' | 77°04.186' | 0 | 0 | 50 | 38 | 17 | 0 |
| 20 | 37°23.879' | 77°20.585' | 0 | 0 | 0 | 56 | 0 | 0 |
| 21 | 37°32.360' | 76°53.790' | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 38°04.045' | 77°00.367' | 0 | 0 | 38 | 38 | 17 | 0 |
| 23 | 37°13.094' | 80°27.788' | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 37°12.279' | 80°33.653' | 0 | 0 | 0 | 40 | 0 | 0 |
| 25 | 38°28.087' | 78°59.051' | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 38°52.080' | 78°32.593' | 0 | 0 | 0 | 77 | 0 | 0 |
| 27 | 38°37.341' | 78°33.583' | 0 | 0 | 0 | 30 | 0 | 0 |
| 28 | 38°40.266' | 78°39.427' | 0 | 0 | 0 | 37 | 0 | 0 |
| 29 | 38°22.366' | 78°53.127' | 0 | 0 | 125 | 61.6 | 0 | 0 |

† Applied pre-plant

‡ Applied with the planter 5 cm to the side and 5 cm below the seed.

Appendix I. Soil characteristics of 29 corn response to fertilizer N-trials conducted in 2006 and 2007 referenced in Chapter 4.

| Site | pH | Mehlich 1 extractable | | | | | | | | |
|--------------------------------|-----|-----------------------|-----|------|-----|------|------|------|------|------|
| | | P | K | Ca | Mg | Zn | Mn | Cu | Fe | B |
| -----mg kg ⁻¹ ----- | | | | | | | | | | |
| 1 | 6.1 | 28 | 97 | 932 | 76 | 3.6 | 17.5 | 1.13 | 30.4 | 0.21 |
| 2 | 6.6 | 38 | 109 | 609 | 85 | 3.4 | 16.2 | 0.88 | 14.5 | 0.21 |
| 3 | 7.7 | 42 | 111 | 1130 | 41 | 4.1 | 21.6 | 1.05 | 34.7 | 0.25 |
| 4 | 6.4 | 24 | 97 | 536 | 79 | 2.5 | 14.3 | 0.92 | 10.7 | 0.20 |
| 5 | 6.3 | 31 | 87 | 532 | 67 | 2.0 | 11.7 | 0.54 | 11.8 | 0.16 |
| 6 | 5.3 | 16 | 80 | 333 | 93 | 1.9 | 11.3 | 0.21 | 19.5 | 0.16 |
| 7 | 6.2 | 99 | 96 | 560 | 80 | 1.3 | 8.4 | 0.24 | 18.3 | 0.18 |
| 8 | 6.8 | 23 | 88 | 701 | 59 | 1.6 | 13.8 | 0.25 | 13.7 | 0.18 |
| 9 | 6.4 | 18 | 118 | 690 | 106 | 2.5 | 36.9 | 0.68 | 13.3 | 0.46 |
| 10 | 6.3 | 17 | 80 | 622 | 121 | 2.8 | 15.3 | 0.91 | 10.3 | 0.32 |
| 11 | 6.0 | 13 | 100 | 456 | 66 | 1.2 | 11.1 | 1.14 | 16.9 | 0.16 |
| 12 | 6.2 | 85 | 94 | 599 | 99 | 2.1 | 4.6 | 0.45 | 22.7 | 0.15 |
| 13 | 5.9 | 6 | 102 | 570 | 46 | 1.8 | 16.9 | 0.39 | 31.6 | 0.21 |
| 14 | 6.6 | 12 | 88 | 648 | 130 | 2.7 | 13.4 | 0.53 | 5.4 | 0.32 |
| 15 | 6.3 | 25 | 107 | 587 | 98 | 1.6 | 15.1 | 0.23 | 15.7 | 0.21 |
| 16 | 6.3 | 21 | 174 | 864 | 148 | 1.6 | 28.0 | 0.17 | 7.0 | 0.34 |
| 17 | 6.1 | 42 | 81 | 389 | 83 | 1.1 | 4.5 | 0.15 | 6.4 | 0.10 |
| 18 | 6.6 | 31 | 95 | 651 | 89 | 1.7 | 4.1 | 0.35 | 10.2 | 0.15 |
| 19 | 6.8 | 133 | 80 | 1045 | 62 | 7.8 | 5.5 | 0.65 | 29.1 | 0.15 |
| 20 | 6.1 | 11 | 99 | 608 | 97 | 0.9 | 12.9 | 0.05 | 3.3 | 0.25 |
| 21 | 5.6 | 39 | 76 | 664 | 136 | 2.1 | 4.5 | 1.00 | 12.0 | 0.15 |
| 22 | 6.0 | 151 | 104 | 913 | 116 | 11.8 | 3.8 | 0.55 | 18.3 | 0.15 |
| 23 | 7.0 | 72 | 134 | 981 | 193 | 1.8 | 13.4 | 0.20 | 4.1 | 0.30 |
| 24 | 6.2 | 24 | 108 | 657 | 112 | 0.6 | 14.9 | 0.05 | 4.3 | 0.20 |
| 25 | 7.6 | 220 | 223 | 3274 | 170 | 11.0 | 20.2 | 0.80 | 5.6 | 1.30 |
| 26 | 5.9 | 61 | 136 | 859 | 130 | 1.9 | 6.0 | 1.95 | 3.1 | 0.20 |
| 27 | 6.8 | 199 | 184 | 1215 | 84 | 4.2 | 10.2 | 0.80 | 6.2 | 0.20 |
| 28 | 7.1 | 26 | 89 | 1302 | 156 | 1.5 | 10.9 | 0.35 | 4.0 | 0.45 |
| 29 | 6.8 | 51 | 74 | 1777 | 139 | 4.0 | 9.0 | 0.20 | 5.1 | 0.35 |

Appendix J. Treatment and plot grain yield of 29 corn response to fertilizer N-trials conducted in 2006 and 2007 referenced in Chapter 4.

| Site | Block | Applied | Yield kg ha ⁻¹ |
|------|-------|---------|------------------------------|
| | | N † | |
| 1 | 1 | 67 | 3637 |
| | 2 | 67 | 5246 |
| | 3 | 67 | 6046 |
| | 4 | 67 | 6378 |
| | 1 | 97 | 5823 |
| | 2 | 97 | 6299 |
| | 3 | 97 | 6464 |
| | 4 | 97 | 8930 |
| | 1 | 127 | 8002 |
| | 2 | 127 | 7085 |
| | 3 | 127 | 9101 |
| | 4 | 127 | 10725 |
| | 1 | 157 | 9697 |
| | 2 | 157 | 8450 |
| | 3 | 157 | 8617 |
| | 4 | 157 | 10264 |
| | 1 | 187 | 8137 |
| | 2 | 187 | 9094 |
| | 3 | 187 | 10309 |
| | 4 | 187 | 10131 |
| | 1 | 217 | 10022 |
| | 2 | 217 | 11976 |
| | 3 | 217 | 10586 |
| | 4 | 217 | 10795 |
| | 1 | 247 | 9557 |
| | 2 | 247 | 9683 |
| | 3 | 247 | 11198 |
| | 4 | 247 | 10742 |
| 1 | 277 | 11113 | |
| 2 | 277 | 9870 | |
| 3 | 277 | 9443 | |
| 4 | 277 | 12287 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 2 | 1 | 36 | 5238 |
| | 2 | 36 | 5705 |
| | 3 | 36 | 5050 |
| | 4 | 36 | 5878 |
| | 1 | 66 | 6376 |
| | 2 | 66 | 7060 |
| | 3 | 66 | 5771 |
| | 4 | 66 | 5914 |
| | 1 | 96 | 7281 |
| | 2 | 96 | 7257 |
| | 3 | 96 | 7322 |
| | 4 | 96 | 7044 |
| | 1 | 126 | 8834 |
| | 2 | 126 | 9960 |
| | 3 | 126 | 7924 |
| | 4 | 126 | 7926 |
| | 1 | 156 | 8932 |
| | 2 | 156 | 9227 |
| | 3 | 156 | 9463 |
| | 4 | 156 | 9197 |
| | 1 | 186 | 9853 |
| | 2 | 186 | 9153 |
| | 3 | 186 | 9846 |
| | 4 | 186 | 9651 |
| | 1 | 216 | 9315 |
| | 2 | 216 | 9002 |
| | 3 | 216 | 9170 |
| | 4 | 216 | 10654 |
| | 1 | 246 | 9250 |
| | 2 | 246 | 10148 |
| | 3 | 246 | 10388 |
| | 4 | 246 | 10014 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 3 | 1 | 45 | 10826 |
| | 2 | 45 | 10153 |
| | 3 | 45 | 9904 |
| | 4 | 45 | 11142 |
| | 1 | 75 | 10328 |
| | 2 | 75 | 11086 |
| | 3 | 75 | 9702 |
| | 4 | 75 | 13072 |
| | 1 | 105 | 11958 |
| | 2 | 105 | 10865 |
| | 3 | 105 | 12413 |
| | 4 | 105 | 11801 |
| | 1 | 135 | 10302 |
| | 2 | 135 | 12723 |
| | 3 | 135 | 11135 |
| | 4 | 135 | 12454 |
| | 1 | 165 | 11293 |
| | 2 | 165 | 13196 |
| | 3 | 165 | 12113 |
| | 4 | 165 | 11322 |
| | 1 | 195 | 11588 |
| | 2 | 195 | 12601 |
| | 3 | 195 | 12430 |
| | 4 | 195 | 14330 |
| | 1 | 225 | 12974 |
| | 2 | 225 | 12242 |
| | 3 | 225 | 13504 |
| | 4 | 225 | 11498 |
| | 1 | 255 | 13383 |
| | 2 | 255 | 10247 |
| | 3 | 255 | 12969 |
| | 4 | 255 | 12776 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 4 | 1 | 36 | 3905 |
| | 2 | 36 | 4389 |
| | 3 | 36 | 5196 |
| | 4 | 36 | 4775 |
| | 1 | 66 | 4514 |
| | 2 | 66 | 4760 |
| | 3 | 66 | 5908 |
| | 4 | 66 | 5325 |
| | 1 | 96 | 5770 |
| | 2 | 96 | 6831 |
| | 3 | 96 | 7416 |
| | 4 | 96 | 5214 |
| | 1 | 126 | 8056 |
| | 2 | 126 | 7673 |
| | 3 | 126 | 5818 |
| | 4 | 126 | 6718 |
| | 1 | 156 | 7479 |
| | 2 | 156 | 5499 |
| | 3 | 156 | 9117 |
| | 4 | 156 | 7564 |
| | 1 | 186 | 7686 |
| | 2 | 186 | 8187 |
| | 3 | 186 | 6553 |
| | 4 | 186 | 8369 |
| | 1 | 216 | 8236 |
| | 2 | 216 | 8570 |
| | 3 | 216 | 7843 |
| | 4 | 216 | 8706 |
| | 1 | 246 | 7085 |
| | 2 | 246 | 5551 |
| | 3 | 246 | 10603 |
| | 4 | 246 | 5499 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield |
|------|-------|----------------------------|-------|
| | | N † kg ha ⁻¹ | |
| 5 | 1 | 45 | 8901 |
| | 2 | 45 | 6609 |
| | 3 | 45 | 7443 |
| | 4 | 45 | 7220 |
| | 1 | 75 | 7954 |
| | 2 | 75 | 8889 |
| | 3 | 75 | 12896 |
| | 4 | 75 | 8710 |
| | 1 | 105 | 9391 |
| | 2 | 105 | 9537 |
| | 3 | 105 | 9394 |
| | 4 | 105 | 10196 |
| | 1 | 135 | 9439 |
| | 2 | 135 | 10193 |
| | 3 | 135 | 9895 |
| | 4 | 135 | 9522 |
| | 1 | 165 | 9832 |
| | 2 | 165 | 11820 |
| | 3 | 165 | 8813 |
| | 4 | 165 | 9319 |
| 1 | 195 | 11124 | |
| 2 | 195 | 10259 | |
| 3 | 195 | 10746 | |
| 4 | 195 | 10032 | |
| 1 | 225 | 9739 | |
| 2 | 225 | 9188 | |
| 3 | 225 | 9942 | |
| 4 | 225 | 9014 | |
| 1 | 255 | 10221 | |
| 2 | 255 | 10969 | |
| 3 | 255 | 8909 | |
| 4 | 255 | 12759 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield |
|------|-------|----------------------------|-------|
| | | N † kg ha ⁻¹ | |
| 6 | 1 | 67 | 5923 |
| | 2 | 67 | 6081 |
| | 3 | 67 | 3025 |
| | 4 | 67 | 7182 |
| | 1 | 97 | 7074 |
| | 2 | 97 | 5419 |
| | 3 | 97 | 6124 |
| | 4 | 97 | 7177 |
| | 1 | 127 | 7298 |
| | 2 | 127 | 6862 |
| | 3 | 127 | 6483 |
| | 4 | 127 | 6472 |
| | 1 | 157 | 10120 |
| | 2 | 157 | 8951 |
| | 3 | 157 | 4639 |
| | 4 | 157 | 7307 |
| | 1 | 187 | 11012 |
| | 2 | 187 | 9336 |
| | 3 | 187 | 8510 |
| | 4 | 187 | 7423 |
| | 1 | 217 | 10096 |
| | 2 | 217 | 7750 |
| | 3 | 217 | 9779 |
| | 4 | 217 | 7984 |
| | 1 | 247 | 11732 |
| | 2 | 247 | 9904 |
| | 3 | 247 | 8205 |
| | 4 | 247 | 8220 |
| 1 | 277 | 10195 | |
| 2 | 277 | 9358 | |
| 3 | 277 | 8610 | |
| 4 | 277 | 10362 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 7 | 1 | 67 | 7969 |
| | 2 | 67 | 8694 |
| | 3 | 67 | 9754 |
| | 4 | 67 | 8208 |
| | 1 | 97 | 8866 |
| | 2 | 97 | 10934 |
| | 3 | 97 | 10074 |
| | 4 | 97 | 8623 |
| | 1 | 127 | 9642 |
| | 2 | 127 | 10446 |
| | 3 | 127 | 9325 |
| | 4 | 127 | 10489 |
| | 1 | 157 | 10903 |
| | 2 | 157 | 9730 |
| | 3 | 157 | 10419 |
| | 4 | 157 | 10975 |
| | 1 | 187 | 10558 |
| | 2 | 187 | 9723 |
| | 3 | 187 | 11561 |
| | 4 | 187 | 10620 |
| | 1 | 217 | 10454 |
| | 2 | 217 | 9242 |
| | 3 | 217 | 11440 |
| | 4 | 217 | 11320 |
| | 1 | 247 | 12233 |
| | 2 | 247 | 10792 |
| | 3 | 247 | 7814 |
| | 4 | 247 | 10534 |
| | 1 | 277 | 10566 |
| | 2 | 277 | 11289 |
| | 3 | 277 | 11844 |
| | 4 | 277 | 11612 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 8 | 1 | 36 | 5364 |
| | 2 | 36 | 5286 |
| | 3 | 36 | 5247 |
| | 4 | 36 | 5434 |
| | 1 | 66 | 6658 |
| | 2 | 66 | 7278 |
| | 3 | 66 | 5833 |
| | 4 | 66 | 5990 |
| | 1 | 96 | 8191 |
| | 2 | 96 | 9133 |
| | 3 | 96 | 7446 |
| | 4 | 96 | 7870 |
| | 1 | 126 | 8489 |
| | 2 | 126 | 7086 |
| | 3 | 126 | 7869 |
| | 4 | 126 | 7250 |
| | 1 | 156 | 9029 |
| | 2 | 156 | 9754 |
| | 3 | 156 | 7790 |
| | 4 | 156 | 8754 |
| 1 | 186 | 9365 | |
| 2 | 186 | 9713 | |
| 3 | 186 | 8981 | |
| 4 | 186 | 9372 | |
| 1 | 216 | 9519 | |
| 2 | 216 | 9308 | |
| 3 | 216 | 11091 | |
| 4 | 216 | 10404 | |
| 1 | 246 | 9611 | |
| 2 | 246 | 9457 | |
| 3 | 246 | 10228 | |
| 4 | 246 | 11331 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield |
|------|-------|----------------------------|-------|
| | | N † kg ha ⁻¹ | |
| 9 | 1 | 45 | 5337 |
| | 2 | 45 | 4679 |
| | 3 | 45 | 3776 |
| | 4 | 45 | 4313 |
| | 1 | 75 | 6761 |
| | 2 | 75 | 8701 |
| | 3 | 75 | 10139 |
| | 4 | 75 | 7020 |
| | 1 | 105 | 8055 |
| | 2 | 105 | 9079 |
| | 3 | 105 | 8340 |
| | 4 | 105 | 10119 |
| | 1 | 135 | 10695 |
| | 2 | 135 | 9404 |
| | 3 | 135 | 10303 |
| | 4 | 135 | 10442 |
| | 1 | 165 | 9724 |
| | 2 | 165 | 10322 |
| | 3 | 165 | 11191 |
| | 4 | 165 | 11560 |
| | 1 | 195 | 11448 |
| | 2 | 195 | 11491 |
| | 3 | 195 | 10683 |
| | 4 | 195 | 10323 |
| | 1 | 225 | 11204 |
| | 2 | 225 | 10020 |
| | 3 | 225 | 11090 |
| | 4 | 225 | 11317 |
| 1 | 255 | 12748 | |
| 2 | 255 | 11058 | |
| 3 | 255 | 11282 | |
| 4 | 255 | 11412 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 10 | 1 | 56 | 7935 |
| | 2 | 56 | 8161 |
| | 3 | 56 | 8372 |
| | 4 | 56 | 8965 |
| | 1 | 86 | 9840 |
| | 2 | 86 | 8185 |
| | 3 | 86 | 9818 |
| | 4 | 86 | 9750 |
| | 1 | 116 | 10064 |
| | 2 | 116 | 10125 |
| | 3 | 116 | 10440 |
| | 4 | 116 | 10742 |
| | 1 | 146 | 11433 |
| | 2 | 146 | 11439 |
| | 3 | 146 | 11515 |
| | 4 | 146 | 10345 |
| | 1 | 176 | 10607 |
| | 2 | 176 | 9663 |
| | 3 | 176 | 11146 |
| | 4 | 176 | 10675 |
| | 1 | 206 | 12067 |
| | 2 | 206 | 12071 |
| | 3 | 206 | 11131 |
| | 4 | 206 | 11767 |
| | 1 | 236 | 11433 |
| | 2 | 236 | 13121 |
| | 3 | 236 | 12112 |
| | 4 | 236 | 11628 |
| | 1 | 266 | 11544 |
| | 2 | 266 | 12231 |
| | 3 | 266 | 10620 |
| | 4 | 266 | 13703 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------|------------------------------|
| | | N † | Yield kg ha ⁻¹ |
| 11 | 1 | 69 | 8311 |
| | 2 | 69 | 9662 |
| | 3 | 69 | 13025 |
| | 4 | 69 | 8385 |
| | 1 | 99 | 10021 |
| | 2 | 99 | 10507 |
| | 3 | 99 | 12035 |
| | 4 | 99 | 11775 |
| | 1 | 129 | 11674 |
| | 2 | 129 | 12461 |
| | 3 | 129 | 13560 |
| | 4 | 129 | 11931 |
| | 1 | 159 | 13061 |
| | 2 | 159 | 15714 |
| | 3 | 159 | 12444 |
| | 4 | 159 | 13442 |
| | 1 | 189 | 13509 |
| | 2 | 189 | 12449 |
| | 3 | 189 | 13057 |
| | 4 | 189 | 12631 |
| | 1 | 219 | 13092 |
| | 2 | 219 | 12956 |
| | 3 | 219 | 13393 |
| | 4 | 219 | 12464 |
| | 1 | 249 | 13089 |
| | 2 | 249 | 13813 |
| | 3 | 249 | 12555 |
| | 4 | 249 | 13431 |
| 1 | 279 | 12234 | |
| 2 | 279 | 12748 | |
| 3 | 279 | 13965 | |
| 4 | 279 | 13064 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield |
|------|-------|----------------------------|-------|
| | | N † kg ha ⁻¹ | |
| 12 | 1 | 73 | 7076 |
| | 2 | 73 | 8275 |
| | 3 | 73 | 9086 |
| | 4 | 73 | 6459 |
| | 1 | 103 | 8505 |
| | 2 | 103 | 9555 |
| | 3 | 103 | 8289 |
| | 4 | 103 | 8230 |
| | 1 | 133 | 8628 |
| | 2 | 133 | 10746 |
| | 3 | 133 | 10100 |
| | 4 | 133 | 9735 |
| | 1 | 163 | 10420 |
| | 2 | 163 | 10033 |
| | 3 | 163 | 9598 |
| | 4 | 163 | 10375 |
| | 1 | 193 | 10243 |
| | 2 | 193 | 10005 |
| | 3 | 193 | 11981 |
| | 4 | 193 | 11567 |
| | 1 | 223 | 7154 |
| | 2 | 223 | 12752 |
| | 3 | 223 | 10273 |
| | 4 | 223 | 11086 |
| | 1 | 253 | 11879 |
| | 2 | 253 | 8589 |
| | 3 | 253 | 11260 |
| | 4 | 253 | 10416 |
| 1 | 283 | 9211 | |
| 2 | 283 | 12449 | |
| 3 | 283 | 11271 | |
| 4 | 283 | 10595 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 13 | 1 | 56 | 10033 |
| | 2 | 56 | 7868 |
| | 3 | 56 | 9547 |
| | 4 | 56 | 7669 |
| | 1 | 86 | 9629 |
| | 2 | 86 | 9407 |
| | 3 | 86 | 9668 |
| | 4 | 86 | 9516 |
| | 1 | 116 | 10180 |
| | 2 | 116 | 11541 |
| | 3 | 116 | 11806 |
| | 4 | 116 | 9739 |
| | 1 | 146 | 10891 |
| | 2 | 146 | 10958 |
| | 3 | 146 | 9872 |
| | 4 | 146 | 11055 |
| | 1 | 176 | 11307 |
| | 2 | 176 | 11048 |
| | 3 | 176 | 10363 |
| | 4 | 176 | 11208 |
| | 1 | 206 | 12442 |
| | 2 | 206 | 10504 |
| | 3 | 206 | 12676 |
| | 4 | 206 | 12193 |
| | 1 | 236 | 10256 |
| | 2 | 236 | 11611 |
| | 3 | 236 | 11606 |
| | 4 | 236 | 10669 |
| 1 | 266 | 12547 | |
| 2 | 266 | 13109 | |
| 3 | 266 | 11887 | |
| 4 | 266 | 11690 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 14 | 1 | 71 | 8946 |
| | 2 | 71 | 8644 |
| | 3 | 71 | 7996 |
| | 4 | 71 | 8676 |
| | 1 | 96 | 10739 |
| | 2 | 96 | 11320 |
| | 3 | 96 | 9011 |
| | 4 | 96 | 8859 |
| | 1 | 121 | 10966 |
| | 2 | 121 | 10286 |
| | 3 | 121 | 9674 |
| | 4 | 121 | 8042 |
| | 1 | 146 | 11205 |
| | 2 | 146 | 11634 |
| | 3 | 146 | 11290 |
| | 4 | 146 | 10892 |
| | 1 | 171 | 9094 |
| | 2 | 171 | 12044 |
| | 3 | 171 | 11877 |
| | 4 | 171 | 12709 |
| | 1 | 196 | 10828 |
| | 2 | 196 | 11760 |
| | 3 | 196 | 11091 |
| | 4 | 196 | 10517 |
| | 1 | 221 | 11506 |
| | 2 | 221 | 11202 |
| | 3 | 221 | 12085 |
| | 4 | 221 | 10115 |
| | 1 | 246 | 11545 |
| | 2 | 246 | 10915 |
| | 3 | 246 | 13200 |
| | 4 | 246 | 12216 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 15 | 1 | 56 | 9648 |
| | 2 | 56 | 10730 |
| | 3 | 56 | 10098 |
| | 4 | 56 | 10354 |
| | 1 | 86 | 10119 |
| | 2 | 86 | 10062 |
| | 3 | 86 | 10138 |
| | 4 | 86 | 10742 |
| | 1 | 116 | 10787 |
| | 2 | 116 | 10243 |
| | 3 | 116 | 10680 |
| | 4 | 116 | 10280 |
| | 1 | 146 | 9810 |
| | 2 | 146 | 11508 |
| | 3 | 146 | 10398 |
| | 4 | 146 | 10729 |
| | 1 | 176 | 11986 |
| | 2 | 176 | 10800 |
| | 3 | 176 | 11554 |
| | 4 | 176 | 10966 |
| | 1 | 206 | 11362 |
| | 2 | 206 | 12196 |
| | 3 | 206 | 9975 |
| | 4 | 206 | 10436 |
| | 1 | 236 | 11270 |
| | 2 | 236 | 11022 |
| | 3 | 236 | 10154 |
| | 4 | 236 | 11642 |
| | 1 | 266 | 11000 |
| | 2 | 266 | 12357 |
| | 3 | 266 | 10806 |
| | 4 | 266 | 10519 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield |
|------|-------|----------------------------|-------|
| | | N † kg ha ⁻¹ | |
| 16 | 1 | 0 | 9442 |
| | 2 | 0 | 7601 |
| | 3 | 0 | 7612 |
| | 4 | 0 | 6413 |
| | 1 | 30 | 9722 |
| | 2 | 30 | 10696 |
| | 3 | 30 | 10367 |
| | 4 | 30 | 9778 |
| | 1 | 60 | 11104 |
| | 2 | 60 | 11537 |
| | 3 | 60 | 11131 |
| | 4 | 60 | 10298 |
| | 1 | 90 | 10479 |
| | 2 | 90 | 10665 |
| | 3 | 90 | 9967 |
| | 4 | 90 | 10322 |
| | 1 | 120 | 11167 |
| | 2 | 120 | 11196 |
| | 3 | 120 | 12524 |
| | 4 | 120 | 10522 |
| | 1 | 150 | 12664 |
| | 2 | 150 | 12844 |
| | 3 | 150 | 11591 |
| | 4 | 150 | 12837 |
| | 1 | 180 | 13306 |
| | 2 | 180 | 12833 |
| | 3 | 180 | 10943 |
| | 4 | 180 | 12255 |
| 1 | 210 | 12805 | |
| 2 | 210 | 12743 | |
| 3 | 210 | 11911 | |
| 4 | 210 | 13021 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 17 | 1 | 62 | 4847 |
| | 2 | 62 | 6561 |
| | 3 | 62 | 5710 |
| | 4 | 62 | 6788 |
| | 1 | 92 | 9347 |
| | 2 | 92 | 7459 |
| | 3 | 92 | 8688 |
| | 4 | 92 | 6384 |
| | 1 | 122 | 8728 |
| | 2 | 122 | 8802 |
| | 3 | 122 | 7385 |
| | 4 | 122 | 8147 |
| | 1 | 152 | 10230 |
| | 2 | 152 | 11857 |
| | 3 | 152 | 10829 |
| | 4 | 152 | 9195 |
| | 1 | 182 | 11681 |
| | 2 | 182 | 8036 |
| | 3 | 182 | 6750 |
| | 4 | 182 | 9641 |
| | 1 | 212 | 8628 |
| | 2 | 212 | 7638 |
| | 3 | 212 | 8795 |
| | 4 | 212 | 6570 |
| | 1 | 242 | 10795 |
| | 2 | 242 | 7383 |
| | 3 | 242 | 8364 |
| | 4 | 242 | 10559 |
| 1 | 272 | 7279 | |
| 2 | 272 | 6903 | |
| 3 | 272 | 12120 | |
| 4 | 272 | 7653 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 18 | 1 | 38 | 5441 |
| | 2 | 38 | 6731 |
| | 3 | 38 | 5537 |
| | 4 | 38 | 5599 |
| | 1 | 68 | 5743 |
| | 2 | 68 | 7265 |
| | 3 | 68 | 5788 |
| | 4 | 68 | 5493 |
| | 1 | 98 | 5498 |
| | 2 | 98 | 7196 |
| | 3 | 98 | 4985 |
| | 4 | 98 | 4906 |
| | 1 | 128 | 6441 |
| | 2 | 128 | 3758 |
| | 3 | 128 | 7141 |
| | 4 | 128 | 7831 |
| | 1 | 158 | 5877 |
| | 2 | 158 | 5967 |
| | 3 | 158 | 4588 |
| | 4 | 158 | 7553 |
| | 1 | 188 | 4128 |
| | 2 | 188 | 5758 |
| | 3 | 188 | 7337 |
| | 4 | 188 | 7082 |
| | 1 | 218 | 5350 |
| | 2 | 218 | 5341 |
| | 3 | 218 | 7174 |
| | 4 | 218 | 5114 |
| | 1 | 248 | 5394 |
| | 2 | 248 | 5808 |
| | 3 | 248 | 4463 |
| | 4 | 248 | 5871 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 19 | 1 | 38 | 2711 |
| | 2 | 38 | 4949 |
| | 3 | 38 | 3804 |
| | 4 | 38 | 2001 |
| | 1 | 68 | 3103 |
| | 2 | 68 | 3207 |
| | 3 | 68 | 3248 |
| | 4 | 68 | 3940 |
| | 1 | 98 | 4732 |
| | 2 | 98 | 4033 |
| | 3 | 98 | 3682 |
| | 4 | 98 | 4309 |
| | 1 | 128 | 2934 |
| | 2 | 128 | 2782 |
| | 3 | 128 | 5207 |
| | 4 | 128 | 4044 |
| | 1 | 158 | 4358 |
| | 2 | 158 | 3625 |
| | 3 | 158 | 3827 |
| | 4 | 158 | 1451 |
| | 1 | 188 | 3271 |
| | 2 | 188 | 4713 |
| | 3 | 188 | 4984 |
| | 4 | 188 | 4431 |
| | 1 | 218 | 4692 |
| | 2 | 218 | 3595 |
| | 3 | 218 | 3548 |
| | 4 | 218 | 3282 |
| | 1 | 248 | 3530 |
| | 2 | 248 | 4300 |
| | 3 | 248 | 2487 |
| | 4 | 248 | 3584 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 20 | 1 | 56 | 8342 |
| | 2 | 56 | 8567 |
| | 3 | 56 | 8332 |
| | 4 | 56 | 7578 |
| | 1 | 86 | 7526 |
| | 2 | 86 | 9019 |
| | 3 | 86 | 10156 |
| | 4 | 86 | 8857 |
| | 1 | 116 | 8424 |
| | 2 | 116 | 7918 |
| | 3 | 116 | 9085 |
| | 4 | 116 | 9953 |
| | 1 | 146 | 8673 |
| | 2 | 146 | 7795 |
| | 3 | 146 | 8620 |
| | 4 | 146 | 9362 |
| | 1 | 176 | 8741 |
| | 2 | 176 | 6118 |
| | 3 | 176 | 8308 |
| | 4 | 176 | 8993 |
| | 1 | 206 | 9228 |
| | 2 | 206 | 8213 |
| | 3 | 206 | 9984 |
| | 4 | 206 | 8802 |
| | 1 | 236 | 8247 |
| | 2 | 236 | 9157 |
| | 3 | 236 | 8360 |
| | 4 | 236 | 8962 |
| | 1 | 266 | 9668 |
| | 2 | 266 | 7730 |
| | 3 | 266 | 6427 |
| | 4 | 266 | 7828 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 21 | 1 | 0 | 10114 |
| | 2 | 0 | 9596 |
| | 3 | 0 | 10317 |
| | 4 | 0 | 9047 |
| | 1 | 30 | 10437 |
| | 2 | 30 | 9130 |
| | 3 | 30 | 8637 |
| | 4 | 30 | 9115 |
| | 1 | 60 | 9096 |
| | 2 | 60 | 9921 |
| | 3 | 60 | 10871 |
| | 4 | 60 | 10875 |
| | 1 | 90 | 7772 |
| | 2 | 90 | 9198 |
| | 3 | 90 | 10830 |
| | 4 | 90 | 11272 |
| | 1 | 120 | 7970 |
| | 2 | 120 | 8729 |
| | 3 | 120 | 8798 |
| | 4 | 120 | 11377 |
| | 1 | 150 | 6064 |
| | 2 | 150 | 9861 |
| | 3 | 150 | 9618 |
| | 4 | 150 | 10695 |
| | 1 | 180 | 8764 |
| | 2 | 180 | 6933 |
| | 3 | 180 | 8439 |
| | 4 | 180 | 10805 |
| | 1 | 210 | 10238 |
| | 2 | 210 | 9088 |
| | 3 | 210 | 8890 |
| | 4 | 210 | 9544 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield kg ha ⁻¹ |
|------|-------|---------|------------------------------|
| | | N † | |
| 22 | 1 | 38 | 4302 |
| | 2 | 38 | 3439 |
| | 3 | 38 | 3972 |
| | 4 | 38 | 3168 |
| | 1 | 68 | 2815 |
| | 2 | 68 | 3165 |
| | 3 | 68 | 3745 |
| | 4 | 68 | 3540 |
| | 1 | 98 | 2513 |
| | 2 | 98 | 3082 |
| | 3 | 98 | 2414 |
| | 4 | 98 | 2379 |
| | 1 | 128 | 3562 |
| | 2 | 128 | 3549 |
| | 3 | 128 | 4508 |
| | 4 | 128 | 3411 |
| | 1 | 158 | 2970 |
| | 2 | 158 | 3957 |
| | 3 | 158 | 2009 |
| | 4 | 158 | 5026 |
| | 1 | 188 | 3235 |
| | 2 | 188 | 3395 |
| | 3 | 188 | 2392 |
| | 4 | 188 | 1168 |
| | 1 | 218 | 3917 |
| | 2 | 218 | 3302 |
| | 3 | 218 | 3590 |
| | 4 | 218 | 2864 |
| 1 | 248 | 2180 | |
| 2 | 248 | 3740 | |
| 3 | 248 | 3206 | |
| 4 | 248 | 3061 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 23 | 1 | 45 | 7906 |
| | 2 | 45 | 7695 |
| | 3 | 45 | 7028 |
| | 4 | 45 | 7134 |
| | 1 | 75 | 7373 |
| | 2 | 75 | . |
| | 3 | 75 | 7204 |
| | 4 | 75 | 7429 |
| | 1 | 105 | 8536 |
| | 2 | 105 | 9597 |
| | 3 | 105 | 11140 |
| | 4 | 105 | 5412 |
| | 1 | 135 | 9235 |
| | 2 | 135 | 9777 |
| | 3 | 135 | 7802 |
| | 4 | 135 | . |
| | 1 | 165 | 6387 |
| | 2 | 165 | 8635 |
| | 3 | 165 | 9995 |
| | 4 | 165 | 8284 |
| | 1 | 195 | 11519 |
| | 2 | 195 | 9197 |
| | 3 | 195 | . |
| | 4 | 195 | 7615 |
| | 1 | 225 | . |
| | 2 | 225 | 9539 |
| | 3 | 225 | 8199 |
| | 4 | 225 | 5614 |
| | 1 | 255 | 8907 |
| | 2 | 255 | 10251 |
| | 3 | 255 | 8883 |
| | 4 | 255 | 8282 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield |
|------|-------|----------------------------|-------|
| | | N † kg ha ⁻¹ | |
| 24 | 1 | 45 | 6262 |
| | 2 | 45 | 7355 |
| | 3 | 45 | 5480 |
| | 4 | 45 | 5474 |
| | 1 | 75 | 5231 |
| | 2 | 75 | 5599 |
| | 3 | 75 | 6299 |
| | 4 | 75 | 7532 |
| | 1 | 105 | 8743 |
| | 2 | 105 | 6992 |
| | 3 | 105 | 7158 |
| | 4 | 105 | 6568 |
| | 1 | 135 | 7761 |
| | 2 | 135 | 6455 |
| | 3 | 135 | 7443 |
| | 4 | 135 | 5052 |
| | 1 | 165 | 6233 |
| | 2 | 165 | 7821 |
| | 3 | 165 | 7077 |
| | 4 | 165 | 7374 |
| | 1 | 195 | 6910 |
| | 2 | 195 | 8244 |
| | 3 | 195 | 5205 |
| | 4 | 195 | 6464 |
| | 1 | 225 | 7752 |
| | 2 | 225 | 7708 |
| | 3 | 225 | 8063 |
| | 4 | 225 | 5535 |
| 1 | 255 | 7999 | |
| 2 | 255 | 6813 | |
| 3 | 255 | 7962 | |
| 4 | 255 | 8014 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield kg ha ⁻¹ |
|------|-------|---------|------------------------------|
| | | N † | |
| 25 | 1 | 0 | 10140 |
| | 2 | 0 | 10918 |
| | 3 | 0 | 5158 |
| | 4 | 0 | 6609 |
| | 1 | 30 | 9711 |
| | 2 | 30 | 7093 |
| | 3 | 30 | 8272 |
| | 4 | 30 | 10128 |
| | 1 | 60 | 9163 |
| | 2 | 60 | 9660 |
| | 3 | 60 | 11846 |
| | 4 | 60 | 6806 |
| | 1 | 90 | 7935 |
| | 2 | 90 | 11215 |
| | 3 | 90 | 11156 |
| | 4 | 90 | 8880 |
| | 1 | 120 | 11091 |
| | 2 | 120 | 10616 |
| | 3 | 120 | 9242 |
| | 4 | 120 | 10500 |
| | 1 | 150 | 9483 |
| | 2 | 150 | 11287 |
| | 3 | 150 | 8854 |
| | 4 | 150 | 7773 |
| | 1 | 180 | 11589 |
| | 2 | 180 | 9788 |
| | 3 | 180 | 12964 |
| | 4 | 180 | 6486 |
| 1 | 210 | 9669 | |
| 2 | 210 | 12859 | |
| 3 | 210 | 8954 | |
| 4 | 210 | 12773 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | Yield |
|------|-------|----------------------------|-------|
| | | N † kg ha ⁻¹ | |
| 26 | 1 | 77 | 9367 |
| | 2 | 77 | 7157 |
| | 3 | 77 | 8013 |
| | 4 | 77 | 7700 |
| | 1 | 107 | 8615 |
| | 2 | 107 | 7809 |
| | 3 | 107 | 9239 |
| | 4 | 107 | 9703 |
| | 1 | 137 | 7717 |
| | 2 | 137 | 8899 |
| | 3 | 137 | 7969 |
| | 4 | 137 | 11331 |
| | 1 | 167 | 10525 |
| | 2 | 167 | 10480 |
| | 3 | 167 | 8763 |
| | 4 | 167 | 9438 |
| | 1 | 197 | 10310 |
| | 2 | 197 | 8857 |
| | 3 | 197 | 10341 |
| | 4 | 197 | 10287 |
| | 1 | 227 | 10292 |
| | 2 | 227 | 9317 |
| | 3 | 227 | 9617 |
| | 4 | 227 | 11599 |
| | 1 | 257 | 9640 |
| | 2 | 257 | 9084 |
| | 3 | 257 | 8234 |
| | 4 | 257 | 11856 |
| 1 | 287 | 7446 | |
| 2 | 287 | 9771 | |
| 3 | 287 | 8884 | |
| 4 | 287 | 8817 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 27 | 1 | 0 | 13099 |
| | 2 | 0 | 9276 |
| | 3 | 0 | 10669 |
| | 4 | 0 | 8363 |
| | 1 | 30 | 7672 |
| | 2 | 30 | 10308 |
| | 3 | 30 | 8332 |
| | 4 | 30 | 8695 |
| | 1 | 60 | 7318 |
| | 2 | 60 | 9827 |
| | 3 | 60 | 8430 |
| | 4 | 60 | 10076 |
| | 1 | 90 | 10421 |
| | 2 | 90 | 8669 |
| | 3 | 90 | 9601 |
| | 4 | 90 | 10220 |
| | 1 | 120 | 10356 |
| | 2 | 120 | 7621 |
| | 3 | 120 | 8802 |
| | 4 | 120 | 10449 |
| | 1 | 150 | 8298 |
| | 2 | 150 | 8609 |
| | 3 | 150 | 10071 |
| | 4 | 150 | 9540 |
| | 1 | 180 | 9005 |
| | 2 | 180 | 9493 |
| | 3 | 180 | 7087 |
| | 4 | 180 | 10482 |
| | 1 | 210 | 8602 |
| | 2 | 210 | 9694 |
| | 3 | 210 | 9602 |
| | 4 | 210 | 8871 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------------------|-------|
| | | N † | Yield |
| | | kg ha ⁻¹ | |
| 28 | 1 | 37 | 7496 |
| | 2 | 37 | 6443 |
| | 3 | 37 | 6044 |
| | 4 | 37 | 6448 |
| | 1 | 67 | 6838 |
| | 2 | 67 | 6222 |
| | 3 | 67 | 6563 |
| | 4 | 67 | 6077 |
| | 1 | 97 | 6322 |
| | 2 | 97 | 8315 |
| | 3 | 97 | 6054 |
| | 4 | 97 | 6579 |
| | 1 | 127 | 7400 |
| | 2 | 127 | 6032 |
| | 3 | 127 | 7379 |
| | 4 | 127 | 5641 |
| | 1 | 157 | 6957 |
| | 2 | 157 | 7559 |
| | 3 | 157 | 6653 |
| | 4 | 157 | 7039 |
| | 1 | 187 | 7429 |
| | 2 | 187 | 6587 |
| | 3 | 187 | 7254 |
| | 4 | 187 | 6998 |
| | 1 | 217 | 6095 |
| | 2 | 217 | 7237 |
| | 3 | 217 | 6643 |
| | 4 | 217 | 7745 |
| | 1 | 247 | 7209 |
| | 2 | 247 | 6203 |
| | 3 | 247 | 6639 |
| | 4 | 247 | 6863 |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

Appendix J. Continued.

| Site | Block | Applied | |
|------|-------|---------|------------------------------|
| | | N † | Yield kg ha ⁻¹ |
| 29 | 1 | 62 | 10934 |
| | 2 | 62 | 11339 |
| | 3 | 62 | 9685 |
| | 4 | 62 | 9425 |
| | 1 | 92 | 10762 |
| | 2 | 92 | 11836 |
| | 3 | 92 | 12395 |
| | 4 | 92 | 11278 |
| | 1 | 122 | 9726 |
| | 2 | 122 | 12084 |
| | 3 | 122 | 11757 |
| | 4 | 122 | 12590 |
| | 1 | 152 | 10777 |
| | 2 | 152 | 11508 |
| | 3 | 152 | 11462 |
| | 4 | 152 | 12450 |
| | 1 | 182 | 10747 |
| | 2 | 182 | 11835 |
| | 3 | 182 | 9670 |
| | 4 | 182 | 12176 |
| | 1 | 212 | 13115 |
| | 2 | 212 | 12588 |
| | 3 | 212 | 11964 |
| | 4 | 212 | 8509 |
| | 1 | 242 | 13392 |
| | 2 | 242 | 13205 |
| | 3 | 242 | 13841 |
| | 4 | 242 | 12693 |
| 1 | 272 | 10377 | |
| 2 | 272 | 12457 | |
| 3 | 272 | 14241 | |
| 4 | 272 | 12259 | |

† Total fertilizer N applied during the growing season; includes broadcast, starter and sidedress N applications

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EXTENSION PRESENTATIONS

- Spargo, J.T. and M.M. Alley. 2007. Does the Illinois Soil N Test Predict Corn Yield Response to Fertilizer N in Virginia? Shenandoah County, producer field-day. New Market, VA. August 6, 2007.
- Spargo, J.T. and M.M. Alley. 2007. Soil quality and N use efficiency. Shenandoah Valley Professional crop advisors update. Verona, VA. January 9, 2007.
- Spargo, J.T. and M.M. Alley. 2006. Soil C and N status after long-term no-tillage management for grain crop production in the Virginia Coastal Plain. NRCS in-service training workshop, New Kent, VA. April 13, 2006.

- Spargo, J.T. and M.M. Alley. 2006. Influence of Tillage on Nitrate Leaching Losses in the Virginia Coastal Plain. NRCS in-service training workshop, New Kent, VA. April 13, 2006.
- Spargo, J.T., and M.M. Alley. 2005. Carbon and nitrogen in long-term no-till soils. Southern States Grow Master Conference, Blacksburg, VA. August 7, 2005

**AWARDS/
RECOGNITIONS**

- Gene A. and Ina Mae James Graduate Scholarship, 2007
- No-Till Innovator Research Team Award – *No-Till Farmer Magazine*, 2007
(Team: John Spargo, Mark Alley, Ron Follett, Chris Lawrence, Brian Noyes, Jim Wallace, and Paul Davis)
- Charles I. Rich CSES Graduate Fellowship Award, 2006
- Samuel Obenshain CSES Graduate Scholarship Award, 2006
- J. Fielding Reed PPI Fellowship Award, 2005
- Henry Budd Virginia Agricultural Council Graduate Scholarship, 2005
- National Garden Club Scholarship 2003
- Texas A&M College of Agriculture Scholarship for Academic Excellence 2002
- Texas A&M President's List; Fall 1999 through Spring 2002

**PROFESIONAL
AFILIATIONS**

- Soil Science Society of American
- American Society of Agronomy
- Soil and Water Conservation Society
- Sigma Xi Scientific Research Society
- Gamma Sigma Delta Honor Society of Agriculture