SHORT-TERM CARBON DIOXIDE AND NITROUS OXIDE FLUX FOLLOWING TILLAGE OF THE CLAY SOIL IN THE RED RIVER VALLEY IN SOUTHERN MANITOBA

BY

ALEXANDER J. KOITER

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

Department of Soil Science
University of Manitoba
Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES
*****
COPYRIGHT PERMISSION

SHORT-TERM CARBON DIOXIDE AND NITROUS OXIDE FLUX FOLLOWING TILLAGE OF THE CLAY SOIL IN THE RED RIVER VALLEY IN SOUTHERN MANITOBA

BY

ALEXANDER J. KOITER

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

MASTER OF SCIENCE

ABSTRACT

Koiter, Alexander J. M.Sc., The University of Manitoba, January, 2008. Short-term carbon dioxide and nitrous oxide flux following tillage of the clay soil in the Red River Valley in Southern Manitoba. Major Professor: Dr. David Lobb.

There has been resurgence in the interest of conservation tillage as a way to sequester carbon from the atmosphere, to help improve soil quality, and as a means to mitigate the increasing concentration of greenhouse gases (GHGs) in the atmosphere. However, the term conservation tillage is qualitative and quite ambiguous, and refers to a wide range of tillage practices. This makes the interpretation of information gathered from different tillage systems difficult. There currently exists a need for the quantification of soil surface properties following different tillage methods because surface properties are closely linked to soil surface processes. Previous research has focused on the long-term impacts of tillage systems and their effects on soil biological processes and properties, such as soil microbial populations and activity, soil organic matter fractions and their role in the production and emission of greenhouse gases. However, the more immediate impacts of tillage on soil physical processes and properties and their role in the production and emission of GHGs are not well understood and are often overlooked.

The first objective of this research addressed the need for better quantification of soil physical properties after tillage practices. This research demonstrated the use of a laser profiling system and digital imagery and image analysis software in measuring soil micro-relief and crop residue cover. Furthermore, comparisons of geostatistical and univariate procedures of quantifying surface roughness were also investigated. There was

a definite advantage in using a geostatistical approach to characterize soil topography as the indices they provide give insight into the characteristics of the surface roughness. Soil disturbance and the addition of corn residue were both found to be significant factors affecting the surface roughness, crop residue cover, exposed surface area, and near-surface porosity.

The second objective of this research focused on the quantification and characterization of the short-term effects of soil disturbance as a result of tillage on the carbon dioxide (CO_2) and nitrous oxide (N_2O) flux from the clay soils of the Red River Valley, Manitoba. The short-term CO_2 flux (up to 5 days) following a soil disturbance event was characterized by an immediate increase in the CO_2 flux following the soil disturbance event that quickly dissipated within the first 24 hours. Both the addition of residue and soil disturbance were found to be significant factors in the cumulative CO_2 loss over the 5-day observation period. However, the incorporation of the residue through the action of soil disturbance was found to be a more important factor than soil disturbance or the addition of residue alone. The effects of residue and soil disturbance on the N_2O flux were highly variable. However, there was some indication that the N_2O flux under certain soil conditions may have a response to soil disturbance similar to that of CO_2.

The third objective is a combination of the previous two objectives and deals with the need to better understand the underlying physical mechanisms that control the CO_2 and N_2O flux. This was accomplished by combining the detailed information on the changes in surface properties and the CO_2 and N_2O fluxes that occur due to soil disturbance. Generally, the soil disturbance treatments that resulted in a rougher surface, greater exposed surface area, greater residue incorporation, and disturbed the greatest volume of soil had the highest initial CO_2 fluxes and the greatest cumulative CO_2 loss following the soil disturbance event. Due to the high variability in the N_2O fluxes following soil disturbance there was no significant relationship found between the N_2O flux and soil surface properties.

ACKNOWLEDGEMENTS

Financial support for this study was provided by Natural Sciences and Engineering Research Council of Canada (NSERC) and BIOCAP as part of the "Temporal dynamics of greenhouse gas fluxes linked to soil biophysical processes and management practices" strategic project (Wagner-Riddle, PI). Development and fabrication of the laser profiling system was provided by the National Optics Institute (INO) and the financial support was provided by Canada Foundation for Innovation (CFI) (Lobb, PI).

I would like to extend my thanks to the technical and field support of Rob Ellis, Brad Sparling, Tim Stem and Syd Jones and to the administrative support of Barb Finkelman and Terri Ramm. To my fellow graduate students, thank you very much for all of your help, friendship and making my stay here in Manitoba a memorable one. Dr. Mario Tenuta and Don Reicosky thank you both for your guidance and insights into this project.

I want to acknowledge Dr. David Lobb for being a great advisor and mentor to me throughout the course of this project. It has been a very positive and rewarding experience for me. I would also like to thank my advisory committee: Dr. Bev Kay, Dr. Brian Amiro and Dr. Henry Janzen for their input into this project.

A very special thanks to my wife Harmony, I appreciate your emotional support and encouragement throughout the past two years. Without you this thesis would not have been possible.

FOREWORD

This thesis has been prepared in the manuscript format in adherence with the guidelines established by the Department of Soil Science at the University of Manitoba.

This research was conducted as part of the "Temporal dynamics of greenhouse gas fluxes linked to soil biophysical processes and management practices" funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) and BIOCAP Canada under the strategic grant initiative. As part of this overall project, measurements are being carried out using micrometeorological techniques, which are ideal for characterizing the temporal dynamics of greenhouse gas (GHG) fluxes. A tunable diode laser (TDL) trace gas spectroscopy is being used to obtain $^{13}CO_2$ and $^{12}CO_2$ fluxes for identification of the source of CO_2 (soil or crop residue), and relating these to N_2O emission episodes. This project is a comparison of the net GHG emissions (N_2O and CO_2 fluxes) in fields managed under conservation-till and conventional-till through year-round studies at the Elora, Ontario (humid) and Glenlea, Manitoba (semi-arid) research stations. Biophysical controls of GHG fluxes will be linked through an array of soil chemical, physical, and microbial measurements. Integration of project results will occur through a modeling approach. Project results will lead to increased understanding of seasonal carbon and nitrogen cycling and identification of strategies for net GHG reduction from agriculture in contrasting soil and climatic conditions. This project is a joint effort between the University of Manitoba, University of Guelph and Agriculture & Agri-Food Canada.

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

1. INTRODUCTION

There has been growing concern among many Canadians about the increasing concentrations of greenhouse gases (GHGs) in the atmosphere and the role these gases play in global warming. In response to this concern, Canada, in 1992 joined an international treaty titled "the United Nations Framework Convention on Climate Change". The objective of this treaty was the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (United Nations Framework Convention on Climate Change, 1992). More recently the Kyoto-protocol was added to the treaty; this is an international and legally binding agreement to reduce greenhouse gases emissions world wide. Canada's ratification of the Kyoto-protocol requires Canada to reduce its GHG emissions to 6% below 1990 levels during the 2008-2012 commitment period.

In 2004, the agriculture sector in Canada accounted for an estimated emission of 55,000 kt CO_2-equivalent (7.2% of the total Canadian emissions of GHGs), and accounted for about 63% and 25% of the total nitrous oxide (N_2O) and methane (CH_4), emissions, respectively (Environment Canada, 2006). Consequently, part of Canada's plan for the achievement of Kyoto-protocol targets includes a substantial role for the agricultural sector. In particular, the adoption of conservation tillage techniques for field crop production has shown the potential for a net reduction of GHGs. The net reduction of GHG emissions through the adoption of conservation tillage is primarily accomplished through the accumulation of soil organic carbon, thereby sequestering carbon dioxide

(CO_2) from the atmosphere into the soil and through the reduction in the consumption of fossil fuels due to fewer field operations being needed (Cole et al., 1997).

Tillage is used in agroecosystems for a wide variety of reasons, predominately for seedbed preparation. Tillage is also used to control weeds, insects and diseases, manage soil moisture and temperature, increase nutrient mineralization and to improve soil structure by alleviating compaction and breaking up soil crusts. In conventional-till systems the soil is intensively disturbed, involving several field operations intended to completely invert the soil and incorporate most of the crop residues and to break up large soil clods to provide a homogeneous seedbed. Conservation-till systems, in comparison to conventional-till systems, use fewer and less intensive tillage operations that disturb a smaller volume of soil and leave a greater portion of the crop residues on the soil surface. In some conservation-till systems the crop is directly seeded into the soil (no-till/zero-till), however, even in these systems there will be some soil disturbance associated with the placement of the seed.

The effectiveness of conservation tillage for mitigating GHG emissions is still uncertain. For example, the effectiveness of these types of tillage systems on carbon (C) sequestration and reducing N_2O emissions varies across Canada, with western Canada showing a greater response compared to eastern Canada (VandenBygaart et al., 2003; Helgason et al., 2005). In addition, the benefits of sequestering C can be offset by relatively small increases in N_2O emissions, as N_2O has a global warming potential 298 times more than CO_2 (Solomon et al., 2007). Consequently, the role of tillage in agroecosystems on the global GHG balance must be fully understood if it is to be used effectively in mitigating the increasing concentrations of GHGs in the atmosphere.

The conversion of cropland from conventional-till systems to conservation-till systems can change many of the physical, chemical, and biological properties of the soil. The underlying assumption using conservation-till systems to sequester C is that these systems leave crop residues on the soil surface which can considerably slow decomposition, leading to an accumulation of organic matter over time (Reicosky et al., 1995). Tillage may also increase soil aeration, which can stimulate microbial respiration (Reicosky et al., 1995). Soils in conservation-till systems often have higher bulk densities and/or higher moisture contents which results in higher water-filled porosity compared to conventional-till systems (Linn and Doran, 1984). This higher-water filled porosity combined with the increase in organic C creates conditions that are more conducive to the production of N_2O through the process of denitrification and nitrification throughout the growing season (Lee et al., 2006). Conversely, conservation-till systems have shown to reduce N_2O emissions during the spring-thaw period due to a lower degree and intensity of freezing because of the insulating effects of the crop residues and snow cover (Wagner-Riddle et al., 2007).

One significant problem identified by Lobb et al. (2007), is the lack of detailed information on tillage systems. The use of qualitative terms such as conventional and conservation tillage to describe tillage practices can be quite problematic as it is ambiguous and a wide range of practices fall into these categories (Lobb et al., 2007). This makes the interpretation of information gathered from different tillage systems and regions difficult. Quantification of tillage practices is especially important in the prairie region of Canada where the different tillage practices used have a narrow range of intensities. Consequently, it is often difficult to differentiate between different tillage systems used in this region and quantification of surface properties will help to better distinguish one practice from another. Detailed information on tillage practices such as the changes in crop residue cover, near-surface porosity, surface roughness, and exposed surface area following a tillage event or sequence is one way the ambiguity of these qualitative terms can be minimized. Soil surface physical properties are closely linked to soil surface processes. Therefore, the characterization and quantification of surface properties may help in part to explain differences in crop growth, soil erosion, hydrology, gas exchange and energy balance between different tillage systems.

Detailed information on surface physical properties may in part be able to explain differences in observed fluxes of GHGs between different tillage systems. By having detailed information about the similarities and differences in soil physical properties and in the GHG flux arising from different tillage systems, the underlying physical mechanisms that control the GHG flux from agricultural soil can be better understood. Understanding these fundamental physical mechanisms will enable the agricultural sector to better identify strategies for the net GHG reduction from agriculture in contrasting soil and climatic conditions. In addition, relationships between the net GHG flux and soil physical properties will allow for the assessment of GHG fluxes based on changes in soil physical properties due to changes in management practices. Therefore, in order to get a national estimate of the net GHG flux from arable land, detailed information and quantification of tillage practices is needed throughout Canada to better quantify the effects of the tillage on the net GHG flux.

Previous research has focused on the long-term impacts of tillage systems (5 to 50 years) and their effects on soil biologic processes and properties, such as soil microbial populations and activity, soil organic matter fractions and their role in the production and emission of GHGs. However, the more immediate impacts of tillage (minutes to days) on physical processes and properties and their role in the production and emission of greenhouse gases are not well understood and are often overlooked. Many past and current C and nitrogen (N) studies neglect or miss these immediate losses following tillage as monitoring equipment often has to be removed to allow the field operations to occur; as well, there can be difficulty in making measurements on the rough and porous surface. The three to six tillage events that occur throughout the year will result in numerous days of unmeasured fluxes. These gaps in the data set can have serious consequences for the study and modeling of the C and N cycles as all C and N inputs and outputs must be accounted for. Quantification of the short-term effects of tillage on the CO_2 and N_2O flux will aid in the understanding of annual C and N cycles.

The gaps in the CO_2 and N_2O flux data set are often filled using interpolation or modeling techniques. Characterization of the short-term effects of tillage on the CO_2 and N_2O flux can provide information on the limitations of these interpolation or modeling techniques in estimating the CO_2 and N_2O flux around tillage events. This will lead to a more accurate estimation of the net GHG flux.

The goal of this research to better understand the cycling of C and N in agroecosystems under different tillage practices, and to identify possible strategies for the net GHG reduction from these systems in the Red River Valley of Manitoba. The three main objectives of this research were to: (1) to examine and characterize the effects of soil disturbance and crop residue and the interaction of these two factors on soil physical properties; (2) to examine and characterize the effects of soil disturbance and crop residue and the interaction of these two factors on the short-term (up to 5 days) CO_2 and N_2O flux; and (3) to relate changes in soil physical properties to the changes in CO_2 and N_2O flux from the clay soils of the Red River Valley, Manitoba. These objectives address the need for more detailed information about tillage systems, a better understanding of the short-term CO_2 and N_2O flux, and a better understanding of the underlying physical mechanisms that control the CO_2 and N_2O flux.

References

Cole, C.V., Duxbury, J., Freney, J., Heinemeyer, O., Minami K., Mosier, A., Paustian, K., Rosenberg, N., Sampson, N., Sauerbeck, D. and Zhao, Q. 1997. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutrient Cycling in Agroecosystems **49**: 221-228.

Helgason B.L., Janzen H.H., Chantigny M.H., Dury, C.F., Ellert, B.H., Gregorich, E.G., Lemke, R.L., Pattey, E., Rochette, P. and Wagner-Riddle, C. 2005. Toward improved coefficients for predicting direct N_2O emissions from soil in Canadian agroecosystems. Nutrient Cycling in Agroecosystems **72**: 87-99.

Lee, J., Six, J., King, A.P., van Kessel, C. and Rolston, D.E. 2006. Tillage and field scale controls on greenhouse gas emissions. J. Environ. Qual. **35**: 714-725.

Linn, D.M. and Doran, J.W., 1984. Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and nontilled Soils. Soil Sci. Soc. Am. J. **48**: 1264-1272.

Lobb, D.A., Huffman, E. and Reicosky, D.C. 2007. Importance of information on tillage practices in the modelling of environmental processes and in the use of environmental indicators. Journal of Environmental Management **82**: 377-387.

Environment Canada, Greenhouse Gas Division. 2006. National Inventory Report. 1990-2004: Greenhouse gas sources and sinks in Canada. The Canadian government's submission to the UN Framework Convention on Climate Change. 7 pp.

Reicosky, D.C., Kemper, W.D., Langdale, G.W., Douglas, C.L. and Rasmussen, P.E. 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil and Water Conser. **50**: 253-261.

Solomon, S., Qin, D., Manning, M., Alley, R.B., Berntsen, T., Bindoff, N.L., Chen, Z., Chidthaisong, A., Gregory, J.M., Hegerl, G.C., Heimann, M., Hewitson, B., Hoskins, B.J., Joos, F., Jouzel, J., Kattsov, V., Lohmann, U., Matsuno, T., Molina, M., Nicholls, N., Overpeck, J., Raga, G., Ramaswamy, V., Ren, J. Rusticucci, M., Somerville, R., Stocker, T.F., Whetton, P., Wood, R.A. and Wratt, D. 2007. Technical Summary. Pages 33-34. *in* S. Solomon et al. (eds.). Climate Change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, U.S.A.

United Nations Framework Convention on Climate Change. 1992. Available online: http://unfccc.int.

VandenBygaart, A.J., Gregorich, E.G. and Angers, D.A. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Can. J. Soil Sci. **83**: 363-380.

Wagner-Riddle, C., Furon, A., McLaughlin, N.L., Lee, I., Barbeau, J., Jayasundara, S., Parkin, G., von Bertoldi, P. and Warland, J. 2007. Intensive measurement of nitrous oxide emissions from a corn-soybean-wheat rotation under two contrasting management systems over 5 years. Global Change Biology **13**: 1722–1736.

2. CHARACTERIZATION OF SOIL SURFACE PROPERTIES FOLLOWING SOIL DISTURBANCE OF THE CLAY SOILS IN SOUTHERN MANITOBA

2.1 Abstract

There has been resurgence in the interest of conservation tillage as a way to sequester carbon from the atmosphere to help improve soil quality and as a means to mitigate the increasing carbon dioxide (CO_2) concentration in the atmosphere. However, the term conservation tillage is qualitative and quite ambiguous and refers to a wide range of practices. Currently, there exists a need for the quantification of surface properties following tillage as a means to differentiate among the different practices. In addition, quantification of surface properties may help to explain differences in CO_2 emissions among different tillage practices as surface properties are closely linked to soil surface processes.

This research demonstrated the use of a laser profiling system (LPS) and digital imagery as useful tools in measuring soil micro-topography and crop residue cover following a soil disturbance event. The soil micro-topography was characterized in terms of surface roughness using two geostatistical approaches; semivariance analysis and the mean absolute-elevation-difference method. A univariate statistical analysis was also used. All three procedures used to describe surface roughness were successful in detecting changes in surface roughness due to soil disturbance and the addition of corn residue. There was a definite advantage in using the geostatistical approaches to characterize surface roughness as the indices they provide give insight into the

characteristics of the surface roughness. Crop residue cover was measured using digital images and image analysis software to contrast the soil and the crop residues.

The series of field experiments examined the roles of both soil disturbance and corn residue and their interactions on surface roughness, crop residue cover, exposed surface area, and near-surface porosity. Soil disturbance and the addition of corn residue were both found to be significant factors affecting the surface roughness, crop residue cover, exposed surface area, and near-surface porosity. Due to the interaction and added effects of crop residue, it was also demonstrated that the calculated surface area may not be a measure of exposed soil area, but rather it is a combination of soil and residue surface areas. Likewise, the roughness of a surface does not only reflect the soil clods produced during tillage but that of the residue itself. Furthermore, it was demonstrated that the information gathered by the LPS and digital imagery can be used to evaluate surface characteristics arising from different tillage practices.

Keywords Surface characterization; Tillage; Surface properties; Residue cover; Surface roughness

2.2 Introduction

There has been resurgence in the interest of conservation tillage as a means to sequester carbon from the atmosphere, to help improve soil quality, and as a practice to mitigate the increasing CO_2 concentration in the atmosphere. Conservation tillage has a wide range of definitions ranging from a broad definition such as "tillage practices specifically intended to reduce soil disturbance during seedbed preparation" (SOWAP, 2007) to a more site specific definition such as tillage systems that result in the amount of randomly distributed surface residue needed and the amount of surface soil disturbance allowed to reduce erosion, improve soil conditions, reduce CO_2 emissions, increase plant-available moisture, and provide food and cover for wildlife to planned objectives (NRCS, 2005; NRCS, 2006). The use of qualitative terms such as conservation tillage to describe tillage practices can be quite problematic as it is ambiguous and a wide range of practices fall into this category (Lobb et al., 2007). This makes the interpretation of information gathered from different tillage systems difficult. Lobb et al. (2007) have identified the need for better quantification of surface properties following a tillage event in order to better distinguish one practice from another. Detailed information on tillage practices is important in the modeling of environmental processes and in the use of environmental indicators (Lobb et al., 2007).

Tillage can result in immediate and dramatic changes in soil physical properties near the surface. The extent and duration of these changes will be closely related to the degree of soil disturbance and crop residue incorporation which will depend primarily on the implements being used and the soil conditions at the time of the tillage operation. A tillage event may result in changes in surface roughness, crop residue cover, surface area (exposed surface area per land area), near-surface porosity, soil moisture and temperature. Characterization of these properties may be an important component of distinguishing different tillage systems. Surface characterization and quantification may help in part to explain differences in crop growth, soil erosion, hydrology, gas exchange and energy balance between different tillage systems.

Clearly, two of the most important properties to consider in distinguishing tillage systems are surface roughness and crop residue cover. These surface properties play an important role in many soil surface processes. Measurements of surface roughness can provide an estimate of the depressional storage capacity (Kamphorst et al., 2000), which is an important factor in reducing runoff by retaining water and promoting greater infiltration (Freebairn et al., 1989). Surface roughness will also affect surface water flow because roughness elements within the field dissipate the energy of the flow reducing the erosive force of the water and ultimately reducing the amount of soil lost (Helming et al., 1998). Increasing the roughness of the soil surface will also increase the surface area, which can impact the energy balance by altering the amount of solar radiation being intercepted per unit horizontal land area, as well as the albedo (Matthias et al., 2000).

Measurements of crop residue cover can be used to estimate how well the soil is protected from rainfall impact, as the residue will intercept the rain and prevent the detachment of the soil particles. Crop residues will also intercept radiant energy, and effectively reduce the amount of energy available for evaporation at the soil surface; as well, crop residues will increase the resistance to gas exchange (Jolata and Prihar, 1998). In addition, crop residues and surface roughness can alter the wind profile near the surface, especially if there are standing senescent stems (standing stubble) (Jolata and Prihar, 1998). The greater the aerodynamic roughness of a surface, the less the amount of energy available for the convective exchange of water vapour and other trace gases (Jolata and Prihar, 1998) and the detachment and transport of soil particles by wind (Horning et al., 1998). The amount and configuration of crop residue is also an important component in the retention of snow (Smika and Whitfield, 1966).

Currently, there are no standard procedures or methods to measure and quantify crop residue cover and surface roughness following tillage. There are many different tools and techniques that can be used for assessing crop residue cover. The most common techniques include the visual-intercept methods and photographic techniques where the amount of residue is manually estimated (Morrison et al., 1993). These methods, however, can be quite subjective and results can vary among interpreters. More technical methods include sensor-based residue meters which use the difference in the fluorescence and reflectance properties of soil and residue to measure crop residue cover (Morrison et al., 1993). Digital imagery and analytical software can also be used to measure crop residue cover by contrasting the darker coloured soil from the lighter coloured residues (Morrison et al., 1993).

Techniques for obtaining soil micro-relief data include the drop-pin micro-relief meter (Kuipers, 1957), the chain method (Saleh, 1993), point-lasers (Huang and Bradford, 1990), laser profilers (Darboux and Huang, 2003; Bertuzzi et al., 1990a), and analytical photogrammetry (Merel and Farres, 1998). The main disadvantage of the first two methods is the lack of resolution and accuracy. The second disadvantage is that the measuring device comes into direct contact with the soil, and thereby alters the surface being measured. The point-laser method is a non-contact method that can provide accurate and high resolution soil micro-topography profiles. The main disadvantage of this system is that only one point can be measured at a time, so the laser system needs to be put onto a track system which will allow it to progressively move and scan a profile.

In addition to the various techniques in which soil micro-topography data may be obtained, there are several mathematical procedures that can be used to quantify soil roughness. The simplest is a univariate procedure, whereby the soil roughness is characterized by the distribution of soil heights about the mean soil height. The soil roughness can then be described by the range, standard deviation, and the standard error